TAMPERE UNIVERSITY
OF APPLIED SCIENCES

TECHNO-ECONOMIC ANALYSIS OF SOLAR PV SYSTEM FOR TAMPERE UNIVERSITY OF APPLIED SCIENCES

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ABSTRACT

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Techno-economic analysis of solar PV system for Tampere University of Applied Sciences
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The purpose of this thesis work was to estimate total amount of solar energy that can be generated by installing solar PV system in Tampere University of Applied Sciences (TAMK). In addition to that, estimation of installation cost and profit or loss it makes was also carried out.

Rooftops of TAMK three buildings (A, B, C) and a parking place in front of Gym hall (L building) were categorized as the best place for setting up solar panels. Carport needs to be built so that it can support solar panels and acts as rooftops for vehicles. Using Google map distance tool, measurement of the area of rooftops and carport was carried out, which was 3833 m^2.

As a result we found that a total of 955 solar panels can be installed, which generates a peak power of 239KWp. In 25 years, this solar PV system can produce 4128.5 MWh of energy making a profit of 404175 € after paying its installation cost of 215100 €. However, this profit does not cover the cost of building a carport.

This project, if considered, should be beneficial for TAMK as it produces clean energy, which definitely helps to maintain a sustainable environment.

Key words: Solar power, Photovoltaic cells, TAMK, Energy

CONTENTS

ABBREVIATIONS AND SYMBOLS

ACRONYMS

TAMK	Tampere University of Applied Sciences
PV	Photovoltaic
IRENA	International Renewable Energy Agency
IEA	International Energy Agency
WEC	World Energy Council
NASA	National Aeronautics and Space Administration
STC	standard test condition
AC	Alternative current
DC	Direct current
Mono	monocrystalline
PVGIS	Photovoltaic Geographical Information System
ABB	ASEA Brown Boveri
MWh	Mega-watt hour
KWh	Kilo-watt hour
h_{panel}	height of solar panel
L_{black}	width of solar panel
$L_{dark\ blue}$	solar panel width at 15°
$L_{distance}$	sum of $L_{darkblue}$ and $L_{lightblue}$
A_{panel}	area covered by panel at different angle
N_s	total number of solar panels
T_a	total area that can be used for solar PV system
S_a	area of one solar panel plus shaded area at 15° angle
E_{mono}	energy produced by mono crystalline panels
N_{mono}	number of mono crystalline panels
P_{mono}	power of a mono crystalline panels
T_{peak}	peak sun hours per year
PR	performance ratio
S_{25year}	saving of 25 years by solar PV system
E_{mono}	total energy produced by solar PV system in 25 years
$C_{electricity}$	price of electricity per MWh

ROMAN SYMBOLS

A	area
h	height
E	energy
L	length
P	power
V	voltage
T	Temperature

GREEK SYMBOLS

α	solar panel area

1 INTRODUCTION

Renewable energy sources can be defined as “energy obtained from the continuous or repetitive currents on energy recurring in the natural environment” or as “energy flows which are replenished at the same rate as they are used”. (Chaar, Iamount, Zein, 2011). Different forms of renewable energy such as solar, wind, hydro, and geothermal are significantly contributing to fulfil the continuously increasing energy demand of the world. Recent data published by International Renewable Energy Agency (IRENA) shows that the deployment of renewable energy reached record level in both power generation and capacity addition with the overall share of renewable energy reaching 19% of the total final energy consumption (TFEC) (IRENA, 2018). But in order to cut down global average temperature to well below 2°C and to pursue efforts to limit the temperature increase to 1.5 °C (Paris agreement on climate change 2015), the share of renewable energy should be somewhere around two-thirds of primary energy supply by 2050 for which the growth rate of renewable must be seven-fold until 2050 (IRENA, 2018)

Solar photovoltaic is one of such renewable energy source, which is one of the fastest growing markets in the world. Big countries like China, India, U.S and EU are investing and installing solar PV in big numbers. Declining price of solar panels is also motivating countries to install more solar PV systems. Figure 1 exhibits the declining price of solar PV cells during the period of 1977 to 2015. 76 $ per watt in 1977 to 0.30 $ per watt in 2015 is a significant drop in price of solar PV cells.

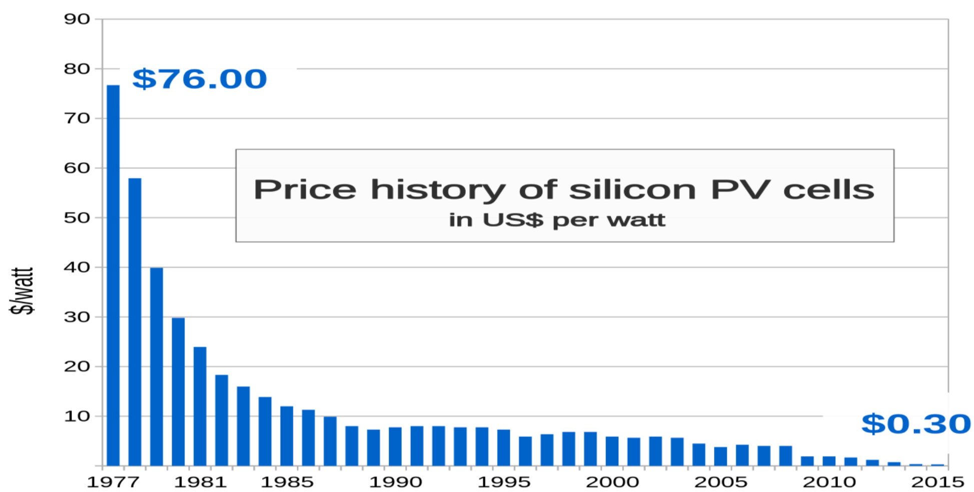


Figure 1. Solar panel prices from 1977- 2015 (Bloomberg new energy finance, 2015)

1.1 Solar Photovoltaic (PV)

Solar photovoltaic (PV) is a technology that generates electricity by using photovoltaic cells. These cells are typically made from silicon, copper, and cadmium. Out of these, most commonly used material is silicon, accounting almost 90% of the world's PV technologies.

A silicon PV cell consists of two types of semiconductor, called phosphorus –doped (N-type) and bored-doped (P-type) silicon, which are sandwiched to give p-n junction. The N-type layer has an excess of electron whereas P-type layer has excess holes. In the depletion zone of p-n junction, all the holes of P-type layer are filled with electrons of N-type layer resulting in the formation of electric field across the cell. When sunlight strikes the surface of the cell, it ejects electrons from silicon, resulting in the formation of holes. The electric field created in depletion zone moves electron to the N-type layer and holes to the P-type layer. This results in the flow of electrons (electric current) when a conductor is connected in between. Figure 2 illustrates the process of electricity production from a solar cell.

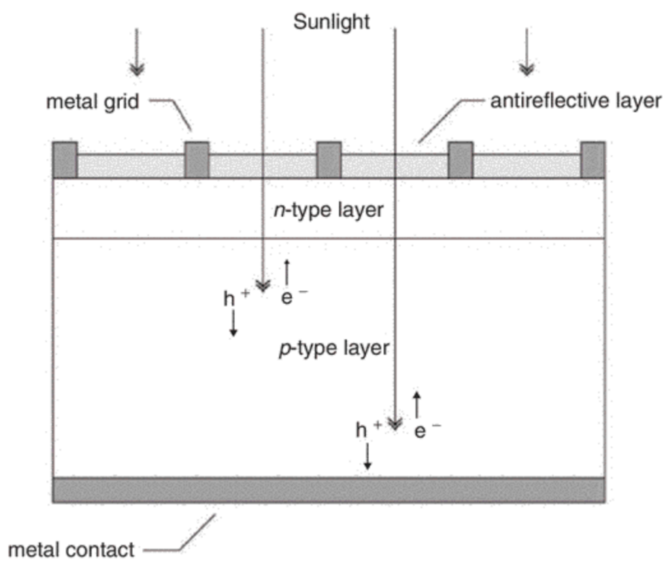


Figure 2. A schematic of a simple conventional solar cell (Luque, Antonio Hegedus, Steven, 2011)

1.2 Solar PV around the world

The amount of solar radiant energy incident on a surface per unit area and per unit time is called irradiance or insolation (WEC, 2013). The annual solar irradiance varies from place to place around the world. The average solar radiation is high in equator compared to poles. Low latitude near equator receives more radiation than high latitudes (NASA). From the figure 3 it can be learned that bluish areas receive very less solar irradiation while yellowish and orange areas receive more. We can easily say that Asia, Africa, Australia, and some parts of America and Europe have huge advantage in producing solar power, as the solar irradiation in these areas is high.

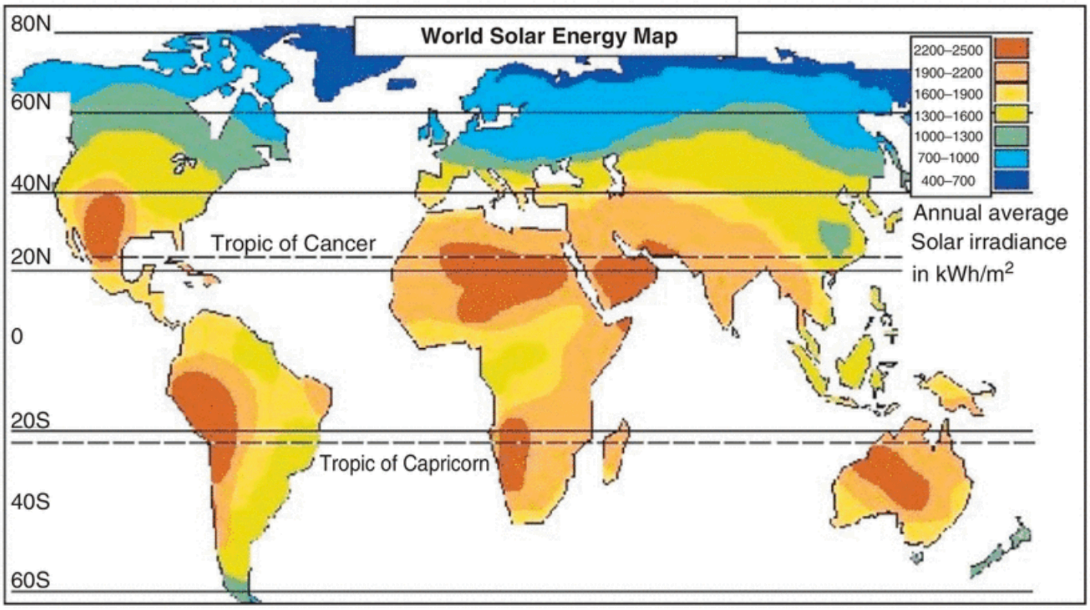


Figure 3. Annual average solar irradiance around the world (Lugue, Antonio Hegedus, Steven, 2011)

In recent years, the production of solar power around the world has increased rapidly. Accordingly to International Energy Agency, China alone installed 34.5 GW of solar power in 2016 out of their 78.1 GW in total. Installation of solar power in China, India, and Japan in 2016 was significantly high contributing in Asia's share of 48% of the global total installed capacity while Europe stood second with 34% (IEA). Figure 4 depicts the top 10 countries in the world based on cumulative installed solar capacity.

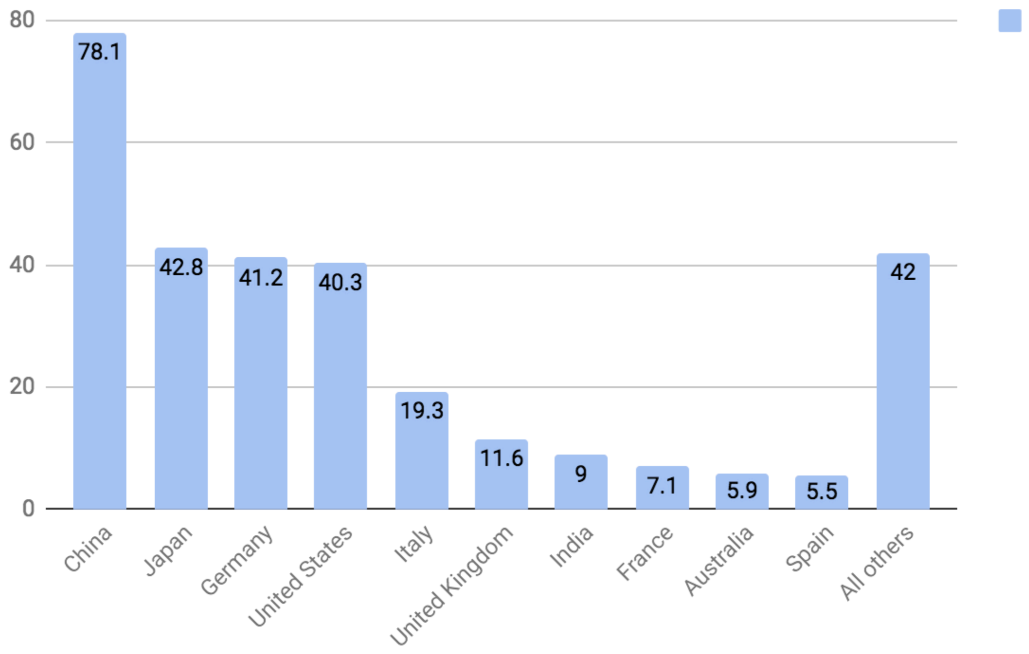


Figure 4. Top 10 countries in 2016 for cumulative installed capacity (IEA, 2017)

2 OBJECTIVES

The main objective of this thesis is to design a solar PV system for Tampere University of Applied Sciences (TAMK). It helps us to estimate the production capacity of solar power utilizing total possible spaces (roofs and carport) in TAMK area. It also includes the discussion about different components such as solar panels, inverters, charge controllers, etc. and their efficiency. In addition, the cost estimation as well as the profit or loss analysis for the installation of solar PV system is also carried out.

3 TAMK SITE SURVEY

For the installation of solar PV array, potential sites around TAMK were observed and two optimum sites were shortlisted. The first site was the existing rooftops while the second site selected was the carport that needs to be built in the future.

3.1 Rooftop

The rooftop of three buildings: building A, building B and, building C were chosen. These rooftops stand higher than other buildings and can hold many solar panels, as each of them occupy an area over 16000 ft^2. Total area of the rooftops was calculated from Google map using distance tool. Though these roofs are not flat, a small support system can be constructed to create the desired angle for the solar panels. Figure 5, 6, and 7 show buildings where solar panels can be installed.

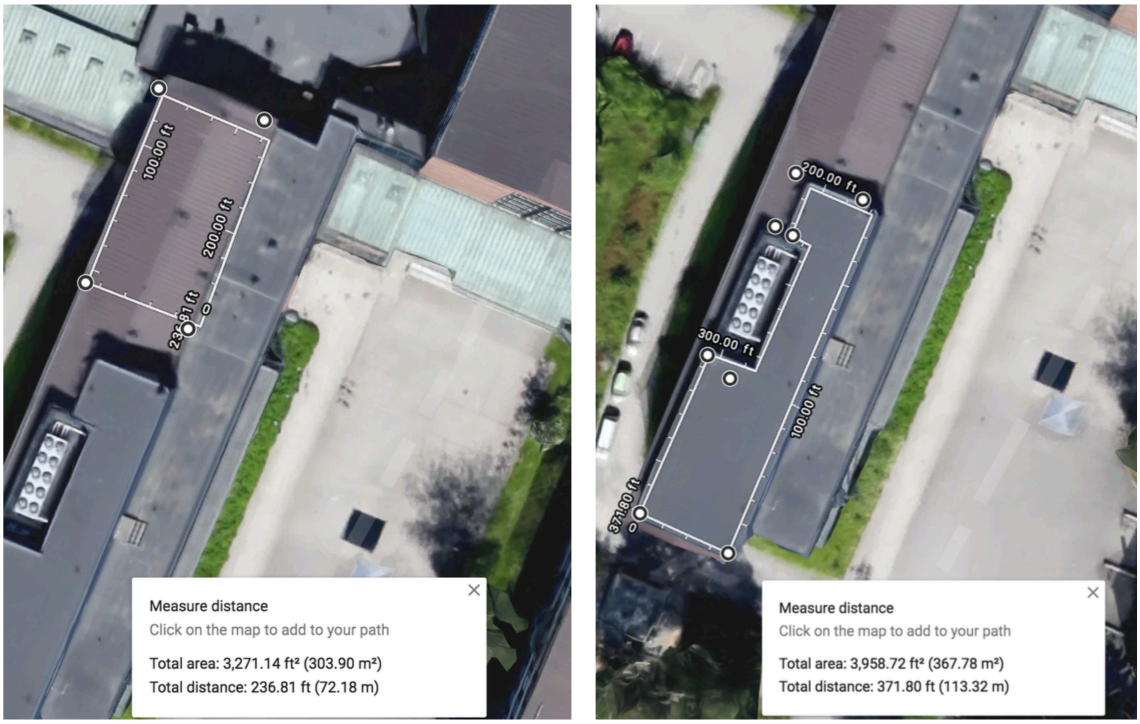


Figure 5. Building C rooftop and the highlighted area considered for installing solar panels

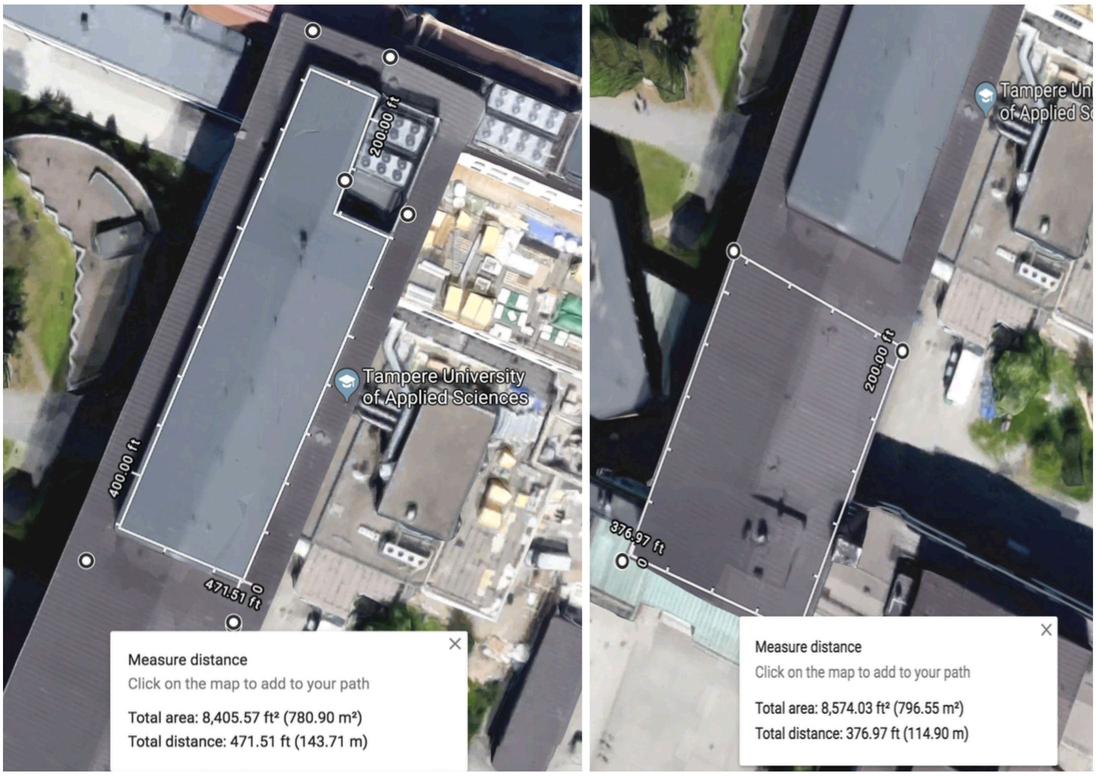


Figure 6. Building B rooftop and the highlighted area considered for installing solar panels

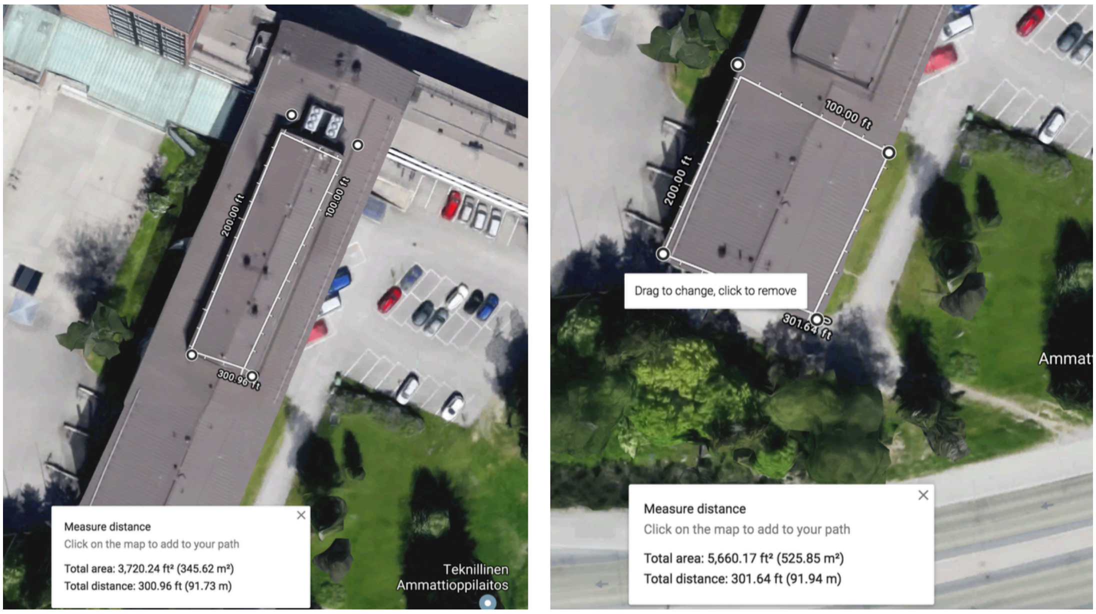


Figure 7. Building A rooftop and the highlighted area considered for installing solar panels

The area obtained using Google map is assumed to be approximately correct and can vary when measured physically. Different sunlight obstacle points and the spaces between solar panels on the rooftops should also be taken into account. To account for these obstacles, spaces and other potential measurement errors, only 80% of the rooftop area is taken into consideration for solar instalment purposes as elaborated in Table 1.

Table 1. Buildings area that can be utilized for a solar PV system.

Buildings	A (m^2)	B (m^2)	C (m^2)
Areas (Google map)	871	1577	671
Areas after 20% reduction	697	1262	537

3.2 Carport

The parking area, in front of TAMK gym hall as shown in Figure 8, can be a feasible place to install solar panels, as it is the largest open car-parking slot available at TAMK. However, the carport structure needs to be built before it can be considered for solar panel installation.

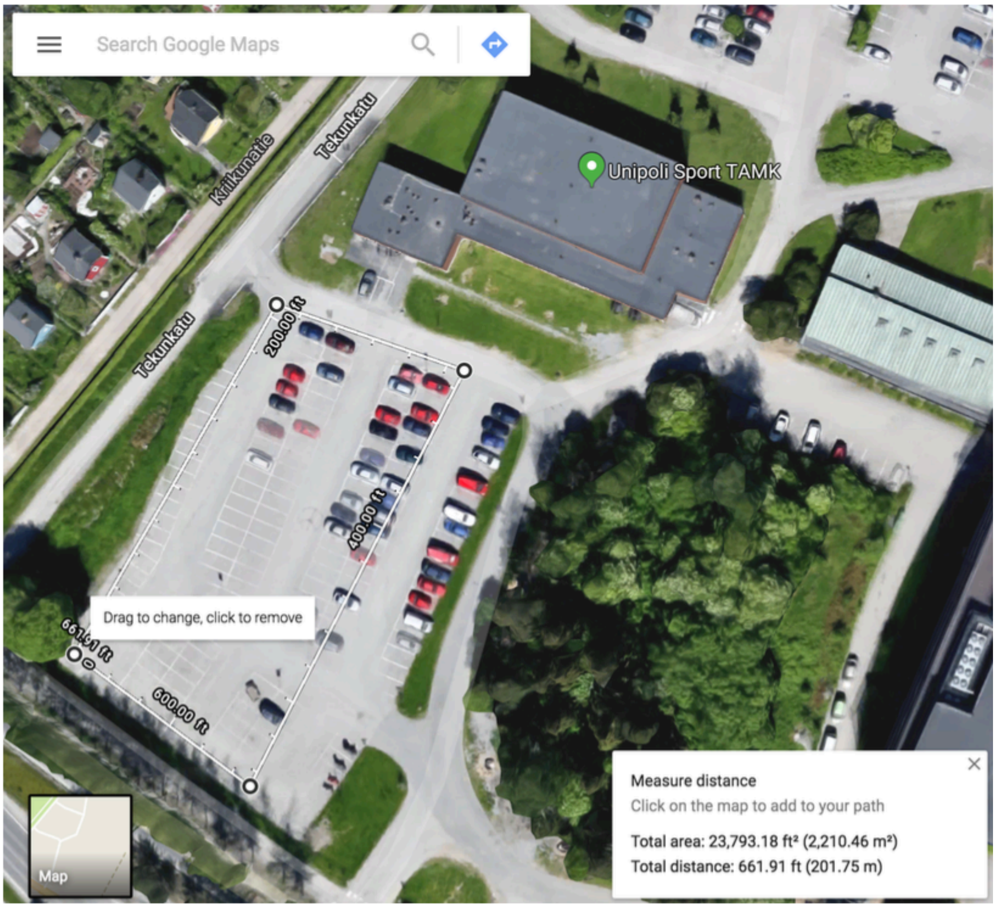


Figure 8. TAMK area where carport can be build.

Figure 9 shows an example of a carport holding numbers of solar panels and similar design can be replicated in TAMK.

Figure 9. Solar panels installed in carport. Photo by- Matthew Borkoski

Carport should be build in such a way that it faces the same direction as the solar panels are supposed to, and also the angle of inclination should be same as the angle of solar panels, which is calculated and presented in Chapter 3.3. In this way, the installation cost of solar PV array can be minimized, as an extra support system like in the rooftops is not required. While building carport, about 40% of the area cannot be used for solar panel installation in order to ease the vehicular movement as shown in Table 2.

Table 2. Carport areas available for installing solar PV system.

Carport	A (m^2)
Total (Google map)	2210
After 40% reduction	1326

3.3 Solar panel support angle

According to Photovoltaic Geographical Information System (PVGIS), the average optimal angle for Tampere region is 42°. Difference of optimal angle in summer and winter is very high ranging from 22° to 80°. So while choosing a support angle, we should consider the season we are targeting to get most out of the solar panels. In a country like Finland, which lies in the northern hemisphere, one should be careful enough to use the most number of sunny days, which mainly falls in summer months (May-August). There is a need to give attention to specific angle best for solar panels during that time. According to PVGIS (2018), the support angle varied from 0° to 40° during summer months and as an average, the optimal angle is 42° as in Figure 10.

Optimal inclination angle is: 42 degrees
Annual irradiation deficit due to shadowing (horizontal): 0.0 %

Month	H_{opt}	$H(15)$	I_{opt}	T_{24h}
Jan	563	357	78	-7.8
Feb	2020	1350	73	-6.1
Mar	3070	2450	59	-2.2
Apr	4650	4200	44	3.3
May	5520	5470	30	10.4
Jun	5410	5610	22	14.1
Jul	5420	5510	25	18.0
Aug	4160	4000	35	15.9
Sep	2870	2490	51	11.2
Oct	1490	1160	64	5.1
Nov	573	406	72	1.6
Dec	306	189	80	-3.2
Year	3010	2770	42	5.0

H_{opt}: Irradiation on optimally inclined plane (Wh/m^2/day)

$H(15)$: Irradiation on plane at angle: 15deg. (Wh/m^2/day)

I_{opt}: Optimal inclination (deg.)

T_{24h}: 24 hour average of temperature (°C)

Figure 10. Solar irradiance at different angles and optimal angle for Tampere. (PVGIS, 2018)

For this calculation, Suntech solar panel of dimensions 1640*992’50 mm is taken and more details of this solar panel are given in section 4.1

Height of panel (h_{panel}) = green line

Width of panel (L_{black}) = black line = 0.992 m

Panel width at 15° = dark blue line

Length of shadow = light blue line

Shadow affected area = grey line

Length of panel = 1.64 m

The calculation of area required for a 15° support angle is shown below whereas Table 3 shows the detailed values of support angle and area required for solar panels.

$h_{panel} = L_{black} * \sin\alpha$

α = support angle

h_{panel} = 0-992 m* sin15° = 0.257 m

$L_{dark\ blue} = L_{black} * cas\alpha$

$L_{dark\ blue}$ = 0.992 m * cos15° = 0.958 m

To find length of shadow coming out of solar panel, small angle is assumed to be ≤ 10.

$L_{light\ blue} = h_{panel}/\tan 10° = 0.257\ m/\ \tan 10° = 1.456\ m$

In Table 3, $L_{distance}$ is the sum of $L_{dark\ blue}$ and $L_{light\ blue}$. If we multiply it by the length of panel (1.64 m), we can get the area required for one solar panel to be installed.

Table 3. Relation between support angle of sun from horizon and area required for solar panels.

Support Angle (°)	0	10	15	25	30	40
h_{panel} (m)	0.00	0.172	0.257	0.419	0.496	0.638
$L_{dark\ blue}$ (m)	0.992	0.977	0.958	0.899	0.859	0.760
$L_{light\ blue}$ (m)	0.00	0.977	1.456	2.378	2.813	3.616
$L_{distance}$ (m)	0.992	1.954	2.414	3.277	3.672	4.376
A_{panel} (m^2)	1.627	3.204	3.959	5.374	6.022	7.177

Based on Table 3, it can be observed that more the support angle more area is required, which restricts from installing more solar panels. It concludes that 15° support angle is a good option, as it allows better exposure to the Sun for more hours and more number of solar panels can be installed in the given area. Figure 11 shows that solar irradiation at optimal inclined plane and at 15° does not differ much but there will be significant decrease in the number of solar panels if support angle is greater than 15°.

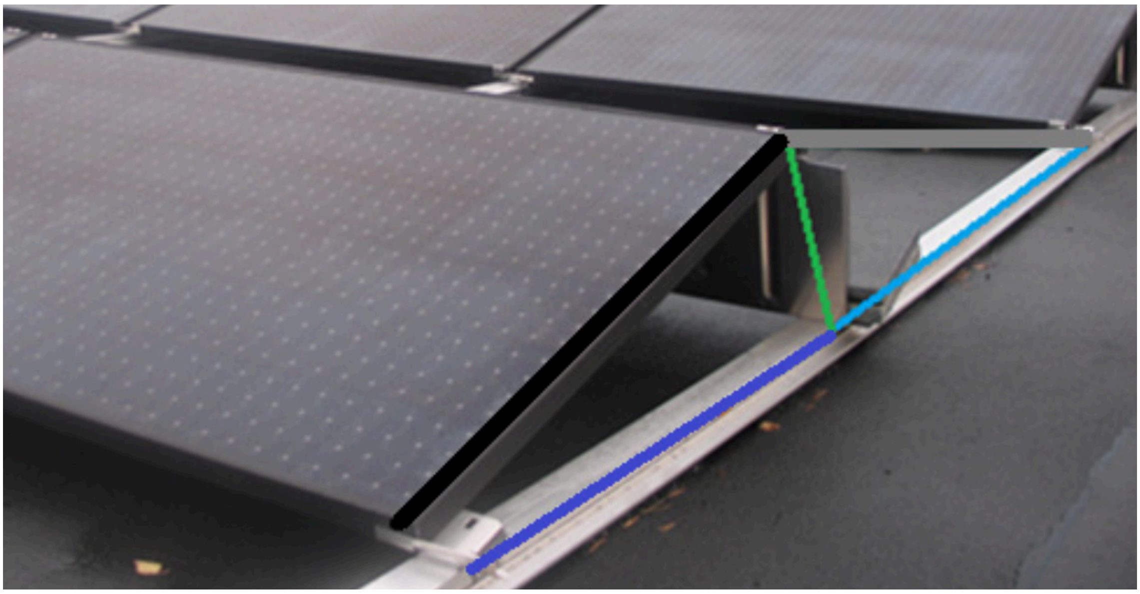


Figure 11. Set up of solar panels at 15° angle showing the distance needed to avoid shadows, LUT 2015

3.4 Weight on the roof

One of the critical factors that should be taken into account before installing solar PV system is the weight on the roof. In other words, the threshold value of the weight the roof can bear per square meter must be known beforehand to avoid any damages. Weight on the roof while installing solar PV system includes the weight of solar panels, ballast, cables and their protection equipment. Other than this, snow and wind should be taken into consideration. Adding all of these weights, the cumulative weight should not exceed the maximum permitted weight of the roof.

4 SOLAR COMPONENTS

For the installation of solar PV module, it requires different electrical components such as solar panels, inverters, cables, and sensors. In this section, the number of solar panels and inverters needed for this solar PV project is estimated. Additionally, the best manufacturers to buy these components are also recommended.

4.1 Solar Panels

The total number of solar panels that can be installed using the buildings rooftop and carport can be determined by dividing total possible area by the area required for one solar panel.

$$N_s = T_a / S_a$$

Where,

N_s Total number of solar panels

T_a Total area that can be used for solar PV system

S_a Area of one solar panel plus shaded area at 15° angle (4 m^2)

$$N_s = (697+1262+537+1326)\ m^2/4\ m^2$$
$$= 3822\ m^2/4\ m^2$$
$$= 955 \text{ solar panels}$$

So, 955 solar panels can be installed in three buildings rooftops and carport.

Since the number of solar panel that can be fitted on the rooftops of TAMK buildings is known, the next work is to figure out what solar panels to be used. Based on desktop research of solar panel production companies, Suntech monocrystalline solar module is a suitable option for this installation. These solar panels are manufactured in China. With dimensions of 1640*992*50 mm and weighing 19.1 kg, it produces 250 W of peak power. This module is certified to withstand extreme wind (3800 Pascal) and snow loads (5400 Pascal). Figure 12 shows the power output of Suntech solar panels at standard test conditions (STC) also considering different solar irradiation intensity.

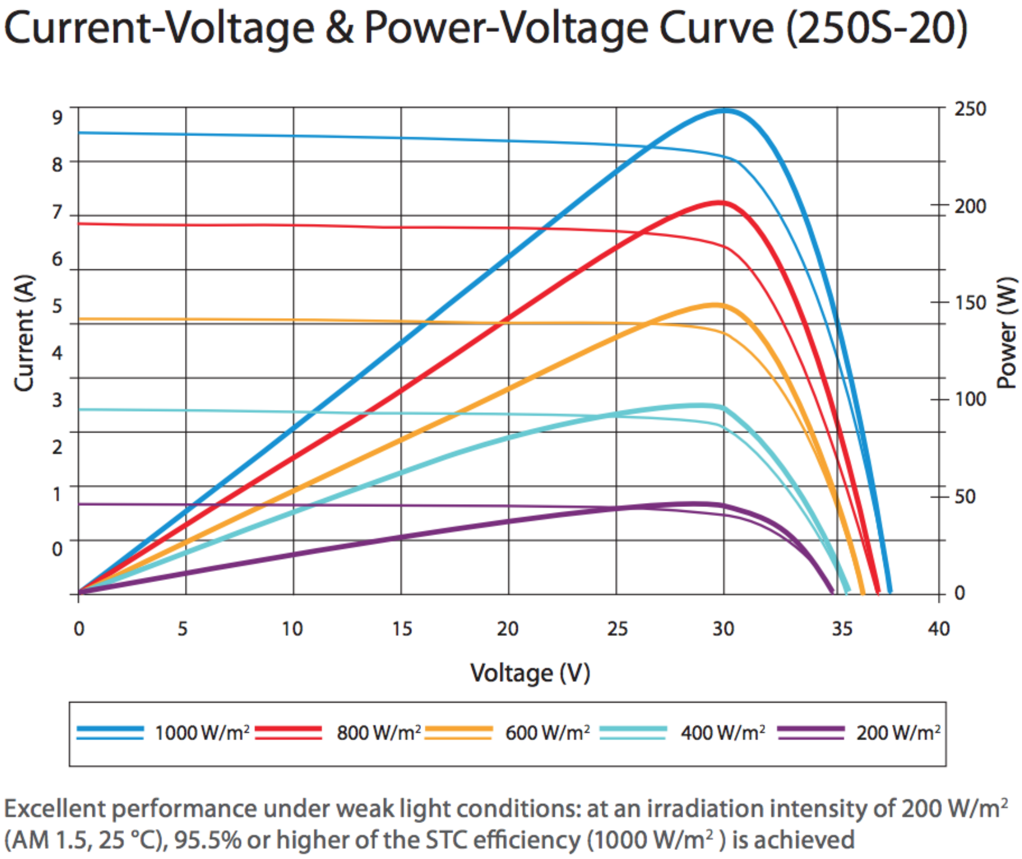


Figure 12. Current-voltage and power-voltage curve at different solar irradiation intensity level.

4.2 Inverters

Solar PV module generates Direct Current (DC). So, it needs to be converted into Alternating Current (AC) before use. Since ABB group are one of the leading solar inverter producers, recently awarded for "leading PV product innovation" at the 2018 Intersolar Awards, ABB solar inverters are recommended for this installation. The number of ABB solar inverters needed for 955 solar panels can be obtained by simple calculation, which is given below:

ABB string inverters PVI-10.0/12.5-TL-OUTD 10 to 12.5 kW = 900 V

SUNTECH solar module's open circuit voltage = 37.4 V

20 module in series = 37.4* 20 = 748 V.

This is within the inverter's MPPT voltage range.

Module's maximum power voltage = 30.7 V.

Inverter MPPT voltage range: 900V. 900/20 = 45 (module maximum power voltage = 30.7)

So, maximum power voltage is in the inverter's voltage range.

ABB string inverters PVI-10.0/12.5-TL-OUTD 10 to 12.5 kW:

Inverter's rated voltage = 580 V

Maximum current = 34 A

Maximum short circuit current = 8.63 A If we put 3 parallel string (1 string consist of 20 series module) = 3*8.63 = 25.89 A

As we need to arrange 955 modules, we need 955/60 = 16 ABB inverters.

5 RESULTS

Based on the calculation in Chapter 4, the total number of solar panels and inverters are ascertained. For calculating total energy production, the total peak power hours of Tampere region is required. Peak power hour is the total number of sun hours where the intensity of sunlight is 1000 W/m^2. Using PVGIS, total number of peak power hours can be obtained. Performance ratio (PR) is also an important factor to be considered before calculation. It accounts for inverter, temperature and cables losses and the value ranging from 0.5 to 0.9. Here, maximum value (0.9) is taken, as the PV system is assumed to be of high quality. Thus the energy production of 955 solar panels altogether can be obtained by a calculation method given below:

E_{mono} $N_{mono}*P_{mono}*T_{peak}*PR$

Where,

E_{mono} Energy produced by mono crystalline panels

N_{mono} number of mono crystalline panels

P_{mono} power of a mono crystalline panels

T_{peak} peak sun hours per year

PR performance ratio

Total energy that can be produced by rooftops solar panels during a year

Eroof mono 624*250 W*860 h/a*0.9

121 MWh/a

Total energy that can be produced by carport solar panels during a year

Ecarport mono 331*250 W*860 h/a*0.9

64 MWh/a

Altogether 185 MWh of energy is produced by solar PV system in a year if the power output of solar panel is 100%. However, no solar panel can deliver 100 % power output as its performance keeps degrading every year. Suntech solar panels give power output of 97% in the first year, thereafter, for years two (2) through twenty-five (25), 0.7% maximum decrease per year, ending with the 80.2% in the 25th year. Figure 13 shows the total amount of energy production for 25 years. In 25 years, solar PV system will produce 4128.5 MWh of energy.

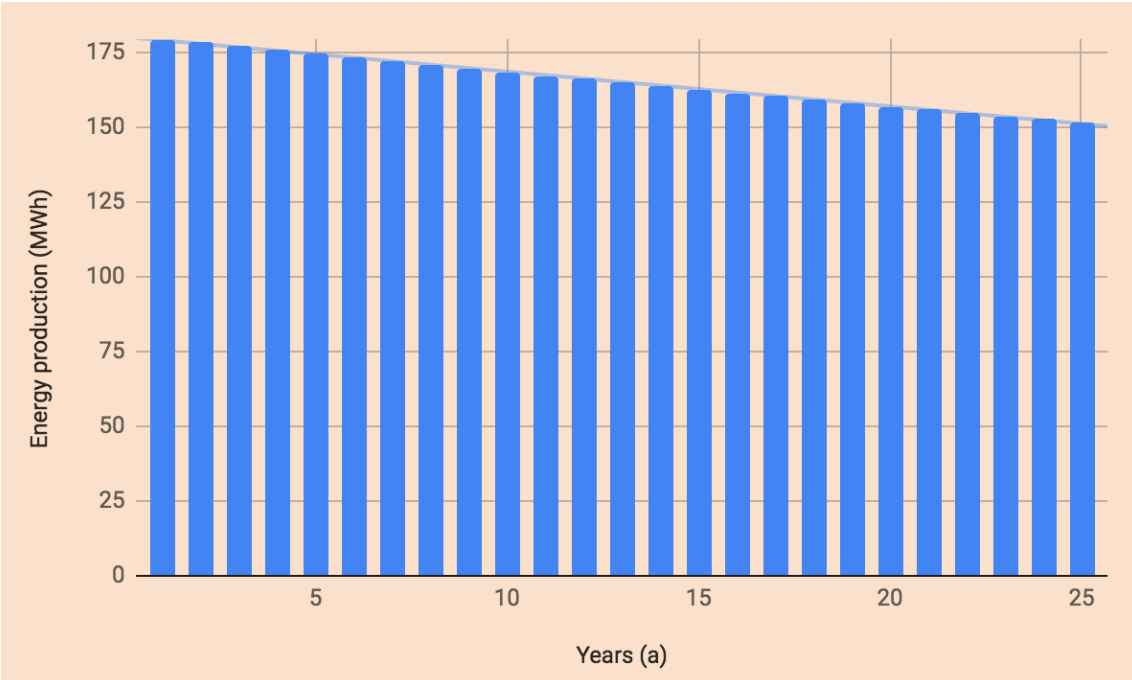


Figure 13. Energy production during 25 years

5.1 Load Survey of G building

Energy consumption of TAMK's G building was acquired from TAMK's authority and is shown in Figure 14. G building is one of the smallest blocks of TAMK and it consists of teaching classes, restaurant, auditorium and labs. The time period of this data is only from March to September 2017 due to the unavailability of full year's data. This data was taken in account to conduct a power production and consumption analysis. It was done by comparing the energy produced by the proposed solar PV system against the energy consumption of G building.

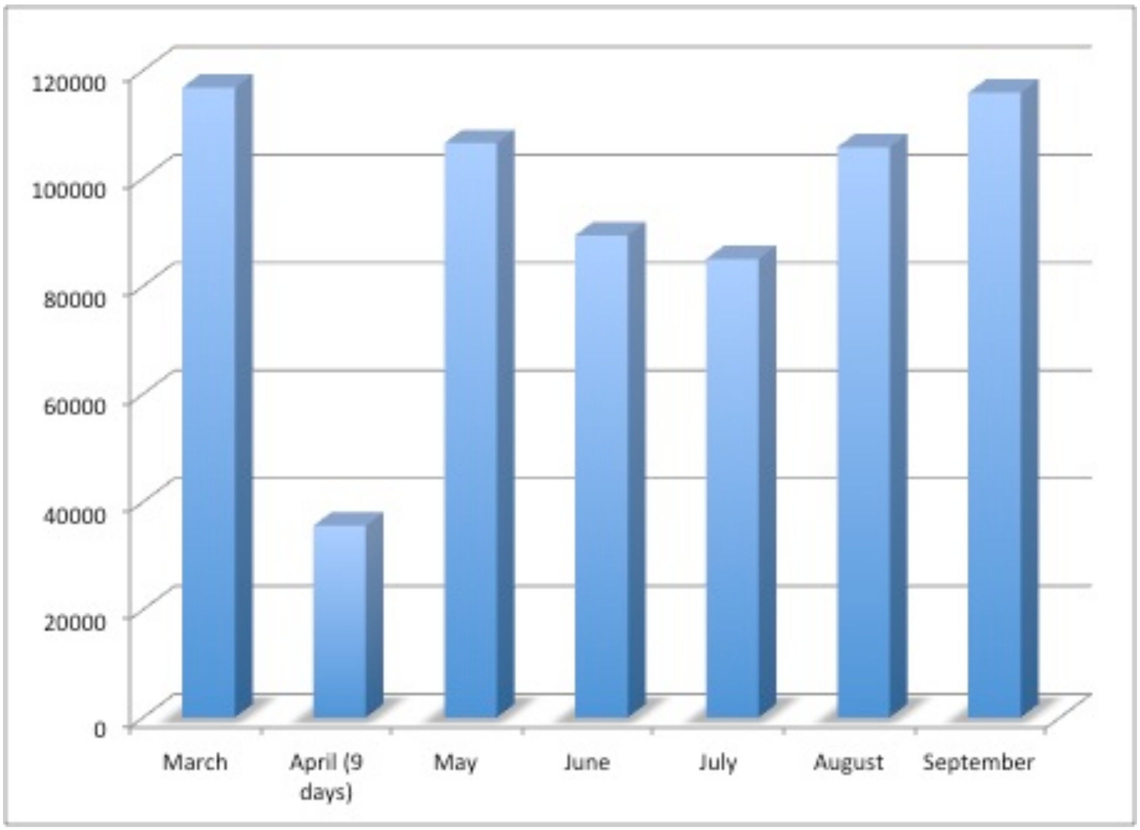


Figure 14. Energy consumption of TAMK's G building

From the above bar diagram, it can be noted that June and July are the only months where the electricity consumption is below 100000 kWh (as April has only data of 9 days). This may be because of the closing of school during summer months. Other than these two months, it has easily crossed 100000 kWh of energy consumption. If this consumption is compared to the energy produced by solar PV system in a year, which is 185000 kWh, the difference is very high as consumption exceeds the production. TAMK solar PV system can generate energy that can only support G building load for one and half months approximately.

5.2 Cost Calculation

The cost of the proposed solar PV project is calculated using Solarpower.net numbers. Solarpower.net had published their installation costs per kW in their web page as of 2016. The cost includes panels, inverter, regulator, brackets and wires and was set to be 1000 € per kWp. As the price of solar panels is on a declining trend and the size of the project (239 kWp) is big, the price will be less than 1000 € per kWp. Given the possibility to receive volume discount, it is fair to consider the cost to be around 900 € per kWp.

Total KWp	Total solar panels* power of one solar panel
	955*250KWp
	239KWp
Total cost	239* 900€
	215100€

5.3 Profit or Loss

Since the total energy produced by solar PV system and its total cost (except the cost of constructing the carport) is known, the simplified total profit or loss calculation can be made. To begin with, the electricity expense per MWh of TAMK is required. For the electricity price, it is assumed that TAMK pays 150€ per MWh including both energy and transfer fee.

$S_{year} = E_{mono} * P_{electricity}$

Where,

S_{25year}	Saving of 25 years by solar PV system
E_{mono}	Total energy produced by solar PV system in 25 years
$C_{electricity}$	Price of electricity per MWh

S_{25year}	4128.5 MWh* 150€/MWh
	619275€

The energy production only for 25 years is considered as the manufacturer provides warranty of solar panels total rated power, which is 80% by the end of 25th year, for that time period only. Though manufacturer does not give warranty after that, solar PV system can still produce energy with decline in power output. However, the calculation does not account production beyond 25 years. In this simple calculation it is assumed that all the produced PV energy is all the time consumed by TAMK. Thus, there will not be any feeding of excess electricity to power grid.

Total profit S_{25year}- Total cost

619275 €-215100 €

404175 €

6 CONCLUSIONS

Finland, being a country in northern hemisphere, gets low amount of solar radiation compared to other southern countries but it does not stop it from opening new solar power plants. Finland's largest solar power plant installed in 2016 with power output of 850KWp in Helsinki district of Kivikko is a fact that solar power energy market is growing. In addition, different departmental stores such as Prisma, K-citymarket's rooftop can be seen covered by solar panels nowadays.

The goal of this thesis work was to estimate the energy production by solar PV module that can be installed in TAMK area and also calculating it's cost along with profit or loss analysis. From the results, it can be concluded that it is a profitable project if gets started, as it can make profit of 404175 € in 25 years. During the usage years, some components need to be changed such as inverters and cables but not solar panels as they have 25 years of warranty. This analysis does not include the cost of carport, which is expected to be high. Besides solar panels installation, it is used as for the primary purpose of safeguarding the vehicles from harsh weather. Especially in winter times when it is snowing, vehicles will be protected. Since the lifetime of carport is more than 50 years, it can be easily used for installation of solar PV system whose lifetime is expected to be 25 years.

Before installing a solar PV system, support angle should be chosen wisely. Solar panels are recommended to be installed slightly tilted on flat roofs by experts so that it self cleans when it rains. While choosing a support angle in TAMK's case, 15 ° angle was selected as a best option. This support angle covers an area of 4 m^2 per solar panel compared to 5.44 m^2 at 25°, 64 m^2 at 30° and 7.24 m^2 at 40°, which helps to install more numbers of solar panels. The difference in solar irradiation value at 15° and optimal angle of 40° was not high when compared with the difference in number of solar panels it would make.

Installing solar PV system should not be compared to profit or loss only but also with the positive environmental impact it makes. Solar energy is a green energy, which does not generate any harmful greenhouse gases. So having a Solar PV system of 239 kWp in TAMK can setup a good image among people and also recognized as one of the universities, which generates large number of renewable energy. Though the energy it generates is nowhere near to the energy consumption of TAMK, it can contribute a little amount of green energy, which will definitely reduce some greenhouse gas coming from nuclear power plant or fossil fuel in order to provide energy for TAMK.

In addition to the green energy production, if this solar PV system is installed in TAMK then there is also an opportunity for students to do some research. Topics such as tracking its performance under clear sky and cloudy sky, during winter and summer time, performance under shading, and so on can be studied as well. Therefore considering this project and working further for it should be the next step for TAMK.

REFERENCES

Luque, Antonio Hegedus, Steven. (2011). *Handbook of Photovoltaic Science and Engineering (2nd Edition) - 3.1 Introduction.* John Wiley & Sons. Retrieved from https://app.knovel.com/hotlink/pdf/id:kt008UI2PN/handbook-photovoltaic/physics-so-introduction

"2016 Snapshot of Global Photovoltaic Markets" (PDF). Report. International Energy Agency, 2017

El Chaar L., Iamont L.A.,El Zein N. . 2011. Review of photovoltaic technologies. United Arab Emirates, Abu Dhabi. USA, Chicago. Reference 20.4.2015. http://www.sciencedirect.com.ezproxy.turkuamk.fi/science/article/pii/S1364032111000050

"How a solar cell works". Article. American Chemical Society https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/past-issues/archive-2013-2014/how-a-solar-cell-works.html

ABB. Product manual, 2011. EN_PVS300_Product_Manual_B_screen.pdf

Miguel Lavado. 2015. Large scale solar power plant flat roof and carport installation in Finland. Lappeenranta, Finland. Lappeenranta University of Technology

Google maps. Retrieved on September 14, 2018. From https://www.google.com/maps/place/TAMK/@61.5033883,23.8022186,687m/data=!3m1!1e3!4m5!3m4!1s0x468f20a676cd6785:0xc1cd20e808c10fee!8m2!3d61.50274!4d23.8053

Fin solar. Average turnkey installation prices of photovoltaic systems, 2016. http://www.finsolar.net/aurinkoenergian-hankintaohjeita/aurinkosahkon-hinnat-ja-kannattavuus/

European Commission. PVGIS. Retrieved on October 4, 2018. From http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php#

Galkin-Aalto Marina. 2016. Finland's largest solar power plant starts operations. Retrieved on October 5, 2018. https://www.helen.fi/en/news/2016/finlands-largest-solar-power-plant-starts-operations/

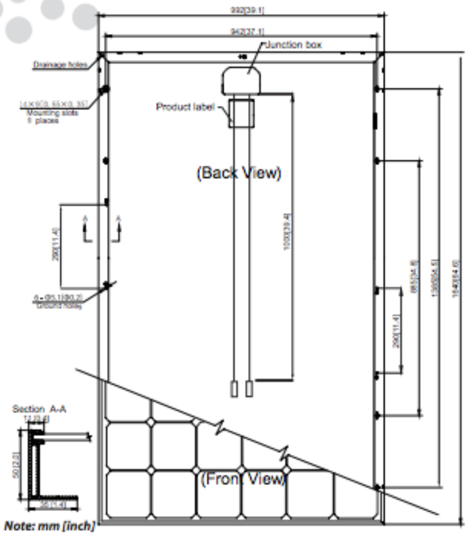
European Commission. International action on climate change. 2015. Retrieved on September 28, 2018.https://ec.europa.eu/clima/policies/international/negotiations/paris_en

APPENDICES

Appendix 1. Suntech solar panels characteristics

STP250S - 20/Wd
STP245S - 20/Wd
STP240S - 20/Wd

SUNTECH



Electrical Characteristics

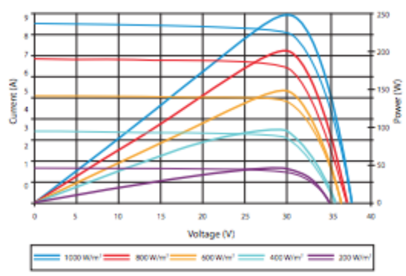
STC	STP250S-20/ Wd	STP245S-20/ Wd	STP240S-20/ Wd
Optimum Operating Voltage (Vmp)	30.7 V	30.5 V	30.2 V
Optimum Operating Current (Imp)	8.15 A	8.04 A	7.95 A
Open Circuit Voltage (Voc)	37.4 V	37.3 V	37.2 V
Short Circuit Current (Isc)	8.63 A	8.52 A	8.43 A
Maximum Power at STC (Pmax)	250 W	245 W	240 W
Module Efficiency	15.4%	15.1%	14.8%
Operating Module Temperature	-40 °C to +85 °C		
Maximum System Voltage	1000 V DC (IEC)		
Maximum Series Fuse Rating	20 A		
Power Tolerance	0/+5 %		

STC: Irradiance 1000 W/m², module temperature 25 °C, AM=1.5;
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

NOCT	STP250S-20/ Wd	STP245S-20/ Wd	STP240S-20/ Wd
Maximum Power at NOCT (Pmax)	183 W	180 W	177 W
Optimum Operating Voltage (Vmp)	27.9 V	27.8 V	27.7 V
Optimum Operating Current (Imp)	6.55 A	6.46 A	6.39 A
Open Circuit Voltage (Voc)	34.4 V	34.3 V	34.2 V
Short Circuit Current (Isc)	6.96 A	6.89 A	6.81 A

NOCT: Irradiance 800 W/m², ambient temperature 20 °C, AM=1.5, wind speed 1 m/s;
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

Current-Voltage & Power-Voltage Curve (250S-20)



Excellent performance under weak light conditions: at an irradiation intensity of 200 W/m² (AM 1.5, 25 °C), 95.5% or higher of the STC efficiency (1000 W/m²) is achieved

Temperature Characteristics

Nominal Operating Cell Temperature (**NOCT**)	45±2°C
Temperature Coefficient of Pmax	-0.45 %/°C
Temperature Coefficient of Voc	-0.34 %/°C
Temperature Coefficient of Isc	0.050 %/°C

Mechanical Characteristics

Solar Cell	Monocrystalline silicon 156 × 156 mm (6 inches)
No. of Cells	60 (6 × 10)
Dimensions	1640 × 992 × 50mm (64.6 × 39.1 × 2.0 inches)
Weight	19.1 kgs (42.1 lbs.)
Front Glass	3.2 mm (0.13 inches) tempered glass
Frame	Anodized aluminium alloy
Junction Box	IP67 rated (3 bypass diodes)
Output Cables	TUV (2Pfg1169:2007), UL 4703, UL44
	4.0 mm² (0.006 inches²), symmetrical lengths (-) 1000mm (39.4 inches) and (+) 1000 mm (39.4 inches)
Connectors	MC4 connectors

Dealer information

Packing Configuration

Container	20' GP	40' HC
Pieces per pallet	21	21
Pallets per container	6	28
Pieces per container	126	588

Appendix 2. Suntech solar panels characteristics

STP250S - 20/Wd
STP245S - 20/Wd
STP240S - 20/Wd

SUNTECH

250 Watt
MONOCRYSTALLINE SOLAR MODULE

Features

High module conversion efficiency
Module efficiency up to 15.4% achieved through advanced cell technology and manufacturing capabilities

Self-cleaning & anti-reflective
Higher module efficiency from anti-reflective, hydrophobic layer with higher light absorption and minimal surface dust

Positive tolerance
Guaranteed positive tolerance of 5% delivers higher outputs reliably

Excellent weak light performance
Excellent performance under low light conditions

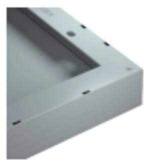
Extended wind and snow load tests
Module certified to withstand extreme wind (3800 Pascal) and snow loads (5400 Pascal) *

Suntech current sorting process
System output maximized by reducing mismatch losses up to 2% with modules sorted & packaged by amperage

Certifications and standards: UL1703, IEC 61215, IEC 61730, conformity to CE

Trust Suntech to Deliver Reliable Performance Over Time

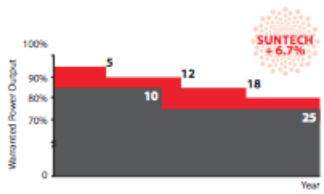
- World's No.1 manufacturer of crystalline silicon photovoltaic modules
- Unrivaled manufacturing capacity and world-class technology
- Rigorous quality control meeting the highest international standards: ISO 9001: 2008, ISO 14001: 2004 and ISO17025: 2005
- Tested for harsh environments (salt mist and ammonia corrosion testing: IEC 61701, DIN 50916:1985 T2)***



New, improved Frame Design

Suntech's new rigid and reliable hollow chamber frame provides additional grounding options for increased design flexibility and easier installation. Anti-counterfeit mark assures product authenticity.

Industry-leading Warranty based on Pnom



- Based on nominal power (Pnom)
- 25-year transferrable power output warranty: 5 years/95%, 12 years/90%, 18 years/85%, 25 years/80% ****
- Warrants 6.7% more than the market standard over 25 years
- 10-year material and workmanship warranty

Most modern IP67 Rated Junction Box

Supports installations in multiple orientation. High performance, low resistance connectors ensure maximum ouptput for highest energy production.

Appendix 3. ABB 900V inverter characteristics

Input side		
Absolute maximum DC input voltage ($V_{max,abs}$)	900 V	
Start-up DC input voltage (V_{start})	360 V (adj. 250...500 V)	
Operating DC input voltage range ($V_{dcmin}...V_{dcmax}$)	0.7 x V_{start}...850 V (min 200 V)	
Rated DC input voltage (V_{dcr})	580 V	
Rated DC input power (P_{dcr})	10300 W	12800 W
Number of independent MPPT	2	
Maximum DC input power for each MPPT ($P_{MPPTmax}$)	6500 W	8000 W
DC input voltage range with parallel configuration of MPPT at P_{acr}	300...750 V	360...750 V
DC power limitation with parallel configuration of MPPT	Linear derating from max to null [750 V≤V_{MPPT}≤850 V]	
DC power limitation for each MPPT with independent configuration of MPPT at P_{acr}, max unbalance example	6500 W [380 V≤V_{MPPT}≤750 V] the other channel: P_{dcr}-6500 W [225 V≤V_{MPPT}≤750 V]	8000 W [445 V≤V_{MPPT}≤750 V] the other channel: P_{dcr}-8000 W [270 V≤V_{MPPT}≤750 V]
Maximum DC input current (I_{dcmax}) / for each MPPT ($I_{MPPTmax}$)	34.0 A / 17.0 A	36.0 A / 18.0 A
Maximum input short circuit current for each MPPT	22.0 A	
Number of DC input pairs for each MPPT	2	
DC connection type	PV quick fit connector [3]	
Input protection		
Reverse polarity protection	Inverter protection only, from limited current source	
Input over voltage protection for each MPPT - varistor	Yes	
Photovoltaic array isolation control	According to local standard	
DC switch rating for each MPPT (version with DC switch)	25 A / 1000 V	
Fuse rating (versions with fuses)	15 A / 1000 V	
Output side		
AC grid connection type	Three-phase 3W+PE or 4W+PE	
Rated AC power (P_{acr}@cosϕ=1)	10000 W	12500 W
Maximum AC output power (P_{acmax} @cosϕ=1)	11000 W [4]	13800 W [5]
Maximum apparent power (S_{max})	11500 VA	13800 VA
Rated AC grid voltage ($V_{ac,r}$)	400 V	
AC voltage range	320...480 V [1]	
Maximum AC output current ($I_{ac,max}$)	16.6 A	20.0 A
Contributory fault current	19.0 A	22.0 A
Rated output frequency (f_r)	50 Hz / 60 Hz	
Output frequency range ($f_{min}...f_{max}$)	47...53 Hz / 57...63 Hz [2]	
Nominal power factor and adjustable range	> 0.995, adj. ± 0.9 with P_{acr}=10.0 kW, ± 0.8 with max 11.5 kVA	> 0.995, adj. ± 0.9 with P_{acr}=12.5 kW, ± 0.8 with max 13.8 kVA
Total current harmonic distortion	< 2%	
AC connection type	Screw terminal block, cable gland M40	
Output protection		
Anti-islanding protection	According to local standard	
Maximum external AC overcurrent protection	25.0 A	
Output overvoltage protection - varistor	3 plus gas arrester	
Operating performance		
Maximum efficiency (η_{max})	97.8%	
Weighted efficiency (EURO/CEC)	97.1% / -	97.2% / -
Feed in power threshold	30.0 W	
Night consumption	< 1.0 W	