Universidade de Évora - Escola de Ciências e Tecnologia

Mestrado em Engenharia da Energia Solar

Relatório de Estágio

Facades and solar parking yield estimation at Utrecht University

Táyzer Damasceno de Oliveira

Orientador(es) | Luís Fialho
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O relatório de estágio foi objeto de apreciação e discussão pública pelo seguinte júri nomeado pelo Diretor da Escola de Ciências e Tecnologia:

- Presidente | Paulo Canhoto (Universidade de Évora)
- Vogal | Fernando Manuel Tim Tim Janeiro (Universidade de Évora)
- Vogal-orientador | Luís Fialho (Universidade de Évora)

Évora 2020

Dedico este trabalho à minha família que sempre me apoiou.

Ao Prof. Luis Fialho pela orientação e toda ajuda que providenciu neste trabalho.

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E a todos os meus amigos que estiveram comigo durante essa jornada.

ASTRACT

Solar energy born as one of the ways to produce energy using renewable resources (like wind, biomass, hydraulic, geothermal and wave energies). The solar energy is divided into three types: thermal, that generates heat (which can be used to produce energy), photovoltaic that only produces electricity and PVT, a hybrid way to generate heat and produce electricity. Photovoltaic (PV) technologies have several uses such as lighting, satellites, solar home systems, pumping, etc. This work pretends to estimate the potential of usage of solar cells and the yield potential at De Uithof campus located in Utrecht, Netherlands. Building attached photovoltaic (BAPV), solar parking lot and charging electric vehicles (EV) were the chosen uses of solar energy for this project. The work method is divided into four parts, firstly a 2D part that was done on ArcGIS software to create the shapefile with the buildings and solar parking information of the incoming radiation for the entire year in Wh/m^2. Secondly, the 3D works on AutoCAD, Autodesk FBX Converter and PVsyst to create the 3D plant and to import the shading scene construction, to install the solar modules on the roofs, facades and solar parking lot. The third part is to choose the charging mode 3 combined with connector type 2 that full charge the Tesla model 3 (which has a battery of 50 kWh) in around five hours (charging 11kW per hour). The fourth part details the input data and calculate the economic viability considering the total cost of initial investment and operation/maintenance costs. Two tests were used to compare different options, VC0 (35.175 kWp) with the solar modules facing south and VC1 (50.796 kWp) on the west-east plus south direction. The chosen PV module was the LG 340 N1C-A5 by LG Electronics and the inverter was the AGILO 100.0-3 Outdoor by Fronius International because they are commercially available equipments. The VC0 has a system production of 27.229 MWh/year and the VC1, 35.285 MWh/year, both are feasible economically because they have the NPV greater than zero, being €68 million for VC0 and €83 million for VC1. In addition, the Payback is much lower than 25 years (lifetime of photovoltaic panels), being 7,69 years and 7,03 years, respectively for VC0 and VC1. Furthermore, the LCOE of the VC0 is 0.058 €/kWh, and for VC1, 0,064 €/kWh.

Keywords: Solar energy; renewable energy, solar parking, building attached photovoltaic

TÍTULO: ESTIMATIVA DA PRODUÇÃO ANUAL NAS FACHADAS, TELHADOS E ESTACIONAMENTO SOLAR NA UNIVERSIDADE DE UTRECHT

RESUMO

A energia solar surgiu como uma das diversas maneiras para produzir energia elétrica utilizando recursos renováveis (como a energia eólica, biomassa, hidráulica, geotérmica e das ondas). A energia solar é dividida em três tipos: térmica, que gera calor (que também pode ser usado para produzir energia), fotovoltaica que somente produz eletricidade e PVT, maneira híbrida de gerar calor e produzir eletricidade. Tecnologia fotovoltaica tem diversos usos como iluminação, satélite, sistemas solares residenciais, bombeamento, entre outros. Este trabalho pretende estimar o potencial do uso de células solares e a potência anual no campus De Uithof que se localiza em Utrecht, Países Baixos. *Building attached photovoltaic* (BAPV), estacionamento solar e carregamento de veículos elétricos (EV) foram os usos da energia escolhidos para este projeto. O método do trabalho se divide em quarto partes, primeiramente a parte 2D que foi feita no software ArcGIS para criar shapefile com as informações da radiação que chega aos prédios e estacionamento durante todo o ano em Wh/m^2. Segundamente, o 3D feito no AutoCAD, Autodesk FBX Converter e PVsyst para criar a planta 3D e importar no *Shading scene construction*, instalar os módulos solares nos telhados, fachadas e estacionamento solar. A terceira parte foi escolher o modo de carregamento 3 combinado com o conector 2 que carrega completamente o Tesla model 3 (possuindo bateria de 50 kWh) em aproximadamente em cinco horas (carregando 11 kW por hora). A quarta parte detalha os dados de entrada e calcula a viabilidade econômica considerando o custo total de investimento e custos de operação/manutenção. Dois testes foram feitos de modo a compará-los, VC0 (35.175 kWp) com os módulos solares virados para sul e VC1 (50.796 kWp) nas direções este-oeste e direção sul. O painel escolhido foi o LG 340 N1C-A5 da LG Electronics e o inversor AGILO 100.0-3 Outdoor da Fronius International porque são equipamentos comerciais. A produção do VC0 é de 27.229 MWh/ano e o VC1, 36.614 MWh/ano, os dois são economicamente viáveis porque possuem o VPL (NPV) maior que zero, sendo €68 millhões para o VC0 e €83 para o VC1. Adicionalmente, o Payback possui um valor bem abaixo de 25 anos (ciclo de vida dos paineis fotovoltaicos), sendo 7,69 anos e 7,03, respectivamente VC0 e VC1. Além do mais, o LCOE do VC0 é 0.058 € /kWh, e para o VC1, 0.064 €/kWh.

Palavras-chave: Energia solar, energia renovável, estacionamento solar, building attached fotovoltaic

Summary

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Acronyms

PVT – Photovoltaic/Thermal

PV – Photovoltaic

CdTe - Cadmium-Telluride

CIS - Copper-Indium-Selenide

CIGS - Copper-Indium-Gallium-Selenide

CPV – Concentrated photovoltaic

BIPV – Building integrated photovoltaic

BAPV – Building attached photovoltaic

BiPVT/a - building-integrated installations

BiPVT/w - Building-integration installations

EV – Electric vehicles

GHG – Greenhouse gases

CAPEX – Capital expenditure

OPEX – Operational expenditure

NPV – Net present value

IRR – Internal rate return

TLCC – Total life-cycle cost

LCOE – Levelized cost of energy

PVC - Polyvinyl chloride

PTFE – Polytetrafluoroethylene

EVSE - Electric vehicle supply equipment

IEC - International Electrotechnical Commission

AC - Alternating Current

DC - Direct Current

PDOK - Public Services On the Map

AHN - Actueel Hoogtebestand Nederland

LCE - Life cycle emission

Pnom - Nominal power

GlobHor - Horizontal global irradiation

DiffHor - Horizontal diffuse irradiation

T_amb - Ambient temperature

GlobEff = Effective global

IAM (Incidence Angle Modifier

Earray = Effective energy

E_Grid = Energy injected into the grid

PR = Performance ratio

1. Introduction

The use of renewable energies is one of the ways for reducing the emission of greenhouse gases, furthermore we do have several sorts of energies that use renewable sources like wind (wind energy), earth heat (geothermal), water (hydropower), sun (solar energy) and wave/tidal (tidal energy).

There are three possibilities for using the solar energy, solar thermal (heat only, which can, in turn, be used to generate electricity), photovoltaic (electricity only) and PVT (heat and electricity).

For solar thermal energy, can be divided into active and passive solar system. Active system is the solar collectors like flat-plate collectors and concentrated solar power systems (compound parabolic collectors, heliostat field collectors, linear fresnel collectors, parabolic dish reflectors, and more). In another side, passive solar system does not have the reliance on external devices, can be used for cooling and heating for sunroom, greenhouse, solariums (Tian, 2013).

Photovoltaic solar energy is used for generating energy but with different PV technologies, based on the commonly characteristics, splits in four majors: Crystalline silicon (Mono or Poli), Thin film (Amorphous, CdTe, CIS, CIGS), Organic and Concentrated photovoltaic (CPV). Furthermore, has several sorts of uses, such as lighting; satellites; solar home systems; pumping; integrated (BIPV) or attached (BAPV) in buildings; charging vehicles/bikes/etc; solar parking; desalination plant; isolated system; etc (Eldin, 2015).

For PVT, we have a hybrid system with photovoltaic and thermal, that have three collector types that are flat plate PVT collectors, concentrating PVT collectors and water and air type PV/T collectors, can be used at building-integrated installations (BiPVT/a), Building-integration installations (BiPVT/w), and more (Charalambous, 2007; Chow, 2010).

1.1. Objective

As the use of solar energy is growing every year, many countries are increasing the use of solar energy on the energy mix. Netherlands, in 2017, added 853MW on the solar power system (Netherlands, 2018), this information shows that the country cares about the gas pollution that happens using fossil fuel to produce energy, and the context takes us to use the solar energy on the commercial/residential buildings and also inside the University demonstrating to the students the importance of using renewable energies (solar energy on this project) and how it works.

At Uithof campus, there are several options for using solar energy, this project focus on BAPV, solar parking and EV charging. The reason to use the BAPV is that the buildings are in use, so this might be cheaper to attach rather than change the structure to integrate the solar panels on the buildings (BIPV). Solar parking is a good way to produce energy using the parking lot spaces, besides protecting them from the meteorological conditions. In addition, choose EV to reduce GHG emission.

The goal for this project is to estimate the yearly yield potential (PVsyst uses a stochastic algorithm that calculates hourly data, using generic data and unspecific year) using solar panels inside the De Uithof campus located at Utrecht, Netherlands which contains the Utrecht Science Park, the campus area of Utrecht University, the vocational University Hogeschool Utrecht and the academic hospital University Medical Center Utrecht (UMCU). Building attached photovoltaic (for the roofs and facades), solar parking lot and charging vehicles are the chosen uses of solar energy for the present project.

Two layouts (VC0 and VC1) are used in this project to compare energy production, first with the modules on the south direction (Azimuth 0°), the second with west-east direction (Azimuth -90° and

90°) plus south direction (Azimuth 0°), even with the specified azimuth, some modules have different azimuth because part of the building (or the entire building) is not turned to the south. About the slope, the tilt angle is 90° for the modules on facades and 34° for the modules on the roofs and solar parking and using the produced energy for charging electric vehicles (EV). Jacobson (2018) did a study estimating the optimal tilt angles for all countries worldwide, and for the Netherlands, he calculated for the city Beek the optimum tilt is 34°.

The following lead question for this thesis is: *is economically feasible to install solar panels around the Uithof campus and provide energy to charge EV through the charging station*?

Using the software ArcGIS, AutoCAD and Pvsyst are possible to construct the entire project that answer: *It is possible to use the solar photovoltaic energy around the campus?*

Simulating the yield potential, and doing a calculus using the produced energy with the charging station and connectors can be possible to answer the question: *Could we use the power electricity for charging EV?*

Estimate the CAPEX, OPEX, taxes, to evaluate the NPV, Payback, IRR and LCOE that answer: *Is it economic feasible to install this power system?*

1.2.Thesis Structure

Section 2 presents the state of the art for photovoltaic technology, solar parking lot (rigid or flexible cover system with the solar panels integrated or attached), building attached photovoltaic (solar panels with metallic support on the roofs and facades) and charging technologies (different levels of charging).

Section 3 describes the method, which contains the step by step to get the result. Firstly, the 2D part consists of using the ArcGIS to make the shapefile of the building/solar parking on the De Uithof campus which shows the solar radiation for the entire year. Then doing the 3D on the AutoCAD with the extrusion using the maximum height of the buildings, plus using the PVsyst to attach the solar panels on the roofs, facades and solar parking that allows the yearly yield simulation that includes the shading and losses. Carbon balance calculus that represents the amount of dioxide carbon emission that will be avoided. The fourth part displays the EV (electric vehicle) and the type of charge used on this work. In sequence, the input data for a short economic analysis.

Section 4 displays the results that splits into three categories: Solar potential, that includes the 2D part, 3D part and Carbon balance; EV charging, which has a rough calculation for the numbers of cars loaded per day and the quantity of charging stations that can work simultaneously; Economical analysis, displays the values for NPV, IRR, Payback, TLCC and LCOE.

Section 5 has a conclusion about the project showing some results. Section 6 illustrates the future works that describe the next steps to get better results with more accuracy.

2. State of the art

Presently, solar energy has several sorts of use, and three of them are going to be used on this work, the chosen sorts are solar parking (Section 2.2), building attached photovoltaic (Section 2.3) and charging electric vehicles (Section 2.4).

2.1.Solar energy technologies

Solar energy is the radiant light and heat that comes from the Sun capable of producing heat, chemical reactions or generating electricity. For generating electricity, there is the photovoltaic technology that consists of a PV cell containing a semiconductor device that converts solar energy into direct-current electricity (Ellabban, 2014).

2.1.1. Photovoltaic

Used for generating energy but with different PV technologies, based on the common characteristics, splits among three majors: Crystalline silicon (Mono or Poly), Thin-film (Amorphous, CdTe, CIS, CIGS) and Organic.

- Crystalline silicon (Mono or Poly)

The first generation of solar cells uses Silicon that is a semiconductor material, with an energy band gap of 1.1 eV. Is the most common PV technology use in the PV industry and have constant development. There are two types of crystalline silicon that depend on the structure of the crystals, mono- and poly- crystalline (Eldin, 2015).

  - Monocrystalline (m-Si)

The Monocrystalline Silicon cells (Figure 1) is the type of PV technology most commonly used, these cells are obtained from cylindric bars made by mono-crystalline silicon that is produced in a special oven. Those bars are cut into thin slices (wafers), with a thickness of around 200 µm with the efficiency reaching up 20% (Eldin, 2015).

Figure 1 - Mono-crystalline cell and module[1]

- Polycrystalline (p-Si)

The Polycrystalline (Figure 2) are produced from the fusion of silicon blocks, in other words, the process to junction the silicon crystals, that reduces the efficiency compared with the mono-crystalline, with the value reaching 15% (El Chaar, 2011).

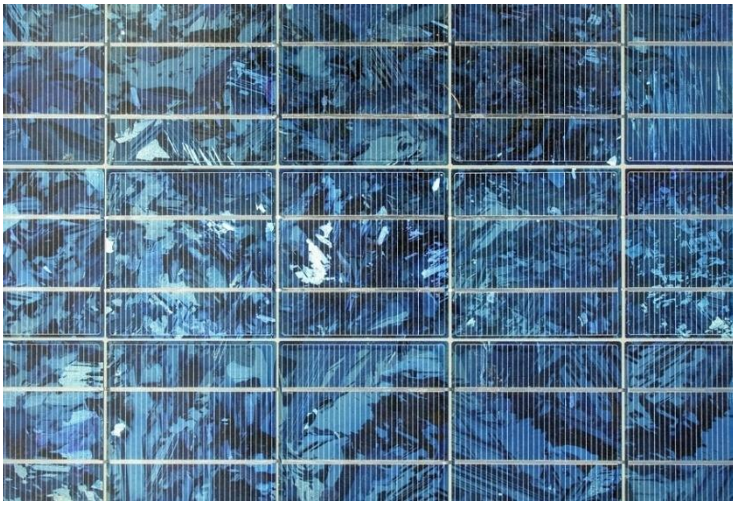


Figure 2 - Poly-crystalline cell and module[1]

- Thin film (Amorphous, CdTe, CIS, CIGS)

With the expensive process for producing solar cells based in crystalline cells, the manufacturing of thin films is a cheaper alternative, i.e., lower manufacturing cost. In addition, this kind of solar cells can be so flexible and lightweight, so has the possibility to be easily installed in BIPV, BAPV, etc (Eldin, 2015). The classify of thin films depends on the substance on the solar cell, existing three types:

[1] Source: https://www.azocleantech.com/

- Amorphous Silicon (a-Si)

Amorphous technology (Figure 3), if we compare with the crystalline silicon, the atoms are randomly located from each other, this property makes the band-gad being higher (1.7 eV) than crystalline silicon (1.1 eV) (El Chaar, 2011). Have lower efficiency (range between 4% to 8%) but do not use toxic heavy metals such as Cadmium or Lead.

Figure 3 - Amorphous solar cells[1]

- Cadmium-Telluride (CdTe)

The big disadvantage of CdTe solar cell (Figure 4) technology is the fact of having Cadmium which is a heavy metal and toxic for the environment, despite the fact that has the ideal band-gap (1.45 eV) with high direct absorption coefficient, the efficiency can reach 15% (El Chaar, 2011).

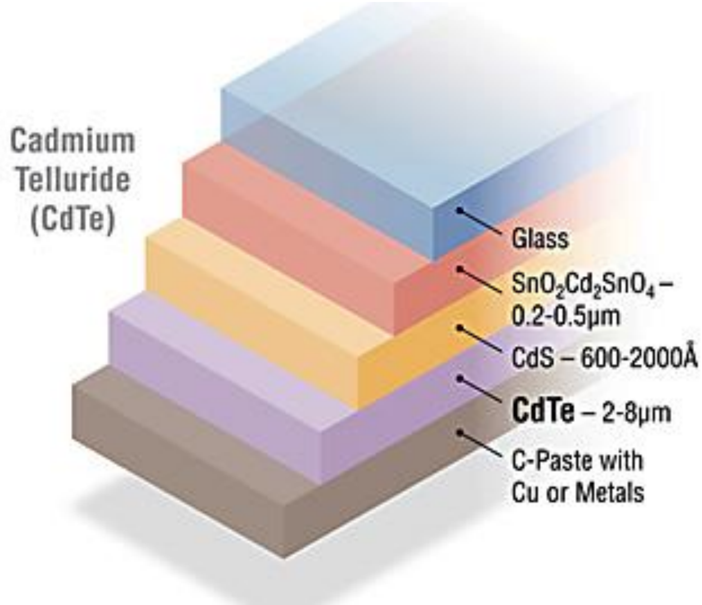


Figure 4 - Cadmium-Telluride solar cell[2]

- Copper-Indium-Selenide (CIS) and Copper-Indium-Gallium-Selenide (CIGS)

CIS cells are made using a thin layer of $CuInSe_2$ with band-gap 1.04 eV and the CIGS (Figure 5), a thin layer of $Cu(In,Ga)_2Se_2$ with band-gap 1.68 eV. The efficiency is the biggest advantage cause can reach 20% with solar cells having 0.5 cm^2 (El Chaar, 2011).

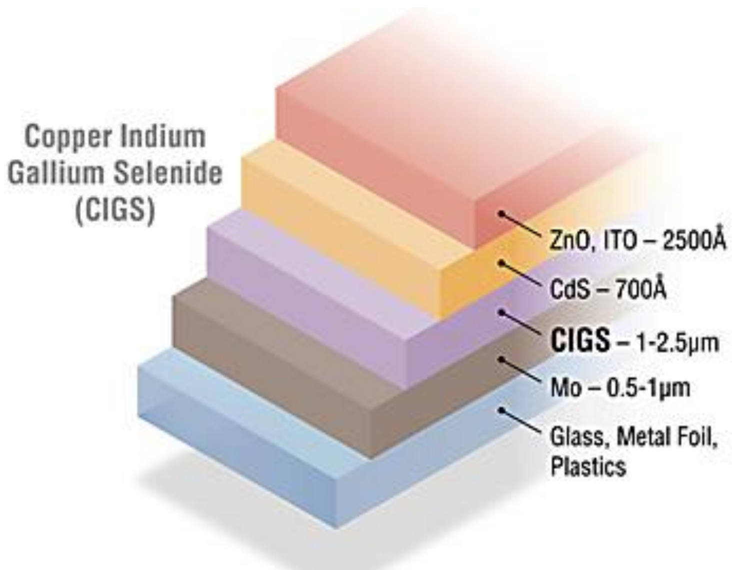


Figure 5 - Copper-Indium-Gallium-Selenide solar cell[2]

- Organic

[2] Source: https://www.nrel.gov/

Organic solar cells (Figure 6) are composed using organic or polymer materials, the manufacturing cost is cheap but unfortunately, this kind of cells are not very efficient. With the possibility to use plastic sheets as a coating that makes the organic solar cells lightweight and flexible (Eldin, 2015).

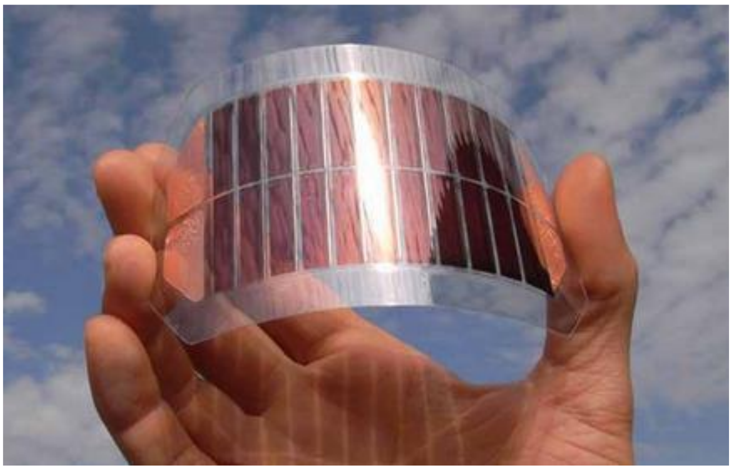


Figure 6 - Organic solar cell[1]

Applications for PV are Building integrated/attached systems (BIPV and BAPV), desalination plant, space, solar home systems, communications, rural electrification, lighting, reverse osmosis plants, pumps, photovoltaic and thermal (PVT) collector technology and others (PARIDA,2011).

2.2. Solar parking lot

The solar parking lot is the possibility of using the PV panels on the roof of the parking lots, sometimes is possible to build the roof using the solar panels rather than attaching the PV panels. This solution is good for charging electric bikes and cars, and possibly electronic equipment (notebooks, cell phones, power banks, etc). This technology is good to protect bikes and cars from meteorological conditions like sun, rain, snow, wind, and hail.

Basically, we have two types of parking lot cover systems that are the most used: rigid cover system and flexible cover system. The rigid system is most used, but both may have a different aesthetic structure.

Correia (2013) presents on their study both types of cover system, beyond showing the possibility to use the PV panels on the parking structures and the different aesthetic structures that were made by some companies.

2.2.1. Rigid cover system

Rigid system is the traditional solution, usually made of steel which has some advantages like the lowest price, fast execution, and maximum use of space with the possibility to do different structures. To avoid corrosion problems, galvanized and stainless steel are used. Other materials can be used for the parking structures like aluminium, glass panels, polymer panels or PVC covers. Figure 7 and Figure 8 displays examples made by two companies using integrated solar parking.

Figure 7 - Car Schell Energy, GREENPARK[3]

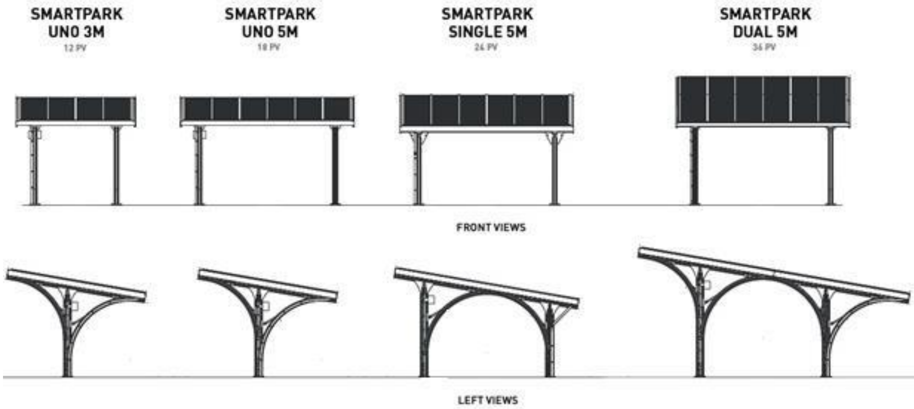


Figure 8 - SmartPark solution – Martifer solar[3]

2.2.2. Flexible cover system

Flexible cover system has metal support for the tensile membrane cover. When adopting this solution, the advantage is a having lightweight roof, fewer numbers of pillars and structural steel, with the possibility to use the PVC, PTFE, glass fiber and silicon. Figure 9 and Figure 10 shows two designs for a membrane cover system with solar panels.

[3] Source: Correia (2013)

Figure 9 - Skyshade solution[3]

Figure 10 - Hightex solution[3]

2.3.Building Attached Photovoltaic (BAPV)

BAPV are added on rather than integrated into the roof or facade, for this option, any PV technology can be used as needs small metal support to fix the PV panels.

2.3.1. Tile-on roof system

This type is used at tile roofs like hollow, flat roof, standard, double slot, roman, plain, scale, bitumen, slate and spanish tiles, the PV modules are fixed on the roof using hooks and mounted using rails and clamps. Figure 11 shows one of the examples of the tile-on roof system.

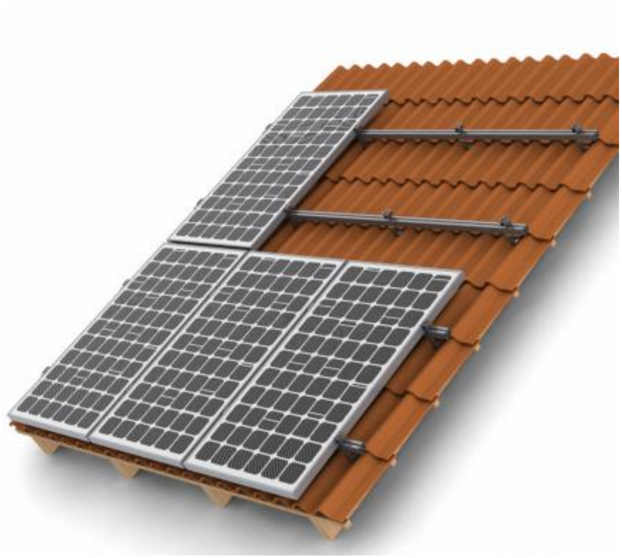


Figure 11 - Tile-on roof system[4]

2.3.2. Metal sheet roof system

This type of system is used in metal sheet roof is considerate hardcore for roof system, but with matched clamp and rail is possible to fix the PV panels on the metal sheet roofs. Figure *12* displays an example.

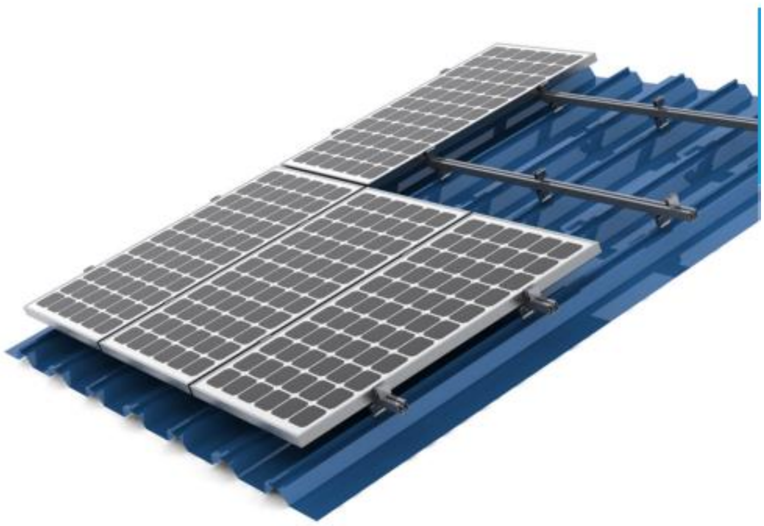


Figure 12 – Metal sheet roof system[4]

[4] Source: http://www.remonsolar.com/en/

2.3.3. Flat roof system

Flat roof system can be used in all kind of flat roofs according to the roof support capacity with the weight of the solar plant and waterproof requirements. Figure 13 illustrates one of the examples that uses concrete (or other material) blocks or chemical anchor bolt to fix the system on the roof.

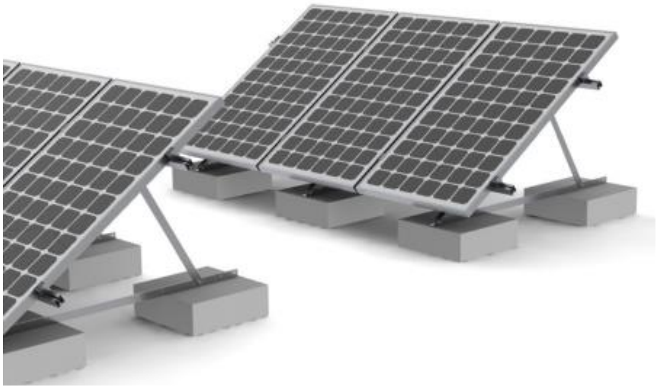


Figure 13 - Flat roof system[4]

2.4. Charging technologies

To charge your electric vehicle (EV) requires plugging into charger equipment that is connected on the electric grid, and the equipment calls electric vehicle supply equipment (EVSE) (Morrow, 2008). There are four models of charging that depends on the amount of power comes from the charger to the battery, furthermore, four connector types. Table 1 shows the charging modes following the IEC-61851-1 standard.

Table 1 - Charging modes using IEC-61851-1 standard[5]

Mode	Specific connector for EV	Type of charge	Maximum current	Protections
Mode 1	No	Slow in AC	16 A per phase (3,7 kW - 11 kW)	The installation requires earth leakage and circuit breaker protection
Mode 2	No	Slow in AC	32 A per phase (3,7 kW - 22 kW)	The installation requires earth leakage and circuit breaker protection
Mode 3	Yes	Slow or semi-quick, Single-phase or three-phase	In accordance with the connector used	Included in the special infrastructure for EV
Mode 4	Yes	In DC	In accordance with the charger	Installed in the infrastructure

Table 2 shows the connectors type following the IEC 62196-2 standard.

[5] Source: http://circutor.com/en

Table 2 – Connectors type using IEC 62196-2 standars[5]

Type	No. pins	Maximum voltage	Maximum current
Type 1	5 (L1, L2/N, PE, CP, CS)	250 V a.c. Single-phase	32 A single-phase (up to 7,2 kW)
Type 2	7 (L1, L2, L3, N, PE, CP, PP)	500 V a.c. Three-phase, 250 V a.c. Single-phase	63 A three-phase (up to 43 kW), 70 A single-phase
Type 3	4, 5 or 7 in accordance with the model (L1, L2, L3, N, PE, CP, PP)	500 V a.c. Three-phase, 250 V a.c. Single-phase	16 / 32 A single-phase, 32 A three-phase (up to 22 kW)
Type 4	9 (2 Power, 7 signal)	500 V d.c	120 A d.c.

3. Method

Section 3 begins with the selection of the location where the PV system will be installed. On Section 3.1, the 2D (only ArcGIS) details the steps to create the buildings/solar parking lot shapefile. The 3D (AutoCAD and PVsyst) is described on Section 3.2 featuring the extrusion on AutoCAD to build the objects in 3D, importing the file on PVsyst and projecting the system inserting input data to simulate the yearly yield potential. Section 3.3 details the dioxide carbon balance calculus. Section 3.4 displays the calculus for estimating the quantity of charging stations working simultaneously and the number of cars that can be charged at the same time. Section 3.5 attributes the input data for economic viability and the variables that will be calculated. Figure 14 displays briefly the step by step to get the result.

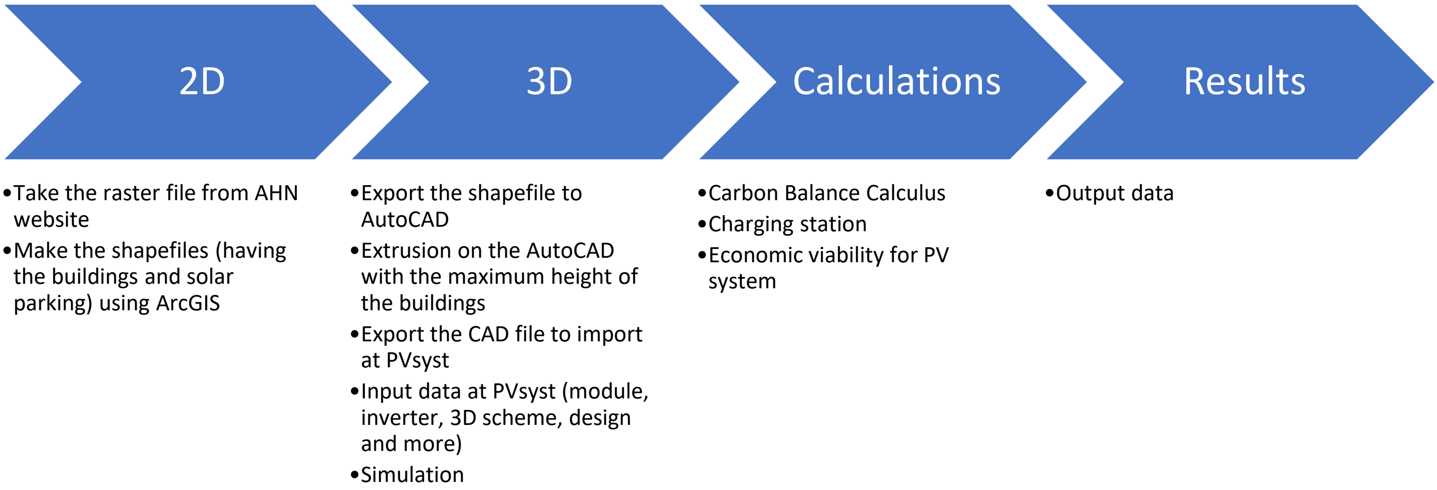


Figure 14 – Method organogram

Firstly, the location for the project needs to be chosen, so for the present project, the De Uithof campus located at Utrecht, Netherlands was selected (Figure 15).

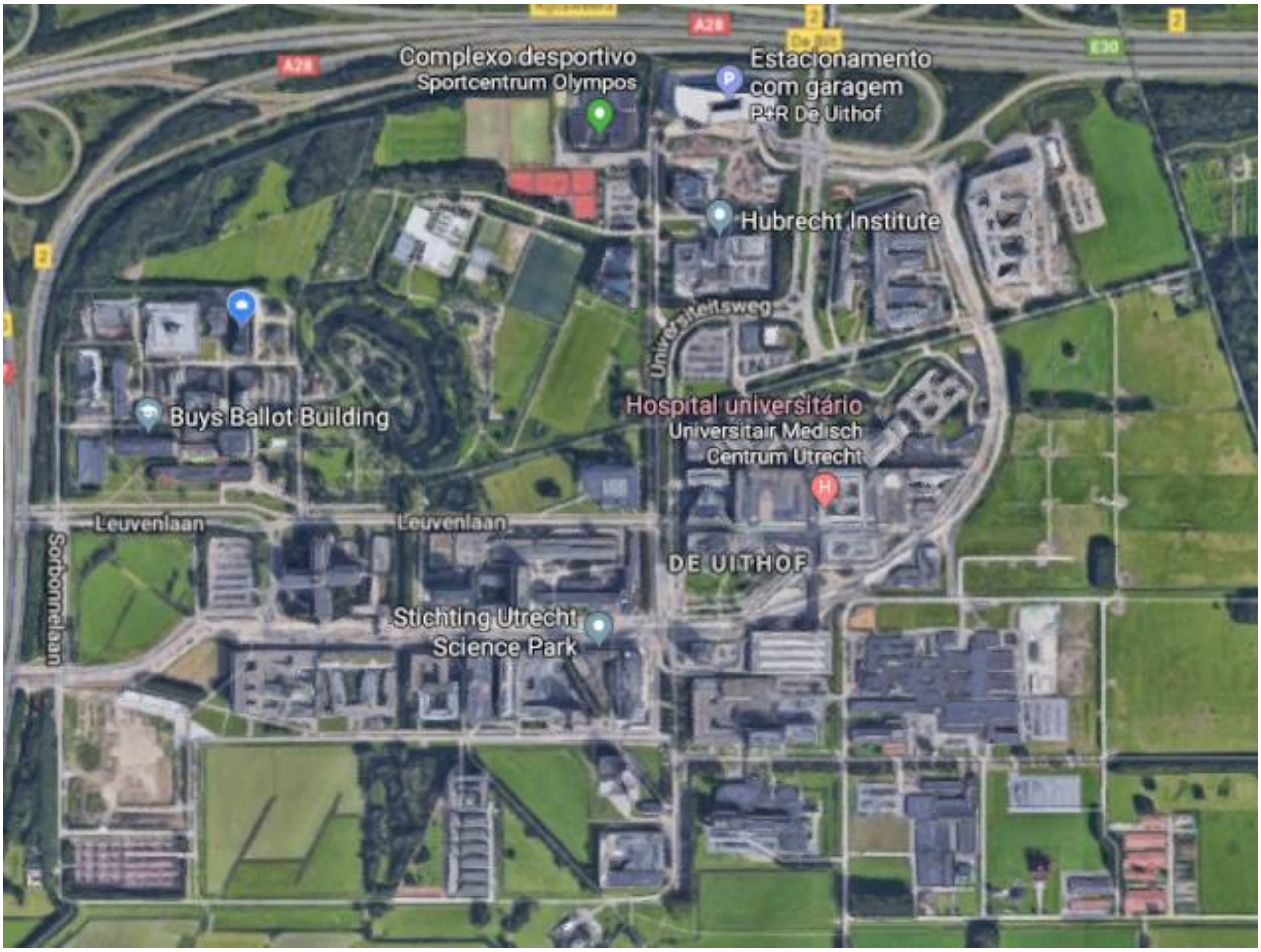


Figure 15 - De Uithof [6]

3.1.2D part

3.1.1. Datasets – take the raster from AHN website

To import the raster files on ArcGIS, the .DSM raster file (*intended as a raw file, with all points except those classified as "water" being resampled to a grid based on a Squared IDW method. No further operations have been performed*) can be found at PDOK (Public Services On the Map) website (AHN, 2019). The files 31HZ2 and 32CZ1 are chosen to be cut and merge using the ArcGIS which is Figure 16. The values show the maximum height considering the sea level as a reference that starts from -1 m (because some parts of Netherlands are below the sea level) reaching to 92 m (tallest building).

[6] Source: Google Earth

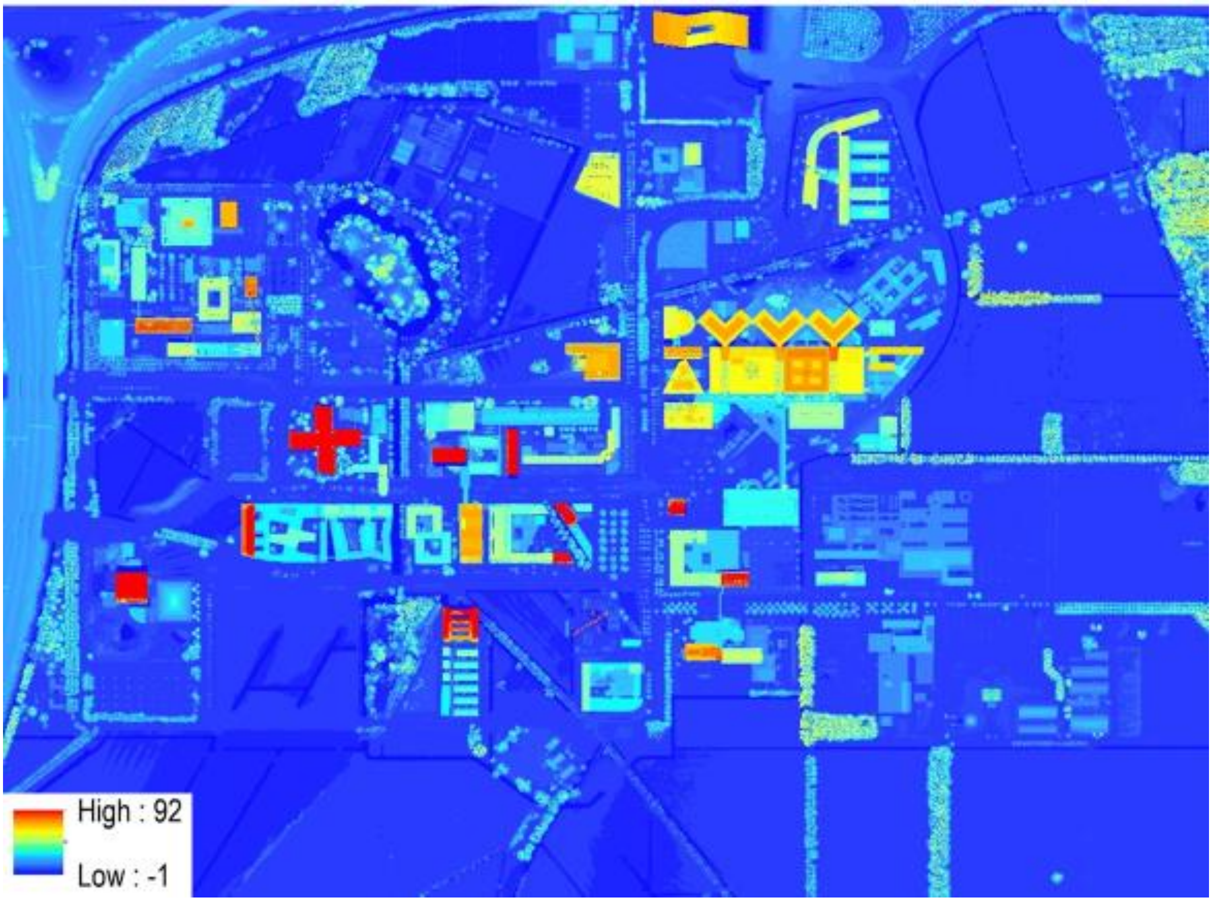


Figure 16 - Height with reference at sea level (m)[7]

3.1.2. Make the shapefile using ArcGIS

Meuser (2018) provides a shapefile showing the entire Netherlands, so was possible to cut the De Uithof campus. Figure 17 and Figure 18 show the De Uithof campus shapefiles focusing on the buildings.

Figure 17 exhibits the maximum height of the buildings that subdivide into five levels ranging from 4,97 m to 87,87 m.

[7] Source: ArcGIS

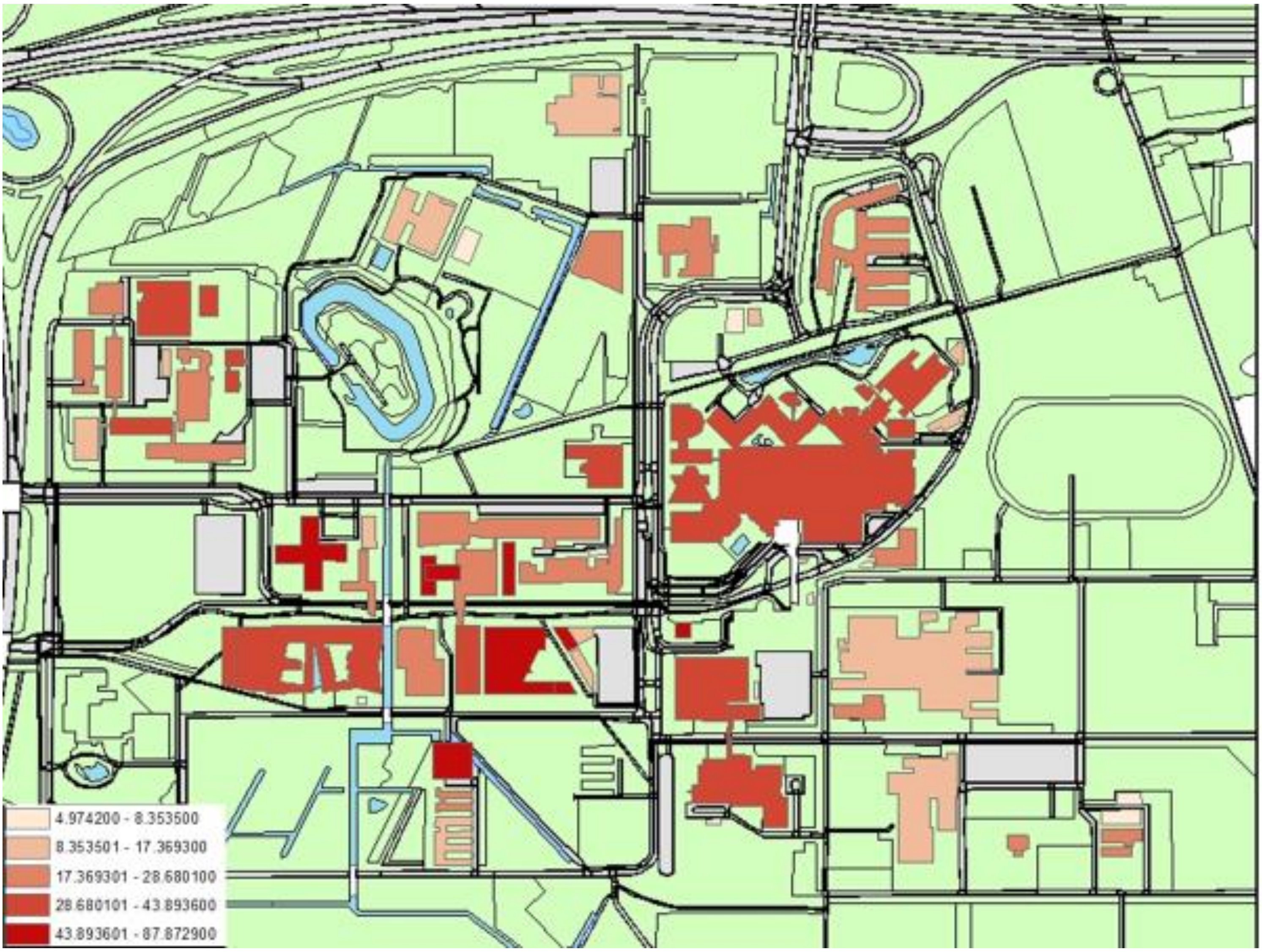


Figure 17 - Maximum height of buildings (m)[7]

Figure 18 illustrates the shape area (in m^2) that represents the geometry area of the buildings. The shape area of the buildings has five levels that go from 31,43 m^2 to 61.335,31 m^2.

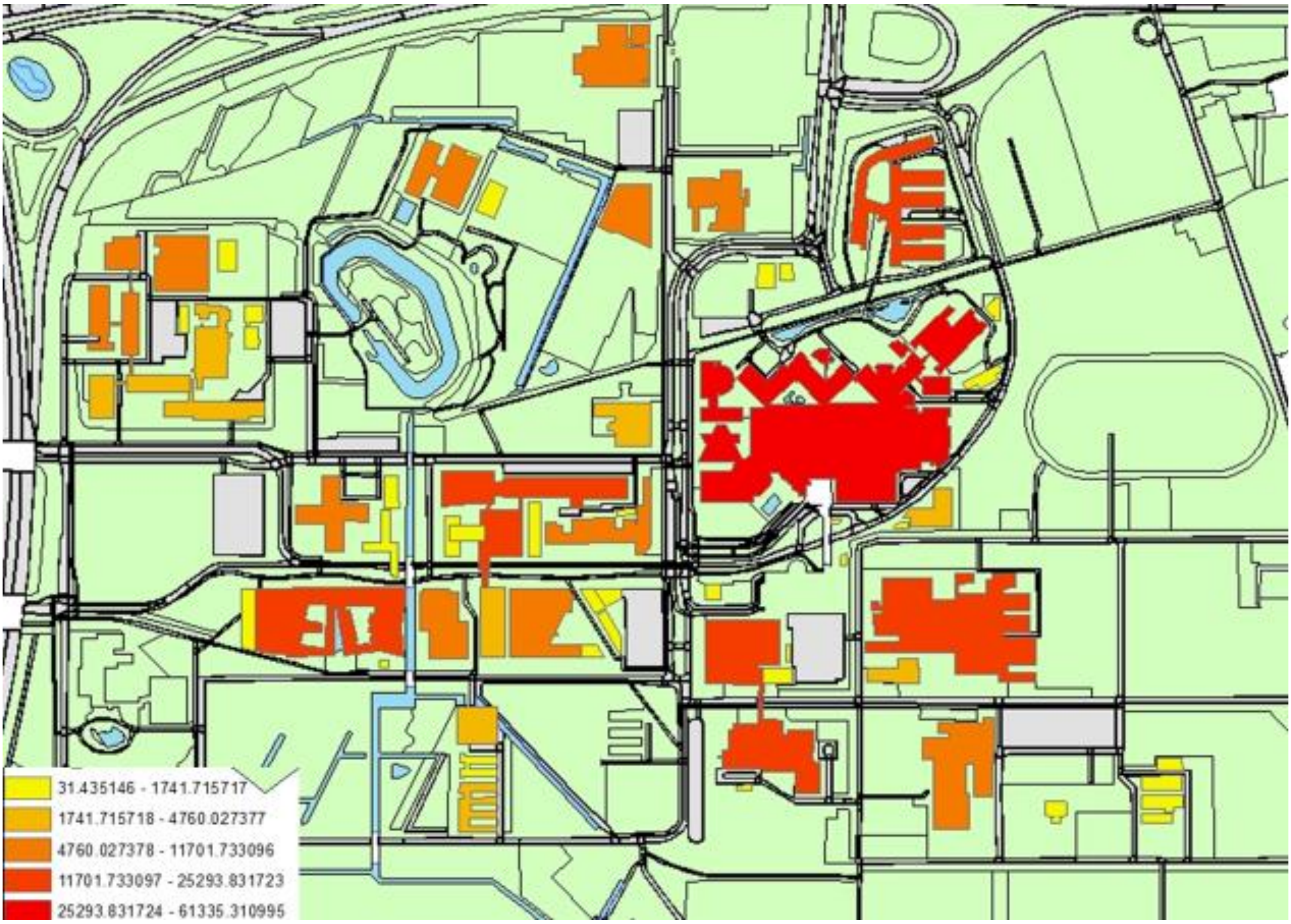


Figure 18 - Shape area of the buildings (m^2)[7]

Figure 19 displays the solar parking places (in black), around the campus there is a possibility to install more solar parking lots, but they are not suitable because they are shaded from the buildings or trees.

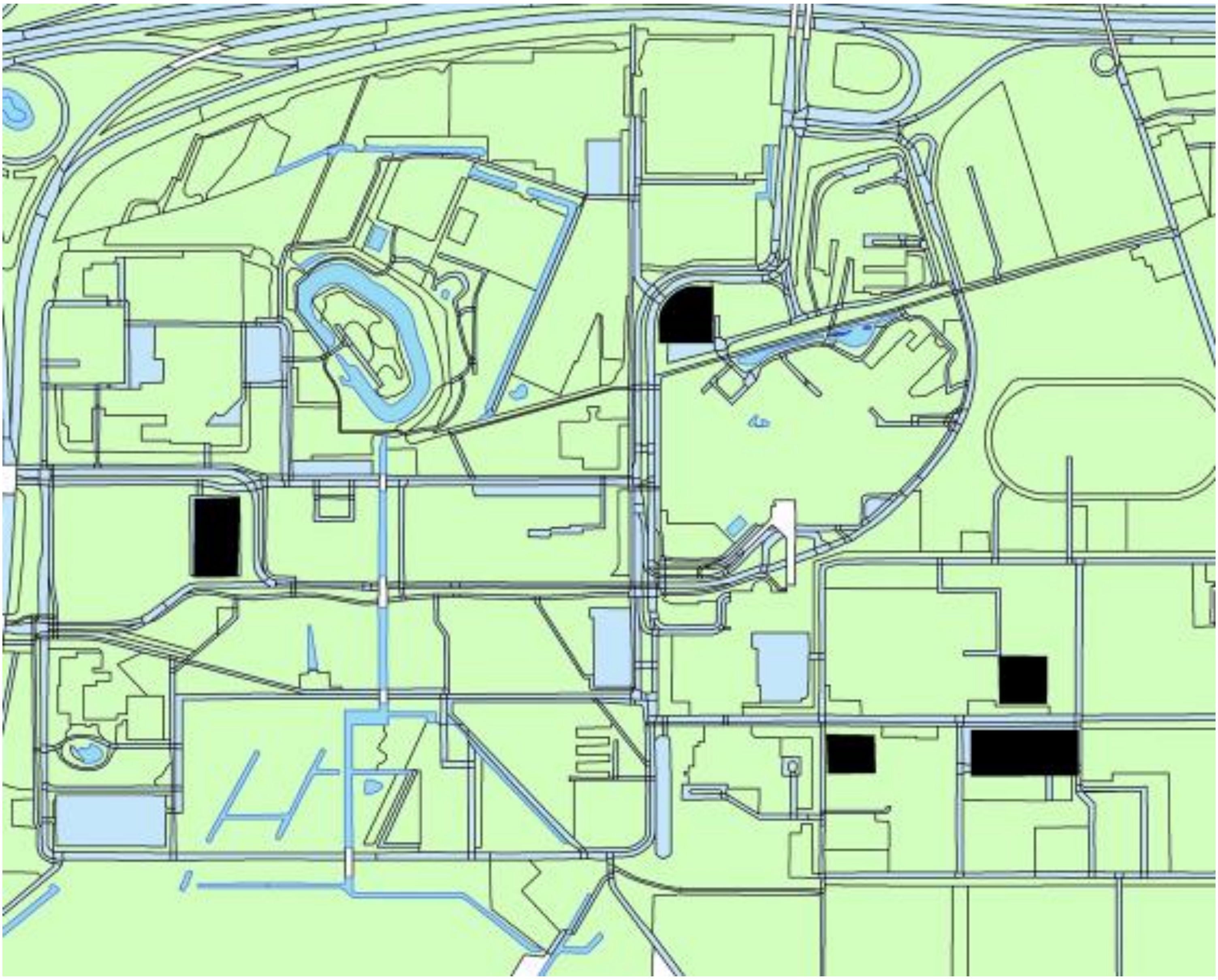


Figure 19 - Solar parking area (black squares)[7]

3.1.3. Tool "Area Solar Radiation."

"*The Area Solar Radiation tool is used to calculate the insolation across an entire landscape. The calculations are repeated for each location in the input topographic surface, producing insolation maps for an entire geographic area"* (Area, 2019), in other words, this tool provide the total amount of incoming solar insolation (direct + diffuse) for the entire year for each location in Wh/m^2.

3.2.3D part

For the 3D, Pvsyst was chosen because is possible to do a three-dimensional project that uses the horizon limitations and objects that produce shadows on the panels. There are four main options to design the project: the PV system as Grid-connected (connect to the grid with the option to use or not a battery), Standalone system, Pumping system or DC grid connected (connected into the grid without battery).

The software has an quite extent input data and allows to choose the PV modules (model, quantity, orientation, etc.), the inverter (model and quantity), number of subarrays (limit of eight subarrays), 3D scene (possibility to draw the PV system in 3D and to introduce the construction and/or elements that cause shadows). The output data has several result options such as yearly yield potential, performance ratio, carbon balance, and other options.

The advantages of using this software are the big database which contains several options of cities where the project can be installed; the modules and inverters available on the software are totally commercial; several parameter options for the panels setup such as fixed, one-axis, two-axis tracking, its subdivisions into arrays and strings; etc.

3.2.1. Export the Shapefile of the buildings to AutoCAD to do the extrusion

Figure 20 displays the buildings (white lines) and solar parking (green line) top view.

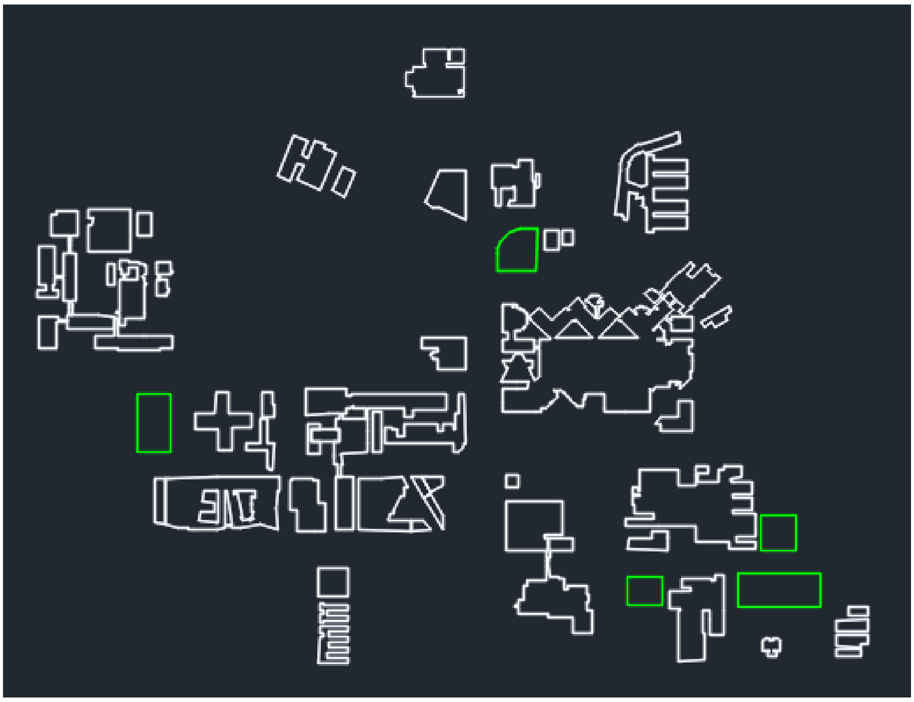


Figure 20 – Buildings and solar parking view from the top[8]

[8] Source: AutoCAD

3.2.2. Import this file on PVsyst;

The software Autodesk FBX Converter converts the AutoCAD file .FBX into a .DAE file that is accepted on PVsyst, in order to import the buildings/solar parking lot 3D drawing on the shading scene construction, where is possible to put the solar panels on the roofs, facades and on the solar parking.

3.2.3. Input data on PVsyst;

For the project, VC0 and VC1 (names provided on the software to the different projects) represent the simulation tests:

- VC0 – with the modules facing South - Azimuth of 0°, but some turned because of the facades or roofs of the buildings; 90° tilt for the facades and 34° tilt for the roofs and solar parking;
- VC1 – with the panels facing South + West-East direction – Azimuth of 90° and -90°, the larger number of modules with the West-East side orientation, but some stayed turned to the South, the Tilt angle is 90° for the facades and 34° for the roofs and solar parking.

On both projects, the entire solar power plant is split into three parts: solar parking, facades, and roofs.

❖ Site and Meteo – for the country and city where the project will be installed

Figure 21 specifies the information about the location of the nearest weather station of Utrecht, in the city called De Bilt. Its latitude is 52,10°N, longitude 5,18°E, time zone UT+1, the altitude of the weather station is 1 m and the albedo is 0,20.

Grid-Connected System: Simulation parameters

Project :	**Campus UU**				
Geographical Site		**De Bilt**		Country	**Netherlands**
Situation		Latitude	52.10° N	Longitude	5.18° E
Time defined as		Legal Time	Time zone UT+1	Altitude	1 m
		Albedo	0.20		
Meteo data:		**De Bilt**	MeteoNorm 7.1 station - Synthetic		

Figure 21 - Location of weather station[9]

❖ Orientation

For both test setups (VC0 and VC1), the tilt is the same, 90° for the facades (Figure 22), and 34° for the roofs and solar parking (Figure 23 for VC0, Figure 24 and Figure 25 for VC1). The difference is in the Azimuth for the roofs and solar parking that on the VC0 are totally facing South (0° and some to other directions due the buildings orientation restrictions), the majority of the modules in VC1 is simulated with the West-East setup (90° and -90° for 100% in solar parking, the roofs have some

[9] Source: PVsyst

exceptions facing South, due to architecture limitations). The facades are the same for both projects (VC0 and VC1).

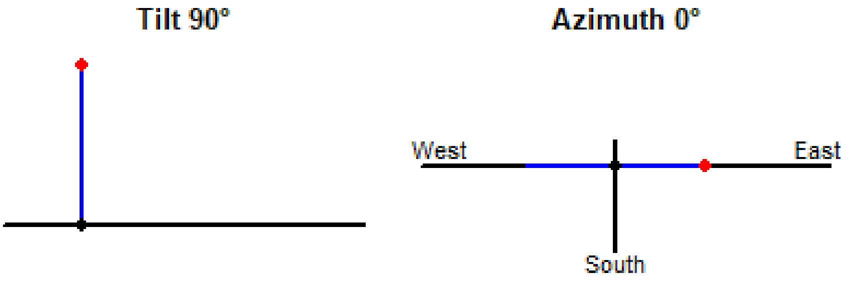


Figure 22 – Facades tilt and azimuth angles for both projects

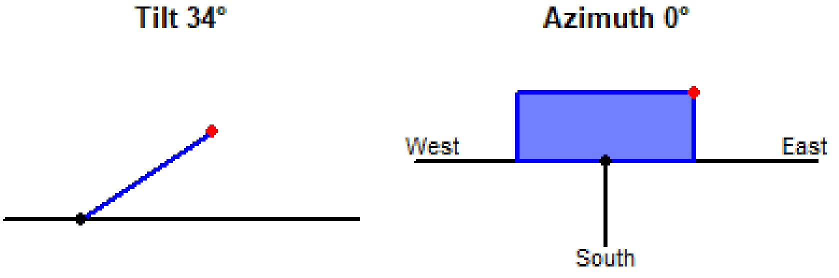


Figure 23 -Tilt and azimuth angles for VC0 used in solar parking and roofs

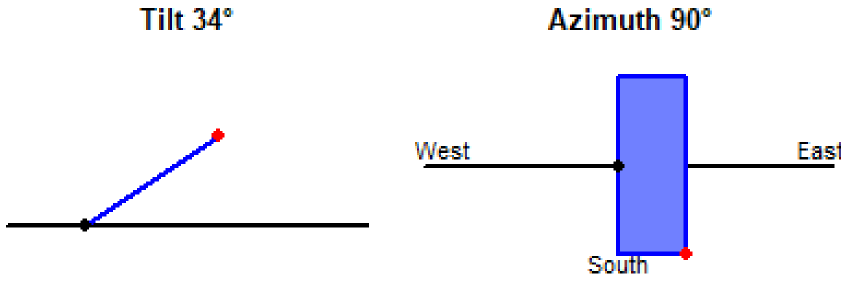


Figure 24 – Tilt and azimuth angles for VC1 used in solar parking and roofs for West direction

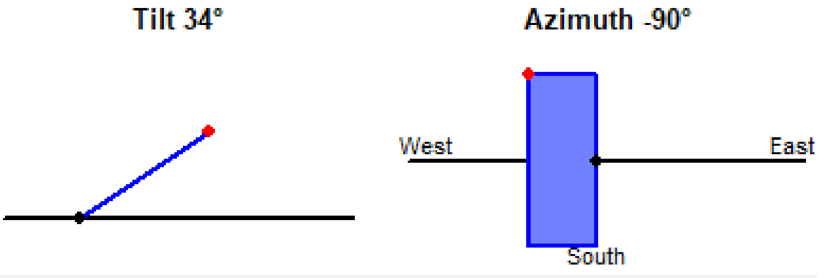


Figure 25 - Tilt and azimuth angles for VC1 used in solar parking and roofs for East direction

- System

The chosen solar module is LG 340 N1C-A5 by LG Electronics (Figure A 1), with nominal power of 340 Wp, the module size is 1,016 m x 1,686 m, resulting in 1,71 m^2 of total module area. Each module has 60 cells with an active area of 1,55 m^2.

Regarding the inverter, it was chosen the AGILO 100.0-3 Outdoor by Fronius International (Figure A 2). The nominal PV power DC at 104 kW, maximum PV power DC at 150 kW. And the operating mode at MPPT (maximum power point tracking) with minimum and maximum voltage at N/A and 820 V, respectively.

- Detailed losses – Default options were used.

- Self-consumption - No auto-consumption was chosen.

- Storage – No storage was chosen.

- Near shading

With the Shading scene construction, it is possible to construct the entire project with the PV modules and the buildings (including the possibility of shading by the building and modules). Figure 26 illustrates the project VC0 with modules facing South. Figure 27 displays the project VC1 with the modules installed with the West-East direction plus South scheme.

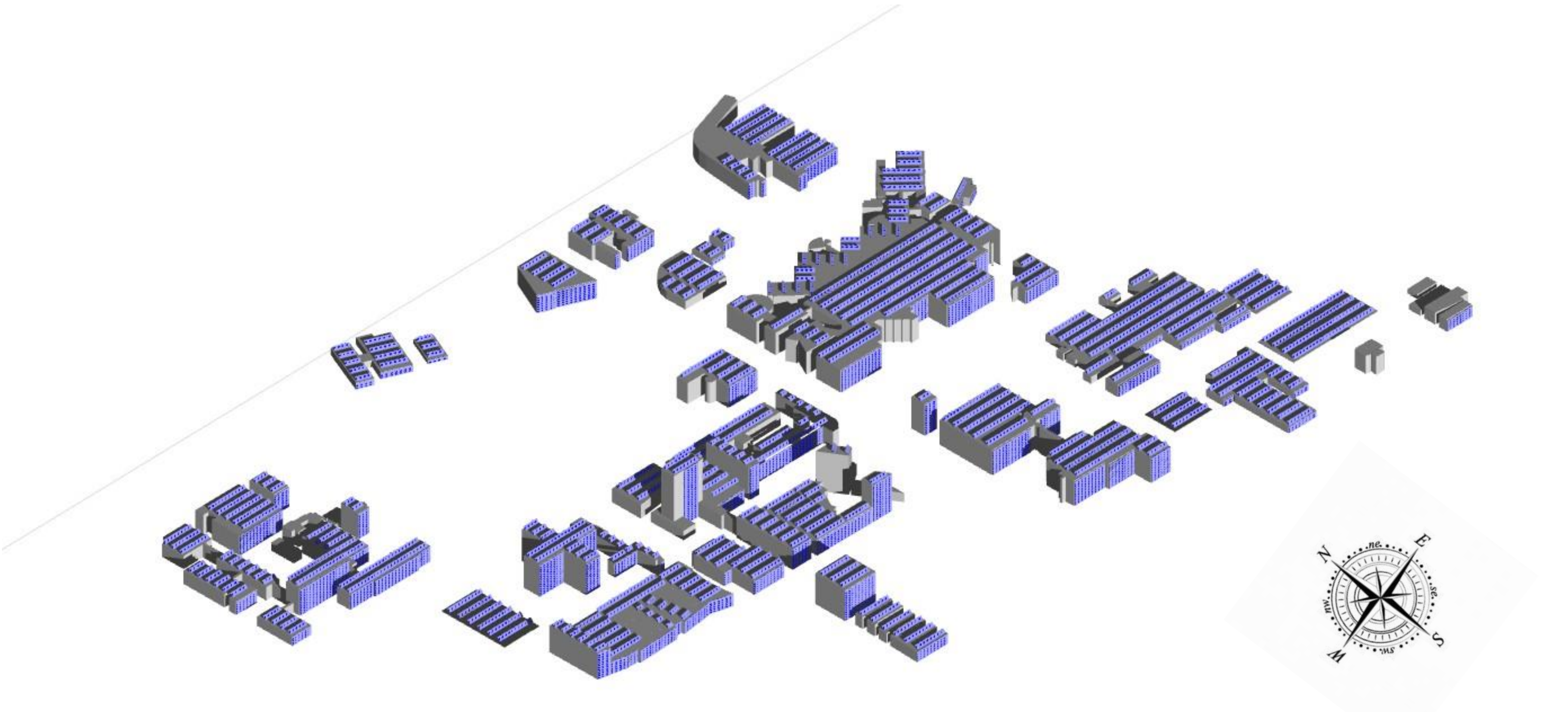


Figure 26 - VC0 project[9]

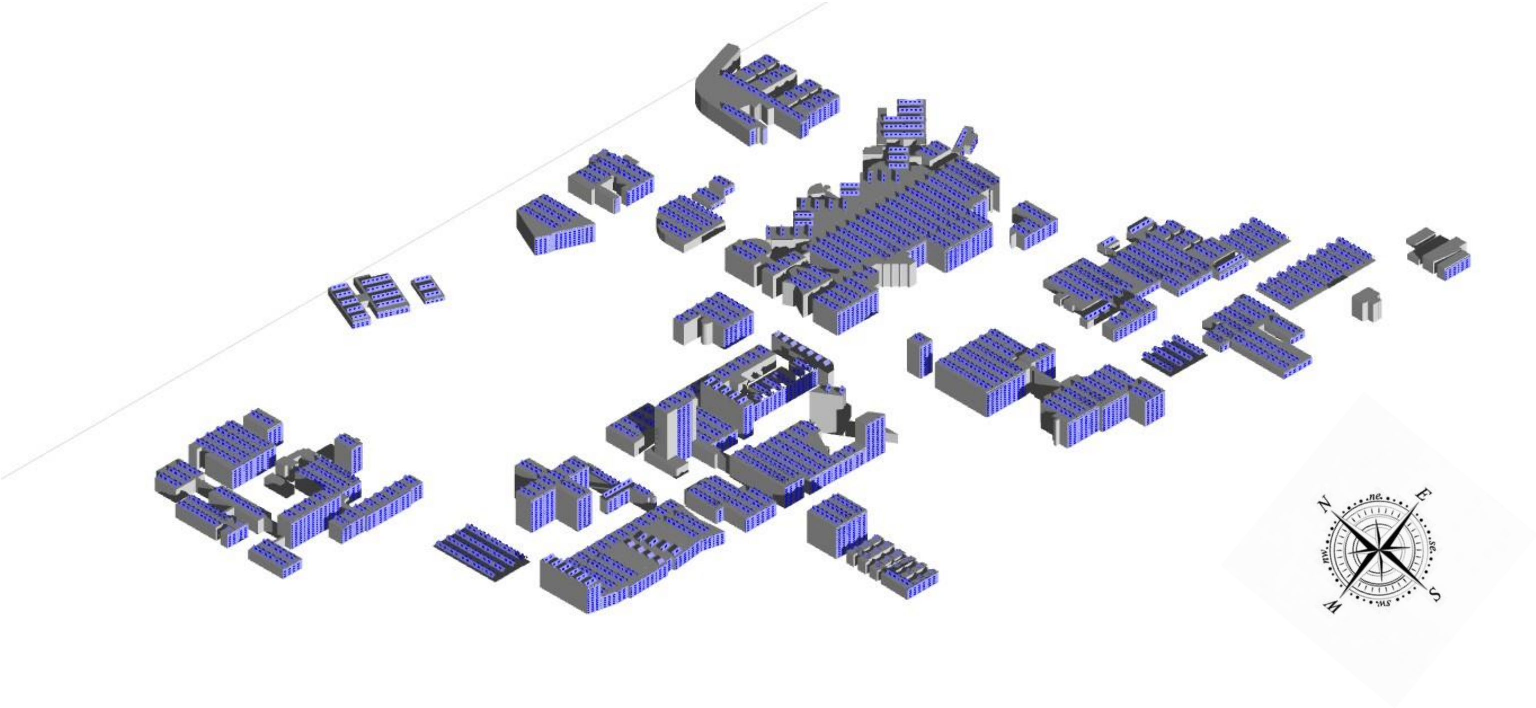


Figure 27 - VC1 project[9]

3.3. Carbon balance calculus

Another valuable tool on PVsyst is the Carbon Balance estimation that represents how much the system will save regarding CO_2 emissions. The calculus is based on the life cycle emission (LCE) method, which represents the emissions of CO_2 associated to a given component or energy amount, including production, operation, maintenance, disposal, etc. (User's, 2012). To estimate the Carbon Balance, Equation 1 shows its balance:

Equation 1

$$B_{Carbono} = E_{Grid} S_{Lifetime} LCE_{Grid} - LCE_{System}$$

Where:

B_{carbon} – Carbon balance (tCO_2).

E_{Grid} – Energy injected into the grid (MWh).

$S_{Lifetime}$ – System Lifetime – Represents the lifetime of the PV installation (Year).

LCE_{Grid} – Grid LCE - Represents the average amount of CO_2 emissions per energy unit for the electricity produced by the grid (Fix value for each country) (gCO_2/kWh).

LCE_{system} – PV system LCE – Represents the total amount of CO_2 emissions caused by the construction and operation of the PV installation (tCO_2).

3.4. Charging stations

With these solar energy systems, it is possible to use the produced energy to charge electric vehicles and bikes. In a preliminary estimation, the EV Tesla Model 3 (Figure 28) was chosen which has a battery of 50,0 kWh, with the real range being approximately between 240 km to 500 km, depending on the weather (if is cold or mild) and the driving area (urban or highway) (Tesla, 2019). Regarding the charging process, there are four different modes of charging (Section 2.4), for the present project and being a commercial usage, mode 3 combined with connector type 2 (accepted on Tesla Model 3 - Figure 29) are adopted as taking around 5 hours, Table 3 displays the different modes of charging using the Type 2 connector, using the charging point for 3-phrase 16A that charges 11kW per hour, the car will be full charge in around 5 hours that is the average time for work/study. The reason to choose Tesla Model 3 is that is one of the commercial brands for EV.

Figure 28 - Tesla Model 3[10]

Figure 29 - Type 2 (Mennekes - IEC 62196)[10]

[10] Source: https://ev-database.uk/car/1060/Tesla-Model-3

Table 3 - Modes of charging using connector Type 2[10]

Charging Point	Max. Power	Power	Time	Rate
Wall Plug (2.3 kW)	230V / 1x10A	2.3 kW	23h45m	8 mph
1-phase 16A (3.7 kW)	230V / 1x16A	3.7 kW	14h45m	13 mph
1-phase 32A (7.4 kW)	230V / 1x32A	7.4 kW	7h30m	25 mph
3-phase 16A (11 kW)	400V / 3x16A	11 kW	5 hours	38 mph
3-phase 32A (22 kW)	400V / 3x16A	11 kW †	5 hours	38 mph

To estimate the number of charging stations working simultaneously for the entire project versus hourly time for the VC0, in other words, the number of cars being charged at the same time using 11 kWh to charge the EV, the calculus uses Equation 2.

Equation 2

$$N_T = \frac{E_{Grid}}{LC}$$

Where:

N_T – Number of charging stations for the entire project

E_Grid – Hourly energy injected into the grid (kWh)

LC – Capacity charged for each car (for example: 11 kWh)

To determine the number of charging stations working simultaneously for the solar parking versus hourly time for the VC0, this calculus uses the following Equation 3.

Equation 3

$$N_{SP} = N_T * \%_{SP}$$

Where:

N_{SP} – Number of charging stations for the solar parking

N_T – Number of charging stations for the entire project

$\%_{SP}$ – Percentage of the Solar Parking (Value of 6,23%)

To quantify the Average number of charged cars per day for the entire project and for the solar parking, Equation 4 and Equation 5, respectively, are used.

Equation 4

$$NC_T = \frac{\sum E_{Grid}}{B_{NL}}$$

Where:

NC_T – Number of charged cars for the entire project.

ΣE_Grid – Sum of the hourly energy injected into the grid (kWh).

B_{NL} – Tesla Model 3 battery capacity (50 kWh).

Equation 5

$$NC_{SP} = N_{CT} * \%_{SP}$$

Where:

NC_{SP} – Number of charged cars for the solar parking.

NC_T – Number of charged cars for the entire project.

$\%_{SP}$ – Percentage of the Solar Parking.

3.5.Economic analysis for the PV project

At this stage, the cash flow spreadsheet contains the initial investments (which represents the CAPEX) and the annual spending with operation and maintenance (OPEX). For this analysis, the parameters are:

- Initial investment: describes the expenses regarding the purchase of: value of the PV panels, inverters, structures (for roofs to use the top of the buildings to produce energy also decreasing the heat inside the building; facades, was not able to find a 90° degree structure; and solar parking, using the up part of the solar parking to produce energy, furthermore to charge EV or other electronic stuff) and labor cost (for installing the solar power plant);
- Annual spending: operation and maintenance.

For a simple economic analysis, four variables need to be calculated: The NPV (Net present value), TLCC (total life-cycle cost), Payback, IRR (Internal rate of return) and LCOE (Levelized cost of energy). The calculus uses a excel tool.

❖ Net present value (NPV)

The NPV is calculated through the sum of the updated cash flow for each year applying an Inflation rate (Equation 6).

Equation 6

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+i)^t}$$

Where:

NPV – Net present value (€)

n – Life cycle of the solar panels, 25 years for the present project

CF_t – Cash flow on the time "t" (€)

i – Inflation rate (%)

t – Time (years)

The NPV was calculated in two different ways:

- Through excel tool called "NPV;"
- Through the sum of updated cash flow.

❖ Total life-cycle cost (TLCC)

TLCC means the sum of the CAPEX (initial investments) and OPEX (operation and maintenance) updated for each year applicated on an Inflation rate. Equation 7 displays the way to calculate the TLCC.

Equation 7

$$TLCC = CAPEX + \sum_{t=1}^{n} \frac{OPEX_t}{(1+i)^t}$$

Where:

TLCC – Total life-cycle cost (€)

CAPEX – Capital expenditure (€)

OPEX – Operational expenditure (€)

i – Inflation rate (%)

t – Time (years)

❖ Payback

Payback consists to estimate the years to take back the initial investment.

❖ Internal rate of return (IRR)

The IRR calculus is done through the determination of the tax that makes the cash flow be zero. To determinate the IRR value, Equation 8 is used:

Equation 8

$$0 = \sum_{t=0}^{n} \frac{CF_t}{(1 + IRR)^t}$$

Where:

n – Life cycle of the solar panels, 25 years for the present project

CF_t – Cash flow on the time “t” (€)

IRR – Internal rate of return (%)

t – Time (years)

❖ Levelized cost of energy (LCOE)

LCOE is the cost of producing energy in kWh (€/kWh), is determinate dividing the sum of updated annual spending for the sum of updated yield yearly energy (Equation 9).

Equation 9

$$LCOE = \frac{TLCC}{\sum_{t=0}^{n} \frac{YYE_t}{(1 + i)^t}}$$

Where:

LCOE – Levelized cost of energy (€/kWh)

YYE - Yearly yield energy (kWh)

i – Inflation rate (%)

t – Time (Years)

❖ Input data

Some parameters are necessary for the input data to estimate the NPV, TLCC, Payback, IRR and LCOE. The first parameter is the CAPEX which is the initial investment.

Table 4 displays the values for the initial investment (CAPEX) of VC0 project.

Table 4 - CAPEX for VC0

Equipments	Price (€)	Quantity	Total price
LG 340 N1C-A5	€ 248,54	103.456	€ 25.712.954,24
Fronius AGILO 100.0-3 Outdoor	€ 15.775,00	265	€ 4.180.375,00
Tin Roof Solar Mounting System (10-unit)	€ 80,30	5.174	€ 415.504,32
Aluminum Solar Carport (30-unit)	€ 1.070,00	215	€ 230.549,33
Charging stations (HOMEBOX SLIM)	€ 1.004,30	1.488	€ 1.494.733,17
Charging connectors (Type 2)	€ 272,00	1.488	€ 404.826,67
Labor cost	-	-	€ 327.252,59

Table 5 shows the values for the initial investment (CAPEX) of VC1 project.

Table 5 - CAPEX for VC1

Equipments	Price (€)	Quantity	Total price
LG 340 N1C-A5	€ 248,54	143.613	€ 35.693.575,02
Fronius AGILO 100.0-3 Outdoor	€ 15.775,00	401	€ 6.325.775,00
Tin Roof Solar Mounting System (10-unit)	€ 80,30	8.497	€ 682.333,19
Aluminum Solar Carport (30-unit)	€ 1.070,00	446	€ 477.648,00
Charging stations (HOMEBOX SLIM)	€ 1.004,30	1.928	€ 1.936.625,17
Charging connectors (Type 2)	€ 272,00	1.928	€ 524.506,67
Labor cost	-	-	€ 327.252,59

The Second parameter is the OPEX, that means the annual spending with operations and maintenance. For the VC0, the maintenance is €2.000 per year, and for VC1, €2.500 per year.

❖ Economic parameters used in this simulation

Eurostat (2018) provided the information about electricity price for Netherlands, that is 0,1706 €/kWh and the Inflation rate at 1,6%. The discount rate is set at 3% and the increase of electricity at 2% (Paardekooper, 2015; Van Sark et al, 2014).

4. Results

With the amount of the results, and better understanding, they subdivide in: Solar potential that represents the 2D and 3D results, EV charging that estimate the number of cars and charging station working simultaneously and economic analysis that shows the economic feasibility of the project.

4.1. Solar potential

The solar potential results split into two parts: 2D results that include the ArcGIS software with the shapefile displaying the solar potential analysis in Wh/m^2 for the entire year; and 3D results contains the results of PVsyst simulation.

4.1.1. 2D results

The output raster (Figure 30) represents the global radiation or total amount of incoming solar insolation (direct + diffuse) calculated for each location of the input surface. The values subdivide into five levels that begins at 8,72 Wh/m^2 until 1.044.596,06 Wh/m^2.

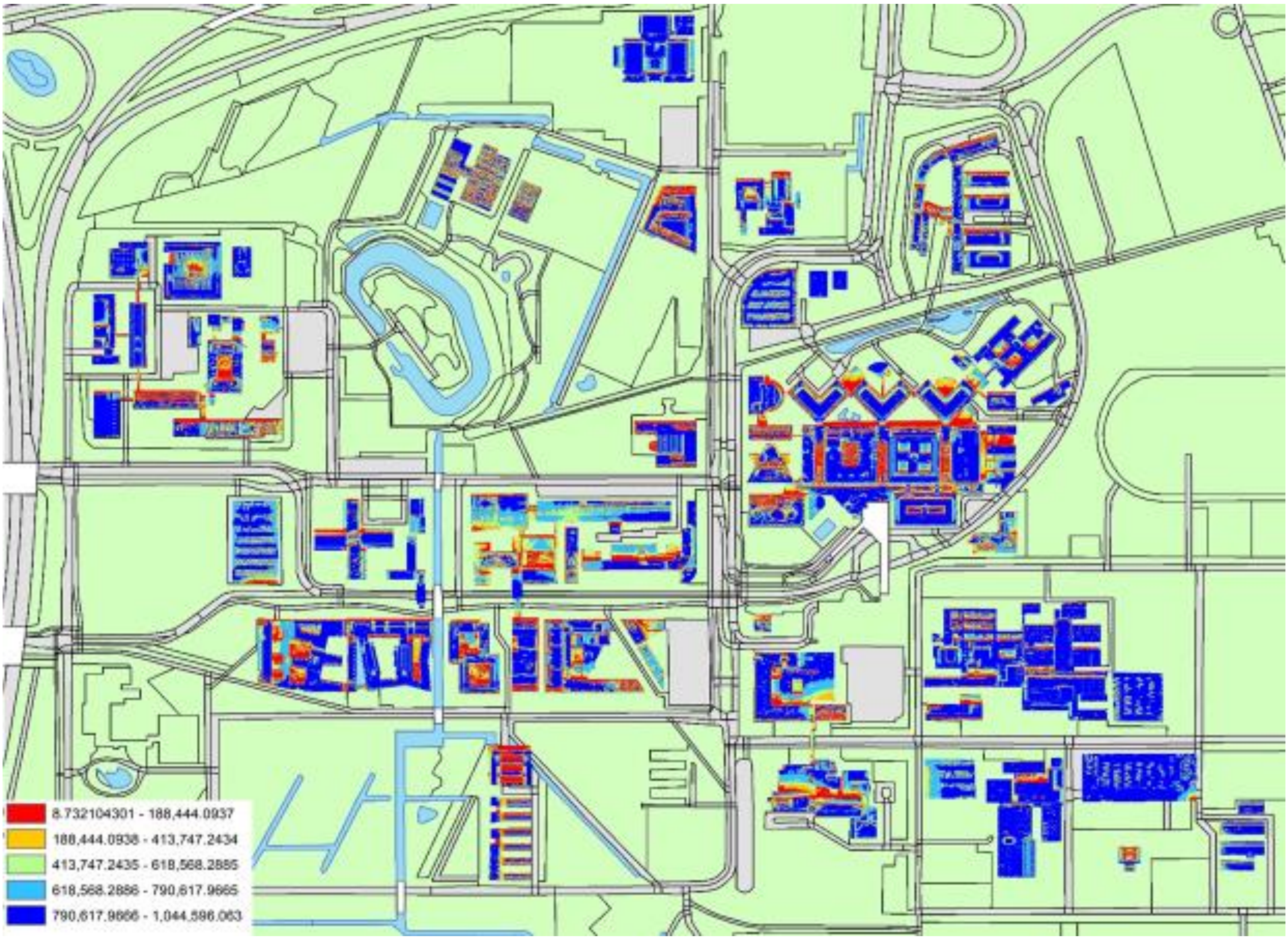


Figure 30 - Radiation for the entire year (Wh/m2)[11]

4.1.2. 3D results

After the 3D simulation on PVsyst, were possible to estimate the yield production in MWh/year for each project. Table 6 displays the overview results of the simulation.

[11] Source: ArcGIS

Table 6 - Results overview

	VC0	VC1
System production [MWh/year]	27.229	35.285
Specific production [kWh/kWp/year]	774	695
Performance ratio	0,775	0,757
Normalized production [kWh/kWp/day]	2,12	1,90
Array losses [kWh/kWp/day]	0,50	0,49
System losses [kWh/kWp/day]	0,12	0,12

Table 7 exhibits the Number of modules, Number of inverters, Area (m^2), Pnom array (kWp) (nominal power for the array) for the facades, solar parking and of roofs, and the percentage for each one comparing with the total number of modules. For the facades, the number of modules is the same, so has the same number of inverters, area and Pnon array, the difference is the percentage from the total Pnom array for the entire project. For the solar parking and roofs, the numbers of modules are different because has distinctive design (azimuth and disposition of the solar modules).

Table 7 - System information

	VC0			VC1		
	Facades	Solar Parking	Roofs	Facades	Solar Parking	Roofs
Number of modules	45.248	6.464	51.744	45.248	13.392	84.973
Number of inverters	119	17	129	119	38	238
Area (m^2)	77.509	11.073	88.636	77.509	23.131	146.765
Pnom array (kWp)	15.384	2.194	17.593	15.384	4.821	30.590
% on the total number of solar invertes	43,74	6,24	50,02	30,29	9,49	60,22

Table 8 and Table 9 represent the simulation, where each column represents:

- Column 0 – Months of the year;
- Column 1 – GlobHor = Horizontal global irradiation;
- Column 2 – DiffHor = Horizontal diffuse irradiation;
- Column 3 – T_amb = Ambient temperature;
- Column 4 – GlobInc – Global incident irradiation on the collector plane;
- Column 5 – GlobEff = Effective global (the radiation that reaches at the solar panel surface), corrected for the IAM (Incidence Angle Modifier) and shadings simultaneously;
- Column 6 – Earray = Effective energy at the output of the array;

- Column 7 – E_Grid = Energy injected into the grid;
- Column 8 – PR = Performance ratio.

The variables GlobHor, DiffHor and T_amb have the same values for both projects because are weather values, in other side, GlobInc and GlobEff have distinguish values because the collector plane is different considering the different values of azimuth and the design of the solar modules (including the value of area).

Table 8 represents the balances and main results for the project VC0, the total value for the EArray is 28.750.955 kWh/year, but with the system losses and efficiencies, the value that reaches on the grid is 27.229.165 kWh/year with the annual average performance ratio for the entire project at 0,77.

Table 8 - Balances and main results of VC0

Months	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	
January	20,70	12,50	3,82	41,60	39,40	1.259.659	1.044.029	0,71
February	34,30	24,30	4,26	48,30	45,60	1.455.705	1.396.601	0,82
March	71,20	47,80	6,24	81,40	76,50	2.422.016	2.331.803	0,81
April	114,70	62,20	9,97	114,00	106,60	3.298.630	3.179.491	0,79
May	147,80	80,70	13,80	125,80	117,20	3.582.542	3.452.858	0,78
June	150,60	88,60	16,17	117,00	108,70	3.295.157	3.172.561	0,77
July	151,70	90,40	18,00	120,80	112,30	3.364.105	3.238.750	0,76
August	128,90	77,50	17,87	114,10	106,30	3.197.083	3.081.140	0,77
September	85,20	52,10	14,69	95,00	89,00	2.714.273	2.617.754	0,78
October	52,00	29,80	11,19	74,60	70,30	2.180.827	1.943.945	0,74
November	22,70	15,50	7,48	36,50	34,40	1.082.210	1.034.756	0,81
December	15,10	10,70	3,66	29,50	27,90	898.749	735.475	0,71
Year	**994,90**	**592,09**	**10,63**	**998,70**	**934,10**	**28.750.955**	**27.229.165**	**0,78**

Table 9 displays the balances and main results for the project VC1, the total value for the EArray is 37.497.882 kWh/year, but with the system losses and efficiencies, the value that reaches into the grid is 35.285.259 kWh/year with the annual average performance ratio for the entire project at 0,80.

Table 9 - Balances and main results for VC1

Months	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	
January	20,70	12,50	3,82	29,40	27,10	1.227.209	1.165.033	0,78
February	34,30	24,30	4,26	37,90	35,10	1.593.926	1.520.591	0,79
March	71,20	47,80	6,24	70,20	65,30	2.948.552	2.832.234	0,80
April	114,70	62,20	9,97	105,10	97,80	4.351.740	4.191.666	0,79
May	147,80	80,70	13,80	125,60	116,90	5.131.537	4.944.239	0,78
June	150,60	88,60	16,17	122,00	113,30	4.924.675	4.307.518	0,70
July	151,70	90,40	18,00	124,60	115,80	4.986.784	4.800.154	0,76
August	128,90	77,50	17,87	111,10	103,30	4.469.089	4.304.496	0,76
September	85,20	52,10	14,69	83,50	77,70	3.403.984	3.021.498	0,71
October	52,00	29,80	11,19	59,40	55,30	2.450.276	2.349.373	0,78
November	22,70	15,50	7,48	27,70	25,60	1.139.231	1.028.550	0,73
December	15,10	10,70	3,66	21,00	19,20	870.878	819.906	0,77
Year	**994,90**	**592,09**	**10,63**	**917,50**	**852,40**	**37.497.882**	**35.285.259**	**0,76**

4.1.3. Carbon balance result

Figure 31 shows that through the generation of 27.229,2 MWh (VC0 project), for a lifetime of 25 years and annual degradation of 1,0%, it saves 196.770,867 tons of CO_2.

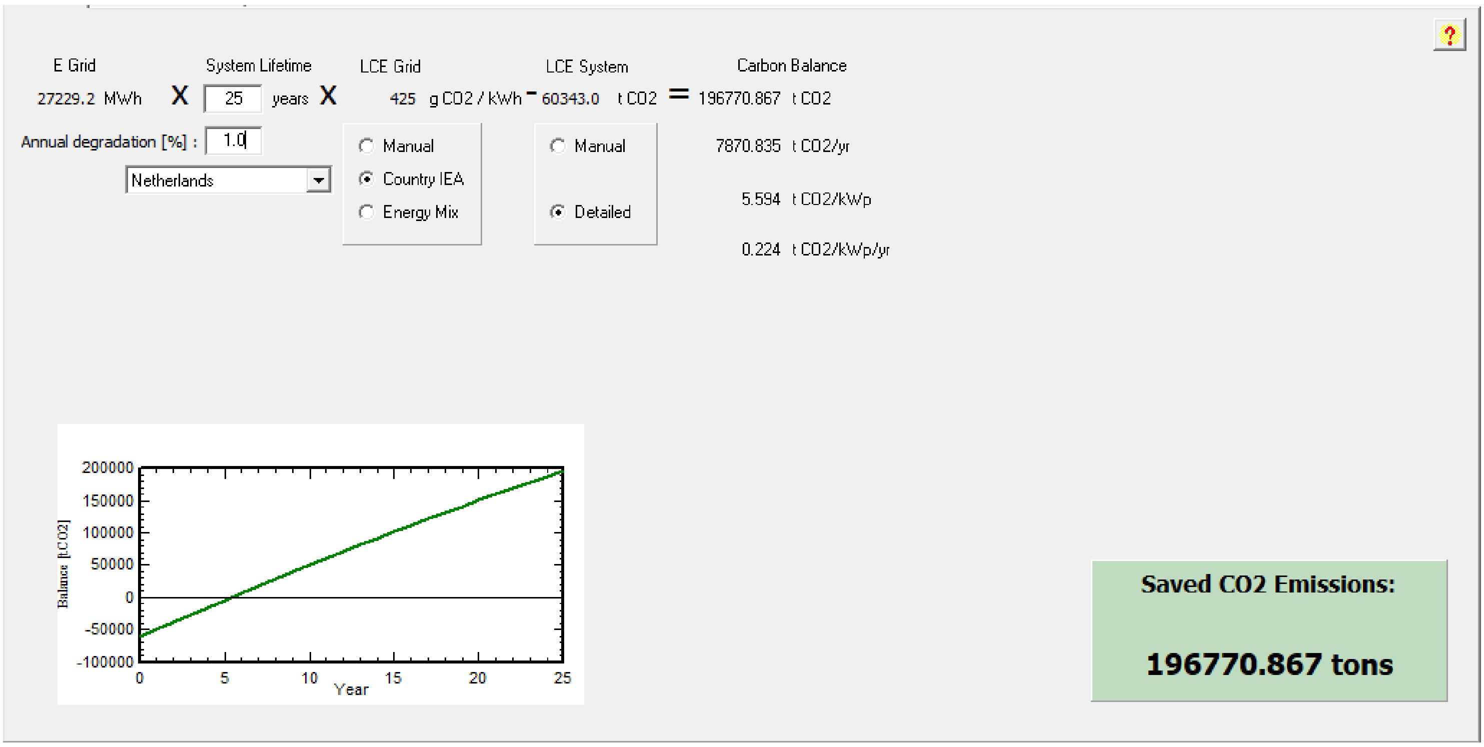


Figure 31 - Carbon balance for VC0[9]

Figure 32 shows that through the generation of 35.285,3 MWh (VC1 project), with the lifetime of 25 years, annual degradation at 1,0%, saves 242.114,490 tons of CO_2.

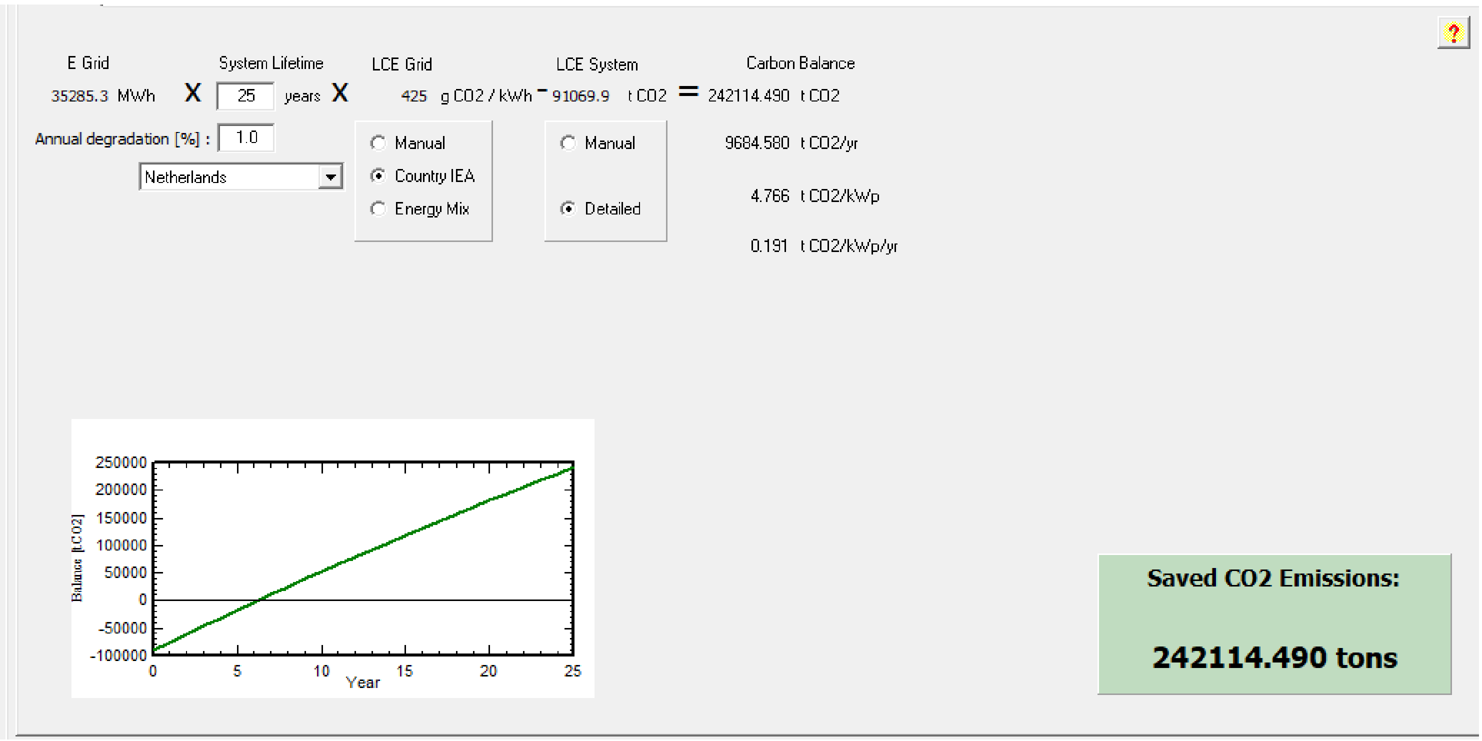


Figure 32 - Carbon balance for VC1[9]

Beyond the reduction of carbon dioxide (CO_2) emission, other greenhouse gases (GHG) also suffer reduction, like methane (CH_4), nitrous oxide (N_2O) and fluorinated gases because their emissions links with the generation of energy using fossil fuels.

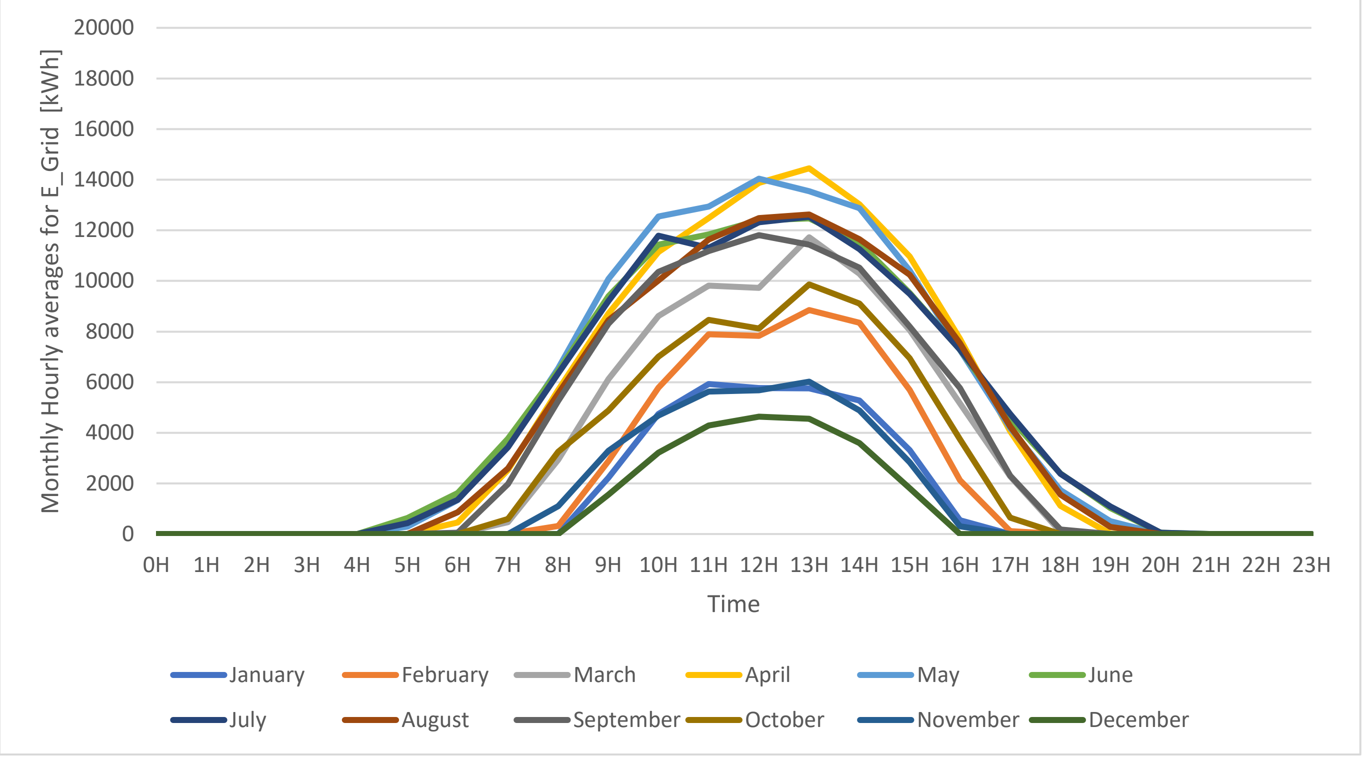
4.2.EV Charging

For the EV charging, it was possible to estimate how many charging stations and cars can be charged per hour and day. Graphic 1 to Graphic 6 display the possibilities for charging vehicles starting with the monthly hourly average of energy injected into the grid, then estimating how many charging stations can be working simultaneously for the entire project and focusing more on the solar parking. The spreadsheet with the values can be found on the **Appendix A**.

It is possible to see that during the spring/summer (middle of March to middle of September), the production of energy has the highest values, as expected. During the autumn/winter (middle of September to middle of March) has the lowest values of energy production.

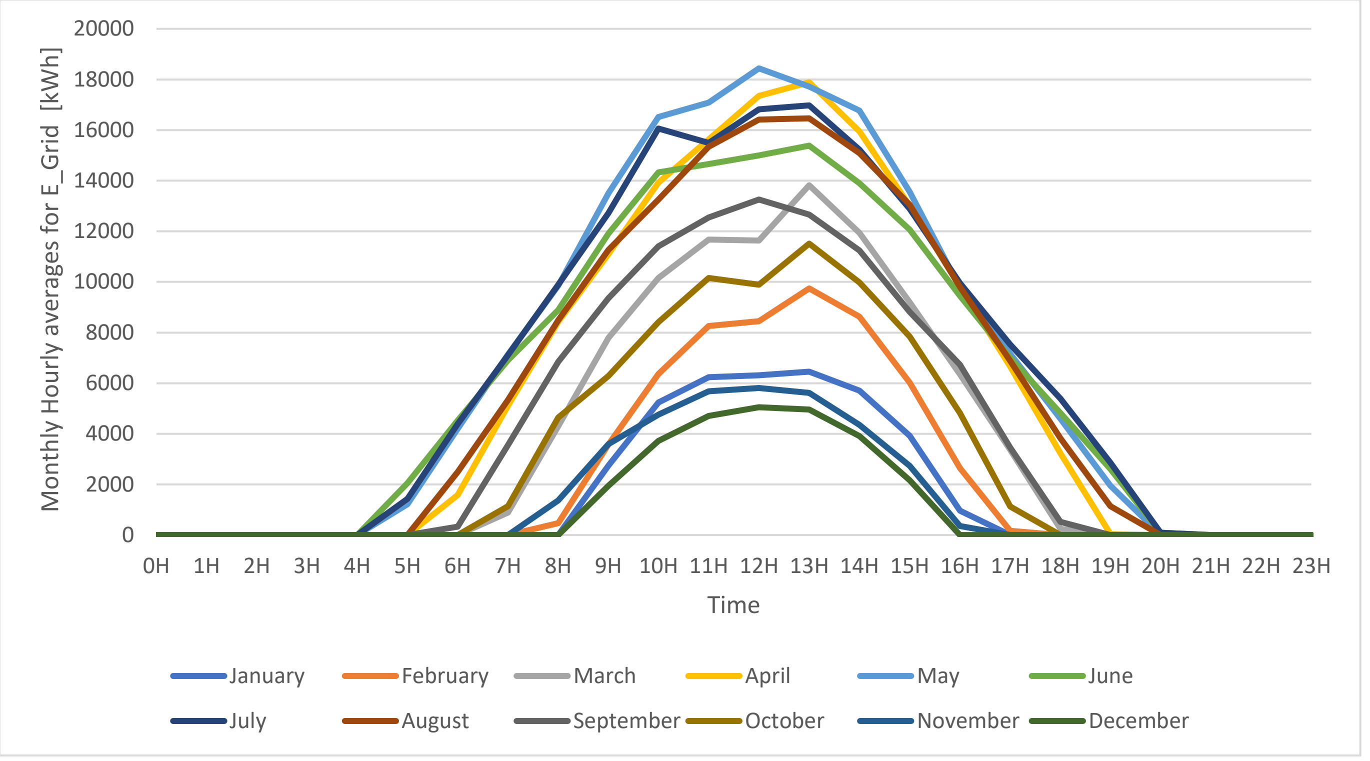
Graphic 1 shows the Monthly hourly average for the E_Grid (kWh) versus the hourly time per day for the VC0.

Graphic 1 - Monthly Average vs Time for VC0



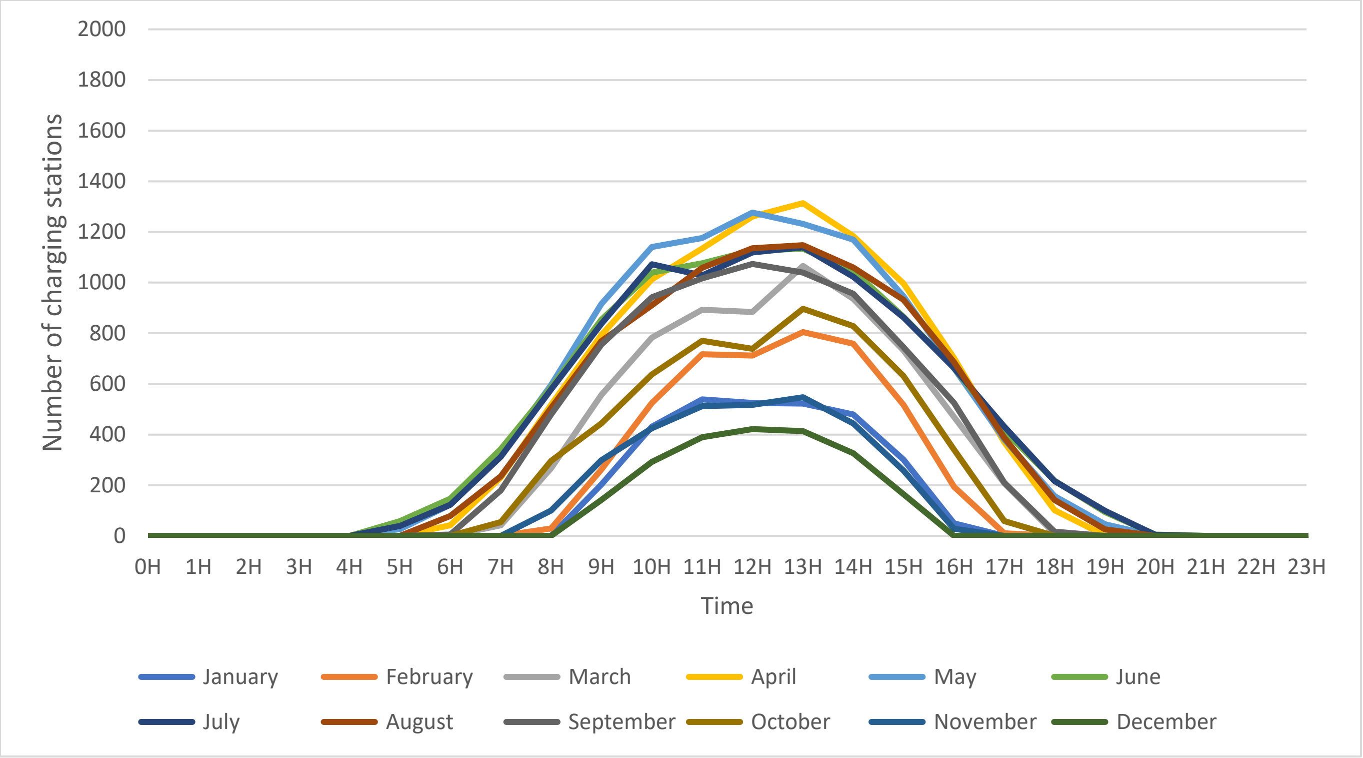
Graphic 2 shows the Monthly hourly average for the E_Grid (kWh) versus the hourly time per day for the VC1.

Graphic 2 - Monthly Average vs Time for VC1



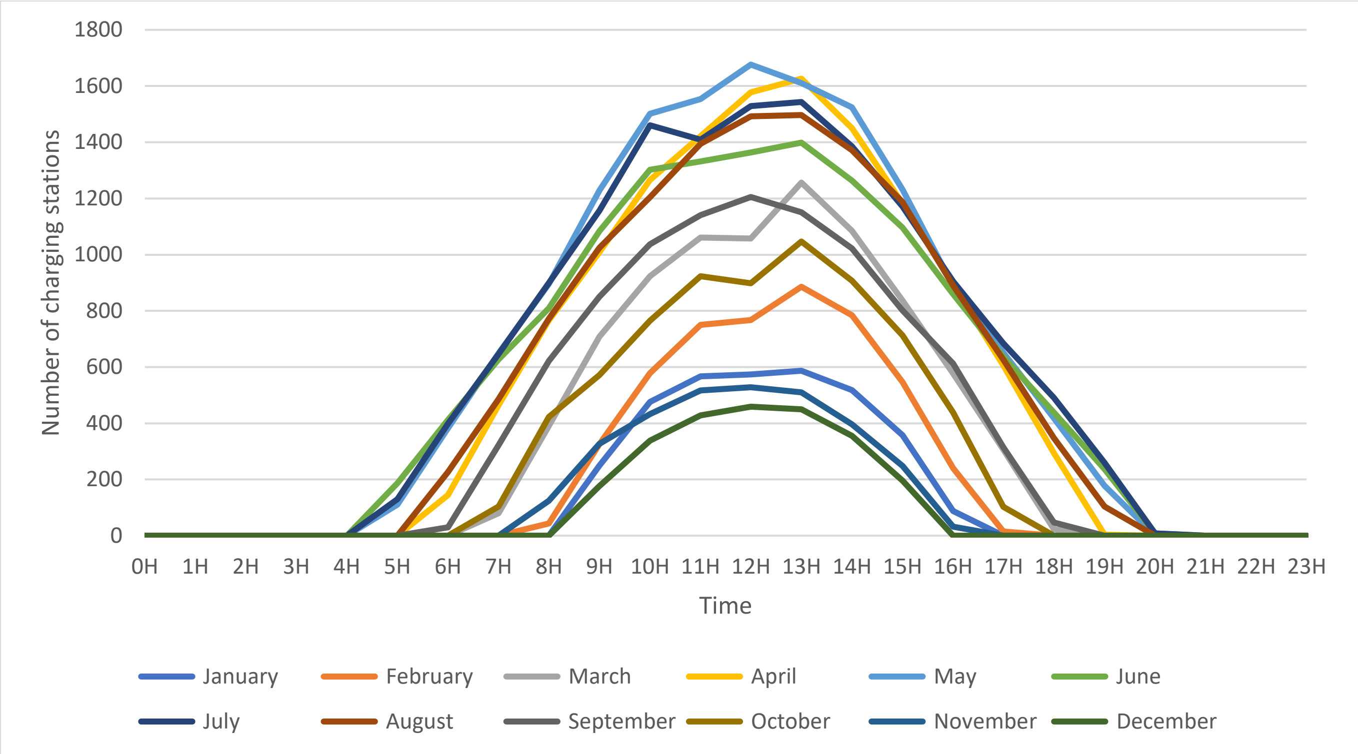
Graphic 3 exhibit of charging stations for the entire project versus hourly time for the VC0, this calculus uses Equation 2.

Graphic 3 - Number of charging stations for entire project vs time for VC0



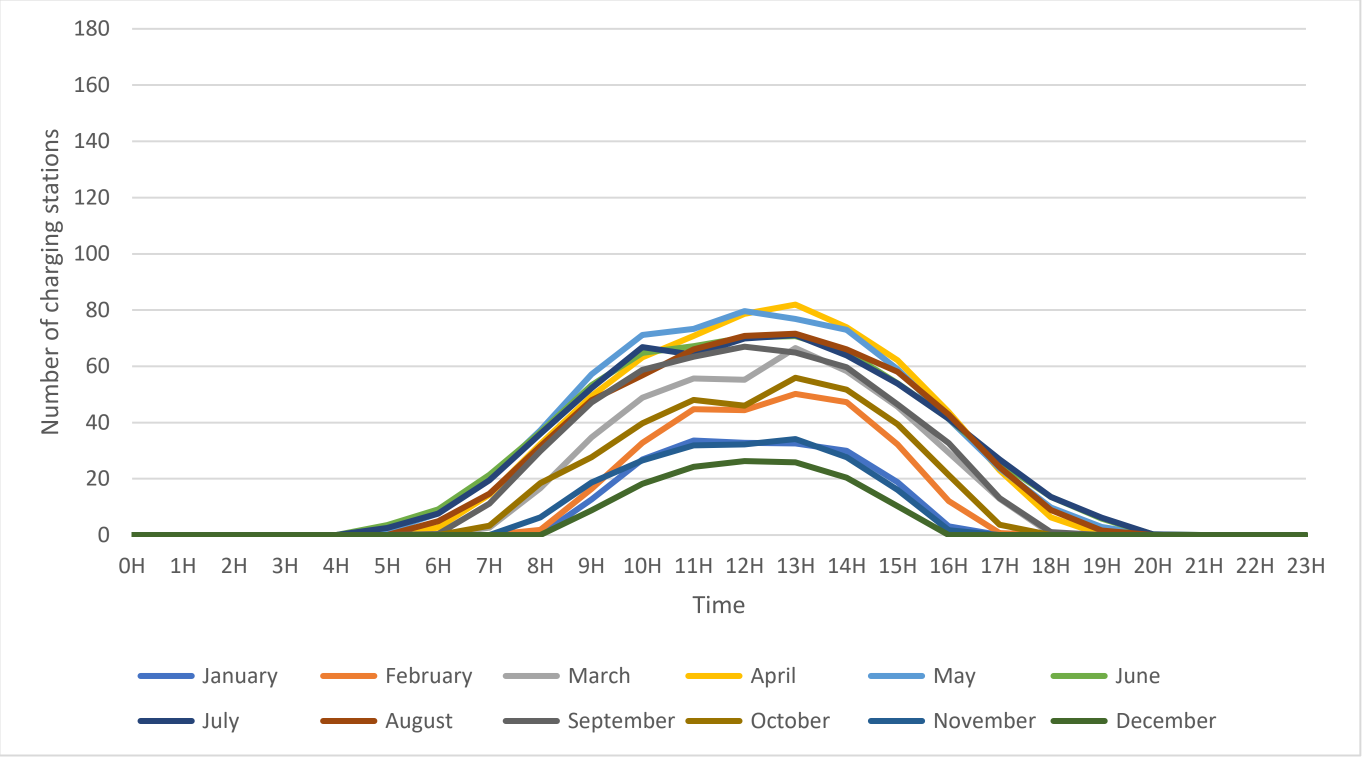
Graphic 4 exhibit of charging stations for the entire project versus hourly time for the VC1, this calculus uses Equation 2.

Graphic 4 - Number of charging stations for entire project vs time for VC1



Graphic 5 displays the number charging stations for the solar parking versus hourly time for the VC0, this calculus uses Equation 3.

Graphic 5 - Number of charging stations for solar parking vs time for VC0



Graphic 6 displays the number charging stations for the solar parking versus hourly time for the VC1, this calculus uses Equation 3.

Graphic 6 - Number of charging stations for solar parking vs time for VC1

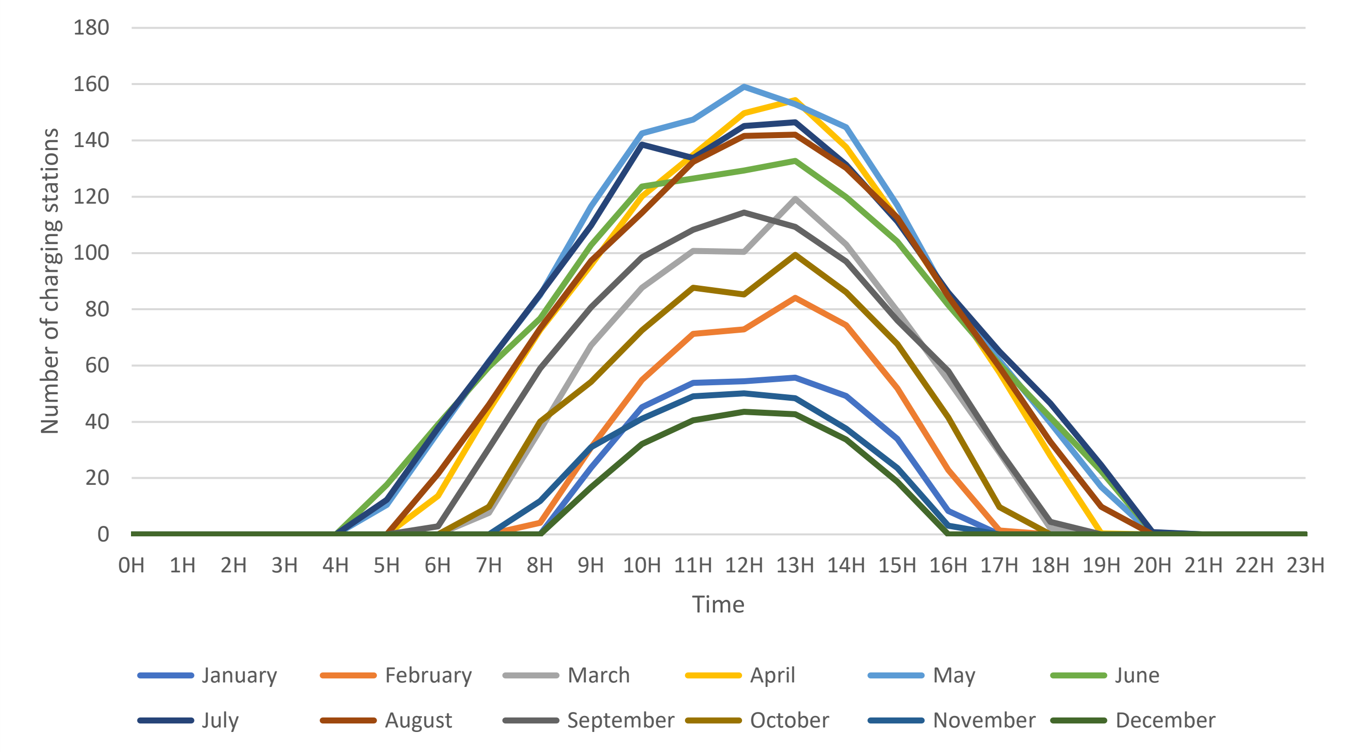


Table 10 shows the Average number of charged cars per day for the entire project (Equation 4) and for solar parking (Equation 5)

During the spring/summer (middle of March to middle of September), have the highest values for producing energy, especially May that can charge 2.237 cars for the entire project and 140 cars focusing on the solar parking for the VC0 project. And for the VC1 project, the value is 3.190 cars for the entire project, 303 cars for only the solar parking.

During the autumn/winter (middle of September to middle of March) have the lowest values for producing energy, especially December that charges 473 cars using the energy for the entire project and 30 cars for solar parking looking on the VC0 project. For VC1, the entire project is 529 cars and 50 cars focusing on solar parking.

Table 10 - Average number of charged cars per day

Months	VC0		VC1	
	Whole Project	Solar Parking 6,23%	Whole Project	Solar Parking 9,49%
January	671	42	752	71
February	997	62	1 086	103
March	1 506	94	1 827	173
April	2 125	133	2 794	265
May	2 237	140	3 190	303
June	2 127	133	2 872	273
July	2 101	131	3 097	294
August	1 996	124	2 777	264
September	1 747	109	2 014	191
October	1 253	78	1 516	144
November	688	43	686	65
December	473	30	529	50
Average	**1 493**	93	**1 928**	183

4.3.Economic analysis

Table 11 and Table 12 show the output data for the economic analysis.

Table 11 shows a positive value of NPV (for both ways of calculus), which results that the project is economically viable. TLCC is the total costs, representing the sum of installation costs (CAPEX) and operation (OPEX) of the solar power plant. The payback has a value of 7,69 years, lower than the lifetime that is 25 years. The LCOE has a value of 0,058 €/kWh when the solar plant is working.

Table 11 - Output data for VC0

NPV	€ 67 995 285,35
NPV Excel	€ 67 974 892,67
TLCC	€ 35 933 969,67
Payback (Years)	7,69
TIR (IRR)	12,21%
LCOE (€/kWh)	0,058

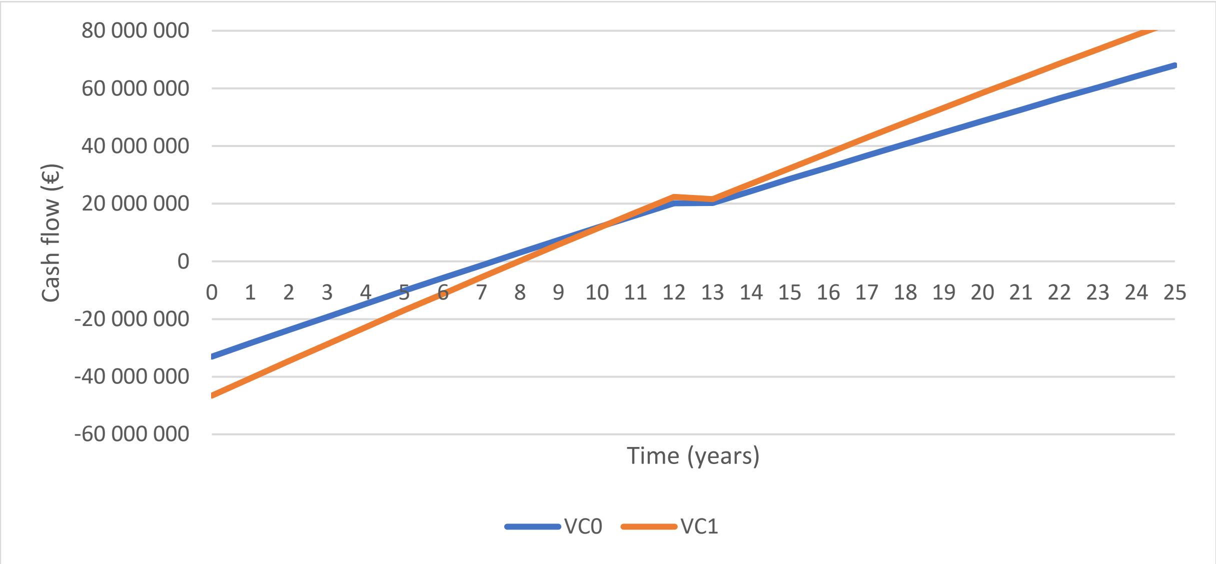
Table 12 shows a positive value of NPV (for both ways of calculus), which results that the project is economically workable. TLCC is the total cost during installing (CAPEX) and operation (OPEX) of the solar power plant. The payback has a value of 7,03 years, lower than the lifetime that is 25 years. The LCOE has a value of 0,063 €/kWh when the solar plant is working.

Table 12 - Output data for VC1

NPV	€ 83 425 409,07
NPV Excel	€ 83 400 388,95
TLCC	€ 50 955 741,32
Payback (Years)	7,03
TIR (IRR)	11%
LCOE (€/kWh)	0,064

Graphic 7 display the accumulated cash flow for both projects that starts at year 0 (for CAPEX) and from year 1 until 25 we have the OPEX, furthermore, at the year 13 we have the changing of the inverter, that is why we have the "same" value for year 12 and 13.

Graphic 7 - Accumulated cash flow for VC0 and VC1



5. Conclusion

The De Uithof campus represents an enormous potential for the usage of solar energy as is possible to install the PV modules in so many places, the roofs being the major possibility, then on the facades, followed by the solar parking setup. During the autumn and winter, the power production is similar for the VC0 and VC1, the production is impaired because those seasons are usually cloudy, and the solar resource is smaller.

The technical results show that the production of VC0 and VC1, that is, respectively, 27.229 MWh/year and 35.285 MWh/year are satisfactory results taking into account the size of the solar plant, because it is possible to obtain good value of yearly average performance ratios for both projects, 0,775 and 0,757 (VC0 and VC1, respectively), as the numbers are near to the unitary value, meaning a very reliable performance of the entire system.

Looking at the number of charging station, due to the VC0 production, is possible to charge 473 EV/day in December (the lowest value) and 2.237 EV/day in May (the highest value). Even focusing on solar parking, the number is quite good, being 30 EV/day in December (lowest value) and 140 EV/day in May (the highest value). For the VC1, the numbers are greater since the VC1 production is higher. If the produced energy is used to charge electric bicycles, surely these numbers will be higher.

Economic analysis demonstrates that both projects are economically feasible because the NPV are positive values (€68 million and €83 million), the payback time (7,69 and 7,03 years) are acceptable for such an investment, being much lower than 25 years, the solar cells usual lifetime cycle, plus with the values of LCOE (0,058 €/kWh for VC0 and 0,064 €/kWh for VC1).

This project represents an environmental positive result since it allows to avoid dioxide carbon emissions (196.770 tons for VC0 and 242.114 tons for VC1), avoiding also emissions of other GHG, currently associated with the production of energy with fossil fuels.

6. Future Works

In order to increase the accuracy regarding these results, some additional tasks could be performed: An updates on the buildings modelling section because some buildings are missing on the shapefile used; Detailed loss calculus due to use of the default options on the present project; Choosing in a more detailed approach the locations to install the panels, considering the shadows during the entire year, mainly the panels closer to the ground, even foreseeing possible future shadows, such as growing trees; Increase the level of details regarding the charging stations calculus for electric vehicles and bikes to obtain increased accuracy for these results; An deeper detailed economic analysis with more detailed costs of installation and commissioning as well as operation of the solar power system, beyond the detailed procurement of the EV charging balance of system.

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Appendix A

Figure A 1 presents the specification of the solar panel LG 340 N1C-A5.

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Characteristics of a PV module

Manufacturer, model :	**LG Electronics, LG 340 N1C-A5**
Availability :	Prod. Since 2017
Data source :	Manufacturer 2017

STC power (manufacturer)	**Pnom**	**340**	**Wp**	**Technology**		**Si-mono**	
Module size (W x L)		1.016 x 1.686	m²	Rough module area	Amodule	1.71	m²
Number of cells		1 x 60		Sensitive area (cells)	Acells	1.55	m²
Specifications for the model (manufacturer or measurement data)							
Reference temperature	TRef	25	°C	Reference irradiance	GRef	1000	W/m²
Open circuit voltage	Voc	41.1	V	Short-circuit current	Isc	10.53	A
Max. power point voltage	Vmpp	34.5	V	Max. power point current	Impp	9.86	A
=> maximum power	Pmpp	340.2	W	Isc temperature coefficient	muIsc	3.2	mA/°C
One-diode model parameters							
Shunt resistance	Rshunt	250	ohm	Diode saturation current	IoRef	0.019	nA
Serie resistance	Rserie	0.21	ohm	Voc temp. coefficient	MuVoc	-123	mV/°C
				Diode quality factor	Gamma	0.99	
Specified Pmax temper. coeff.	muPMaxR	-0.37	%/°C	Diode factor temper. coeff.	muGamma	0.000	1/°C
Reverse Bias Parameters, for use in behaviour of PV arrays under partial shadings or mismatch							
Reverse characteristics (dark)	BRev	3.20	mA/V²	(quadratic factor (per cell))			
Number of by-pass diodes per module		3		Direct voltage of by-pass diodes		-0.7	V

Model results for standard conditions (STC: T=25°C, G=1000 W/m², AM=1.5)							
Max. power point voltage	Vmpp	34.2	V	Max. power point current	Impp	9.95	A
Maximum power	Pmpp	340.3	Wc	Power temper. coefficient	muPmpp	-0.36	%/°C
Efficiency(/ Module area)	Eff_mod	19.9	%	Fill factor	FF	0.786	
Efficiency(/ Cells area)	Eff_cells	22.0	%				

Figure A 1 - Characteristics of LG 340 N1C-A5[7]

Figure A 2 displays the specification of the inverter AGILO 100.0-3 Outdoor

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Characteristics of a grid inverter

Manufacturer, model : **Fronius International, AGILO 100.0-3 Outdoor**

Availability : Prod. Since 2013

Data source : Manufacturer 2016

460

Operating mode		**MPPT**				
Minimum MPP Voltage	**Vmin**	**N/A V**	Nominal PV Power	Pnom DC	104	kW
Maximum MPP Voltage	**Vmax**	**820 V**	Maximum PV Power	Pmax DC	150	kW
Absolute max. PV Voltage	Vmax array	950 V	Maximum PV Current	Imax DC	N/A	A
Min. Voltage for PNom	Vmin PNom	460 V	Power Threshold	Pthresh.	520	W
Behaviour at Vmin/Vmax		Limitation	Behaviour at Pnom		Limitation	

Output characteristics (AC grid side)

Grid Voltage	Unom	400 V	**Nominal AC Power**	**Pnom AC**	**100**	**kWac**
Grid frequency	Freq	50/60 Hz	Maximum AC Power	Pmax AC	100	kWac
	Triphased		Nominal AC current	Inom AC	145	A
			Maximum AC current	Imax AC	153	A

Efficiency defined for 3 voltages	460 V	640 V	820 V
Maximum efficiency	97.2 %	96.8 %	96.3 %
European average efficiency	96.6 %	96.1 %	95.4 %

Remarks and Technical features

Array nominal power should be lower than then Max. PV Power,
This is a contractual requirement of the manufacturer.
Array isolation monitoring, Internal DC switch,
Internal AC switch, Output Voltage disconnect adjustement,
ENS protection,

Technology: LF Transformer
Protection: IP 44
Control: graphical display, backlit
PC board replacement concept
Module Manager

Sizes: Width 1204 mm
Height 1913 mm
Depth 862 mm
Weight 806.00 kg

Figure A 2 - Characteristics of AGILO 100.0-3 Outdoor[7]

From Table A 1 to Table A 6 we can find the detailed spreadsheet values for the Graphics 1 to 6 on the Section 4.3.

The Table A 1 displays the values for Monthly Hourly averages for E_Grid [kWh] for VC0 project.

Table A 1 - Monthly Hourly averages for E_Grid [kWh] for VC0

Months	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H
January	-	-	-	-	2 228	4 747	5 928	5 774	5 750	5 276	3 311	543	-	-	-
February	-	-	-	320	2 884	5 776	7 890	7 830	8 850	8 342	5 689	2 132	118	-	-
March	-	-	467	2 930	6 128	8 617	9 818	9 727	11 725	10 288	8 058	5 163	2 279	92	-
April	-	462	2 529	5 694	8 717	11 149	12 481	13 868	14 450	13 021	10 965	7 714	4 065	1 116	19
May	299	1 349	3 542	6 557	10 078	12 546	12 937	14 041	13 544	12 874	10 404	7 276	4 188	1 731	505
June	635	1 616	3 776	6 447	9 395	11 432	11 837	12 391	12 472	11 512	9 521	7 289	4 559	2 392	1 024
July	436	1 351	3 430	6 354	9 208	11 791	11 307	12 318	12 534	11 253	9 492	7 290	4 744	2 386	1 090
August	3	859	2 595	5 556	8 454	10 020	11 639	12 488	12 625	11 652	10 247	7 545	4 257	1 562	278
September	-	54	1 976	5 267	8 307	10 363	11 184	11 810	11 435	10 522	8 196	5 770	2 305	176	-
October	-	-	595	3 257	4 881	7 014	8 468	8 118	9 862	9 112	6 941	3 747	646	-	-
November	-	-	-	1 099	3 290	4 676	5 628	5 684	6 020	4 879	2 839	304	-	-	-
December	-	-	-	-	1 553	3 217	4 286	4 638	4 550	3 590	1 814	-	-	-	-

The Table A 2 illustrates the number of charging stations for the entire VC0 project.

Table A 2 - Number of charging stations for the entire project of VC0

Months	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H
January	-	-	-	-	203	432	539	525	523	480	301	49	-	-	-
February	-	-	-	29	262	525	717	712	805	758	517	194	11	-	-
March	-	-	42	266	557	783	893	884	1 066	935	733	469	207	8	-
April	-	42	230	518	792	1 014	1 135	1 261	1 314	1 184	997	701	370	101	2
May	27	123	322	596	916	1 141	1 176	1 276	1 231	1 170	946	661	381	157	46
June	58	147	343	586	854	1 039	1 076	1 126	1 134	1 047	866	663	414	217	93
July	40	123	312	578	837	1 072	1 028	1 120	1 139	1 023	863	663	431	217	99
August	0	78	236	505	769	911	1 058	1 135	1 148	1 059	932	686	387	142	25
September	-	5	180	479	755	942	1 017	1 074	1 040	957	745	525	210	16	-
October	-	-	54	296	444	638	770	738	897	828	631	341	59	-	-
November	-	-	-	100	299	425	512	517	547	444	258	28	-	-	-
December	-	-	-	-	141	292	390	422	414	326	165	-	-	-	-

The Table A 3 displays the number of charging stations for the solar parking VC0 project.

Table A 3 - Number of charging stations for solar parking of VC0

Months	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H
January	-	-	-	-	13	27	34	33	33	30	19	3	-	-	-
February	-	-	-	2	16	33	45	44	50	47	32	12	1	-	-
March	-	-	3	17	35	49	56	55	66	58	46	29	13	1	-
April	-	3	14	32	49	63	71	79	82	74	62	44	23	6	0
May	2	8	20	37	57	71	73	80	77	73	59	41	24	10	3
June	4	9	21	37	53	65	67	70	71	65	54	41	26	14	6
July	2	8	19	36	52	67	64	70	71	64	54	41	27	14	6
August	0	5	15	32	48	57	66	71	72	66	58	43	24	9	2
September	-	0	11	30	47	59	63	67	65	60	46	33	13	1	-
October	-	-	3	18	28	40	48	46	56	52	39	21	4	-	-
November	-	-	-	6	19	27	32	32	34	28	16	2	-	-	-
December	-	-	-	-	9	18	24	26	26	20	10	-	-	-	-

The Table A 4 displays the values for Monthly Hourly averages for E_Grid [kWh] for VC1 project.

Table A 4 - Monthly Hourly averages for E_Grid [kWh] for VC1

Months	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H
January	-	-	-	-	2 747	5 240	6 240	6 307	6 456	5 702	3 927	963	-	-	-	-
February	-	-	-	472	3 582	6 360	8 254	8 446	9 744	8 622	6 016	2 649	162	-	-	-
March	-	-	884	4 297	7 791	10 159	11 671	11 631	13 820	11 936	9 201	6 354	3 371	248	-	-
April	-	1 586	5 116	8 422	11 100	13 925	15 637	17 348	17 888	15 952	13 000	9 820	6 660	3 232	36	-
May	1 221	4 206	7 137	9 852	13 509	16 517	17 085	18 439	17 716	16 766	13 553	9 765	7 163	4 598	1 955	10
June	2 053	4 532	6 903	8 897	11 917	14 326	14 654	14 994	15 385	13 896	12 060	9 454	7 001	4 821	2 602	87
July	1 429	4 386	7 109	9 894	12 723	16 061	15 496	16 817	16 976	15 232	12 888	9 960	7 531	5 395	2 855	92
August	2	2 494	5 343	8 489	11 273	13 252	15 341	16 412	16 464	15 088	13 055	9 798	6 886	3 815	1 142	-
September	-	329	3 551	6 838	9 357	11 409	12 542	13 257	12 665	11 242	8 814	6 732	3 459	521	-	-
October	-	-	1 141	4 641	6 282	8 410	10 159	9 885	11 514	9 976	7 838	4 817	1 124	-	-	-
November	-	-	-	1 368	3 595	4 762	5 686	5 810	5 612	4 355	2 737	358	-	-	-	-
December	-	-	-	-	1 946	3 725	4 705	5 050	4 953	3 910	2 160	-	-	-	-	-

The Table A 5 illustrates the number of charging stations for the entire VC1 project.

Table A 5 - Number of charging stations for the entire project of VC1

Months	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H
January	-	-	-	-	250	476	567	573	587	518	357	88	-	-	-	-
February	-	-	-	43	326	578	750	768	886	784	547	241	15	-	-	-
March	-	-	80	391	708	924	1 061	1 057	1 256	1 085	836	578	306	23	-	-
April	-	144	465	766	1 009	1 266	1 422	1 577	1 626	1 450	1 182	893	605	294	3	-
May	111	382	649	896	1 228	1 502	1 553	1 676	1 611	1 524	1 232	888	651	418	178	1
June	187	412	628	809	1 083	1 302	1 332	1 363	1 399	1 263	1 096	859	636	438	237	8
July	130	399	646	899	1 157	1 460	1 409	1 529	1 543	1 385	1 172	905	685	490	260	8
August	0	227	486	772	1 025	1 205	1 395	1 492	1 497	1 372	1 187	891	626	347	104	-
September	-	30	323	622	851	1 037	1 140	1 205	1 151	1 022	801	612	314	47	-	-
October	-	-	104	422	571	765	924	899	1 047	907	713	438	102	-	-	-
November	-	-	-	124	327	433	517	528	510	396	249	33	-	-	-	-
December	-	-	-	-	177	339	428	459	450	355	196	-	-	-	-	-

The Table A 6 displays the number of charging stations for solar parking of VC1 project.

Table A 6 - Number of charging stations for solar parking of VC1

Months	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H
January	-	-	-	-	24	45	54	54	56	49	34	8	-	-	-	-
February	-	-	-	4	31	55	71	73	84	74	52	23	1	-	-	-
March	-	-	8	37	67	88	101	100	119	103	79	55	29	2	-	-
April	-	14	44	73	96	120	135	150	154	138	112	85	57	28	0	-
May	11	36	62	85	117	142	147	159	153	145	117	84	62	40	17	0
June	18	39	60	77	103	124	126	129	133	120	104	82	60	42	22	1
July	12	38	61	85	110	139	134	145	146	131	111	86	65	47	25	1
August	0	22	46	73	97	114	132	142	142	130	113	85	59	33	10	-
September	-	3	31	59	81	98	108	114	109	97	76	58	30	4	-	-
October	-	-	10	40	54	73	88	85	99	86	68	42	10	-	-	-
November	-	-	-	12	31	41	49	50	48	38	24	3	-	-	-	-
December	-	-	-	-	17	32	41	44	43	34	19	-	-	-	-	-

From Table A 7 to Table A 10 it is possible to see how was the economic analysis done on the Microsoft excel.

Table A 7 displays the economic table for VC0 from year 0 till year 12.

Table A 7 - Economic table for VC0 pt1

Ano	0	1	2	3	4	5	6	7	8	9	10	11	12
Energy analysis													
Yield yearly energy (kWh)		27 229 165	27 011 332	26 795 241	26 580 879	26 368 232	26 157 286	25 948 028	25 740 444	25 534 520	25 330 244	25 127 602	24 926 581
Value of produced energy (€)		4 646 225	4 609 055	4 572 182	4 535 605	4 499 320	4 463 326	4 427 619	4 392 198	4 357 060	4 322 204	4 287 626	4 253 325
Economic analysis	33 052 511	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
Updated Economic analysis	33 052 511	1 942	1 885	1 830	1 777	1 725	1 675	1 626	1 579	1 533	1 488	1 445	1 403
CAPEX													
Solar panels	25 712 954												
Inverters	4 180 375												
Roof mouting system	685 588												
Solar parking system	246 782												
Facades mounting system	0												
Charging station	1 494 733												
Charging connectors	404 827												
Labor cost	327 253												
OPEX													
Replacement													
Maintenance		2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
Cashflow	-33 052 511	4 644 225	4 607 055	4 570 182	4 533 605	4 497 320	4 461 326	4 425 619	4 390 198	4 355 060	4 320 204	4 285 626	4 251 325
Updated Cashflow	-33 052 511	4 642 832	4 604 292	4 566 072	4 528 169	4 490 580	4 453 304	4 416 336	4 379 676	4 343 319	4 307 265	4 271 509	4 236 050
Accumulated Cashflow	-33 052 511	-28 409 680	-23 805 388	-19 239 316	-14 711 147	-10 220 567	-5 767 264	-1 350 928	3 028 748	7 372 067	11 679 332	15 950 841	20 186 892
Fraction row (for payback)	-	-	-	-	-	-	-	-	0,6915	1,6973	2,7115	3,7342	4,7655

Table A 8 illustrate the economic table for VC0 from year 13 till year 25.

Table A 8 - Economic table for VC0 pt2

Ano	13	14	15	16	17	18	19	20	21	22	23	24	25
Energy analysis													
Yield yearly energy (kWh)	24 727 169	24 529 351	24 333 116	24 138 451	23 945 344	23 753 781	23 563 751	23 375 241	23 188 239	23 002 733	22 818 711	22 636 161	22 455 072
Value of produced energy (€)	4 219 299	4 185 544	4 152 060	4 118 843	4 085 893	4 053 206	4 020 780	3 988 614	3 956 705	3 925 051	3 893 651	3 862 501	3 831 601
Economic analysis	4 182 375	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
Updated Economic analysis	2 847 994	1 322	1 284	1 246	1 210	1 175	1 141	1 107	1 075	1 044	1 013	984	955
CAPEX													
Solar panels													
Inverters													
Roof mouting system													
Solar parking system													
Facades mounting system													
Charging station													
Charging connectors													
Labor cost													
OPEX													
Replacement	4 180 375												
Maintenance	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000
Cashflow	36 924	4 183 544	4 150 060	4 116 843	4 083 893	4 051 206	4 018 780	3 986 614	3 954 705	3 923 051	3 891 651	3 860 501	3 829 601
Updated Cashflow	36 780	4 166 013	4 131 429	4 097 133	4 063 121	4 029 391	3 995 941	3 962 769	3 929 872	3 897 248	3 864 895	3 832 810	3 800 991
Accumulated Cashflow	20 223 671	24 389 684	28 521 114	32 618 247	36 681 368	40 710 759	44 706 700	48 669 469	52 599 342	56 496 590	60 361 484	64 194 294	67 995 285
Fraction row (for payback)	549,8559	5,8544	6,9034	7,9612	9,0279	10,1035	11,1880	12,2817	13,3845	14,4965	15,6179	16,7486	17,8888

Table A 9 displays the economic table for VC1 from year 0 till year 12.

Table A 9 - Economic table for VC1 pt1

Ano	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Energy analysis														
Yield yearly energy (kWh)		35 285 259	35 002 977	34 722 953	34 445 169	34 169 608	33 896 251	33 625 081	33 356 081	33 089 232	32 824 518	32 561 922	32 301 427	32 043 015
Value of produced energy (€)		6 020 869	5 972 702	5 924 921	5 877 521	5 830 501	5 783 857	5 737 586	5 691 685	5 646 152	5 600 983	5 556 175	5 511 726	5 467 632
Economic analysis	46 578 544	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	6 329 775
Updated Economic analysis	46 578 544	3 883	3 770	3 661	3 554	3 450	3 350	3 252	3 158	3 066	2 976	2 890	2 806	4 310 269
CAPEX														
Solar panels	35 693 575													
Inverters	6 325 775													
Roof mouting system	1 125 899													
Solar parking system	510 990													
Facades mounting system	0													
Charging station	1 936 625													
Charging connectors	524 507													
Labor cost	461 174													
OPEX														
Replacement														6 325 775
Maintenance		4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000
Cashflow	-46 578 544	6 016 869	5 968 702	5 920 921	5 873 521	5 826 501	5 779 857	5 733 586	5 687 685	5 642 152	5 596 983	5 552 175	5 507 726	-862 143
Updated Cashflow	-46 578 544	6 015 065	5 965 123	5 915 595	5 866 478	5 817 769	5 769 464	5 721 560	5 674 053	5 626 941	5 580 219	5 533 886	5 487 936	-858 788
Accumulated Cashflow	-46 578 544	-40 563 479	-34 598 357	-28 682 762	-22 816 283	-16 998 514	-11 229 050	-5 507 490	166 563	5 793 504	11 373 724	16 907 609	22 395 546	21 536 758
Fraction row (for payback)	-	-	-	-	-	-	-	-	0,0294	1,0296	2,0382	3,0553	4,0809	25,0781

Table A 10 displays the economic table for VC1 from year 13 till year 25.

Table A 10 - Economic table for VC1 pt2

Ano	13	14	15	16	17	18	19	20	21	22	23	24	25
Energy analysis													
Yield yearly energy (kWh)	32 043 015	31 786 671	31 532 378	31 280 119	31 029 878	30 781 639	30 535 386	30 291 102	30 048 774	29 808 383	29 569 916	29 333 357	29 098 690
Value of produced energy (€)	5 467 632	5 423 891	5 380 500	5 337 456	5 294 756	5 252 398	5 210 379	5 168 696	5 127 346	5 086 327	5 045 637	5 005 272	4 965 229
Economic analysis	6 329 775	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000
Updated Economic analysis	4 310 269	2 644	2 567	2 493	2 420	2 350	2 281	2 215	2 150	2 088	2 027	1 968	1 910
CAPEX													
Solar panels													
Inverters													
Roof mouting system													
Solar parking system													
Facades mounting system													
Charging station													
Charging connectors													
Labor cost													
OPEX													
Replacement	6 325 775												
Maintenance	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000
Cashflow	-862 143	5 419 891	5 376 500	5 333 456	5 290 756	5 248 398	5 206 379	5 164 696	5 123 346	5 082 327	5 041 637	5 001 272	4 961 229
Updated Cashflow	-858 788	5 397 178	5 352 363	5 307 920	5 263 846	5 220 137	5 176 791	5 133 805	5 091 175	5 048 899	5 006 974	4 965 397	4 924 165
Accumulated Cashflow	21 536 758	26 933 936	32 286 299	37 594 219	42 858 065	48 078 202	53 254 993	58 388 798	63 479 973	68 528 873	73 535 847	78 501 244	83 425 409
Fraction row (for payback)	25,0781	4,9904	6,0322	7,0827	8,1420	9,2101	10,2873	11,3734	12,4686	13,5730	14,6867	15,8097	16,9420