NUST H-12 CAMPUS SOLARIZATION; A TECHNO-ECONOMIC ANALYSIS

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APPROVAL SHEET

It is certified that contents and form of thesis entitled “NUST H-12 Campus Solarization; a Techno-economic Analysis” submitted by Hamna Shahid, Zain Sajid and Haseeb Khan have been found satisfactory for the requirement of the degree.

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Dedication

We dedicate this thesis to our family and friends for their unconditional love, support and guidance that helps us move mountains and cross oceans with ease.

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C	Degree Celsius
%	Percentage
AC	Alternating Current
AEDB	Alternative Energy Development Board
ARDL	Autoregressive distributed lag
CAPEX	Capital Expenditure
CIS	Copper, Indium, Selenide cell
CO^2	Carbon Dioxide
DC	Direct current
DISCO	Distribution company
IESCO	Islamabad Electric Supply Company
GHI	Global Horizontal Irradiance
GHG	Greenhouse Gas
GW	Gigawatt
MW	Megawatt
MWh	Megawatt hour
HV	High Voltage
kV	Kilovolt
kW	Kilowatt
LCOE -	Levelized Cost of Electricity
LID	Light-Induced Degradation
MDG	Millennium Development Goals
Mtoe	Million tonnes of oil equivalent
NEPRA	National Electric Power Regulatory Authority
O&M	Operation and Maintenance
OPEX	Operational Expenditure
PKR	Pakistani Rupees
PMO	Project Management Office
PPA	Power Purchase Agreement
PV	Photovoltaic

RE	Renewable Energy
SAM	System Advisor Model
SDG	Sustainable Development Goals
Tg	Tera grams
TMY	Typical Meteorological Year
USD	US Dollar
USPCAS-E	U.S. Pakistan Center for Advanced Studied in Energy
UN	United Nations
W	Watt
WHO	World Health Organization
WB	World Bank

Abstract

Study context and objectives

For millions of years around the world, fossil fuels, such as coal, oil, and gas, have been used to generate electricity. Around 84% of global primary energy is being taken from fossil fuels, while only 11% of the total energy consumption in the world consists of renewables. This not only causes global climate change but also has a detrimental effect on human health and well-being. In addition, worldwide, electricity consumption is growing at an alarming rate. Soon enough, countries will not be able to generate their own economy without sustainable and secure electricity supply. There are still 2.8 billion people around the world who require access to clean and safe technologies. Even in the 21st century, we still have more than 789 million people across the globe with no access to electricity. Keeping all these factors in mind, we conducted a Techno-economic assessment of viable options for the solarization of NUST, and then we designed the most viable option using multiple software to finalize the sizing and specifications of our system along with a way forward for the right implementation of the project.

Technical assessment results

A technical assessment was conducted using two software, PVSyst and SAM. From PVSyst we obtained values of the potential that can be installed for every selected location of NUST including both its rooftop and its parking area available. From this analysis we could deduce the total theoretical installation capacity of NUST when rooftops and parking areas are catered to as 15MW. Next, we used SAM to input the relevant module and inverter details along with the losses in the system to find the net energy that would be produced in a year as 25,205,292 kWh. This value was obtained after catering to the losses including the lifetime degradation of the solar PV modules. The concept of net metering was introduced into the analysis which would provide the excess energy produced back to the grid to gain financial benefits.

Environmental assessment

A GHG emission analysis was conducted using RETScreen software to analyze how much of CO^2 emissions can be saved when a 15MW solar plant is installed at NUST. From the analysis we found that 10,308 tonnes of CO^2 emissions can be prevented and this figure was equated to find that it is equivalent to 1888 cars and trucks not used.

Economic and financial analysis results

Four major economic factors were considered in order to find the financial feasibility of the system, namely; LCOE, NPV and payback period. The LCOE value is minimal at 3.81 cents/kWh and the NPV is positive, indicating that the project investment is healthy. The simple payback period of the project would be 11.1 years and cash flows would slightly decrease over time due to the discount rate. Total direct costs of the project equal $9,085,819 and total indirect costs equal $1,513,546.

Chapter 1

1 Introduction

1.1 The situation around the world

For millions of years around the world, multiple fossil fuels like coal, oil, and gas have all been used as a source for the production of electricity. However, a major downside to this has been the grave danger the environment has been put in by the production of high levels of greenhouse gas (GHG) emissions. This not only causes climate change issues around the world but also negatively impacts the health and well-being of people. Additionally, all around the world, the global use of electricity is rising at a rapid rate. Soon enough, countries will be unable to power their economies without a stable and secure electricity supply.

An energy system provides aid to all of the sectors; medicine, business, education, agriculture, communication, and even extremely high-technology. Developing countries have begun to work to accelerate their energy efficiency and consumption and more and more countries have experienced the use of renewable energy. There are still 2.8 billion people worldwide who need access to clean and safe technology. Even in the 21st century, we still have over 789 million people worldwide without access to electricity.

1.2 Sustainable Development Goals (SDGs)

The Sustainable Development Goals (SDGs) were set out at the United Nations (UN) Summit on Sustainable Development, held in Rio de Janeiro, Brazil in 2012. , economic and political challenges facing our world. Unlike their predecessor, the Millennium Development Goals (MDGs), the SDGs clearly call on all businesses to use their ingenuity and expertise to solve the challenges of sustainable development.

Keeping this in mind, we aligned our project with Sustainable Development Goal number 7, which is to “ensure access to affordable, reliable, and modern energy for all”. This goal is not just pertinent to developing countries, but the entire world is trying its best to make advancements regarding clean energy. This can be seen reflected in a recent UN SDG report, which states that countries are trying to double the rate of improvement in global energy efficiency by 2030. (*SDG Indicators*, 2020). The national goal of Pakistan includes the deployment of a minimum of 9700 MW of clean energy in the national grid by 2030. Similarly, multiple educational institutes are playing their role in the generation of clean energy around the world. In this context, NUST aims to make its campus carbon neutral in the years to come. (NUST, 2018)

1.3 Facts and Figures

Some of the facts and figures which lead us to problem identification and problem resolution are stated. Only 11% of the total energy consumption in the world consists of renewables (Ritchie and Roser, 2020) which are very less when compared to fossil fuels which make 84.3% of the world's primary energy (BP, 2020). 'World energy outlook' is expecting a 12% rise in global energy consumption by 2030 and 100% of this rise will be occurring in developing nations (*World Energy Outlook 2020 – Analysis - IEA*, no date). When it comes to Pakistan, it is among the top 40 globally most attractive countries for renewable investment (*Global Review 2020 | EY - Global*, no date) but unfortunately, we are still heavily dependent on conventional practices resulting in 2.26 trillion rupees in circular debt. (Public Accounts Committee, 2020).

Pakistan is currently producing its electricity using four methods, which are hydroelectric generation, thermal generation, nuclear generation, and renewable energy. When compared to 2019, a drop was observed in renewable energy usage in 2020. It is mainly because of our dependency on hydroelectric and thermal energy. This is another clear indication that a lot of work is still needed to be done in this field.

1.4 Pakistan's current scenario

On average, Pakistan receives good solar insolation of 5-7 $kWh/m^2/day$ in more than 95% of its area with over 85% of persistence factor. (Sheikh, 2010)

1.5 Problem Statement

GHG emissions of high carbon content fossil fuels are the main drive behind climatic changes besides causing air pollution issues. Pakistan's GHG emissions alone include 158.10 Mt of CO2 (54%), 116.60 Mt of CH4 (36%), 27.90 Mt of N2O (9%), 2.17 Mt of CO (0.75%), and 0.93 Mt of volatile organic carbon (VOC) (0.3%). Overall, Pakistan is expected to observe a rise from 347 million tons of CO2 equivalent in 2011 to 4621 Mt of CO2 equivalent in 2050. (Abas *et al.*, 2017)

WHO also reports that carbon emissions cause 4.3 million deaths every year. Additionally, unaffordable energy has been a threat to Pakistan's security for the last two decades. With regards to energy source mix, Pakistan is reported to have one of the most expensive power generation costs in the world, with an extreme dependence and over-reliance on expensive furnace oil (*Climate change and health*, no date).

1.6 Objectives:

There are two main objectives that we were meant to achieve by the end of this project.

Techno-economic assessment of viable options for the solarization of NUST, where we used multiple software to find the technical and economic feasibility of the complete solarization.

Design of the most viable options where we use multiple software to finalize the sizing and specifications of our system along with a way forward for the right implementation of the project.

1.7 Innovation:

Our project is the first detailed analysis of NUST H-12's solar potential at an undergraduate level which includes

- Technical analysis
- Economic analysis
- Climate co-benefit analysis
- Optimization using multiple software

1.8 Scope of the project

Our scope consists of technical, economical, and climate co-benefit assessment at NUST H-12 campus using PV technology. To perform the techno-economic analysis we used software like RETScreen, PV Sol, Sam, and PVSyst. In climate co-benefits, we dealt with the reduction of GHG emissions using RETScreen. Our work boundary was NUST H-12 and the solar technology used is photovoltaics. Our proposed transmission system is an on-grid system to incorporate net-metering. The project was heavily dependent on data availability and input of this data into the software.

1.9 Application:

The concept of NUST solarization and its affective feasibility will serve as a roadmap for the solarization of other institutions and housing authorities around Pakistan and help promote the net metering system through feasibility analysis by incorporating its subsequent benefits into the calculations. This concept of net metering through feasibility analysis could also serve as a sustainable and profitable business model. It could promote and inculcate a sense of healthy competition for electricity generation, and consequently be a source of revenue thus resulting in reducing the circular debt of Pakistan.

Chapter 2

2 Literature Review

2.1 Assessment of solar energy potential and its deployment for cleaner production in Pakistan

This research paper has provided a detailed review of the power and energy of solar vision in Pakistan as a major source of sustainable and renewable energy. Hydropower infrastructure and the major causes of the energy crisis in Pakistan are brought in following a detailed solar energy test. The results obtained from solar atlas and the release of PV electricity show great solar power across the country. An estimated value of 4.1 kWh / kWp per day is available at an installed capacity of 1 KWp. In addition, Pakistan's total total solar energy potential is around 2900 GW and its efficient use will contribute to the country's economic growth by reducing oil imports. It is predicted that current research will help countries develop and use solar energy in their countries more efficiently and effectively (Rafique *et al.*, 2020).

2.2 Domestic sector energy demand and prediction models for Punjab Pakistan

Pakistan's domestic sector accounts for about 48% of Pakistan's total energy needs, including biofuels. Pakistan is a developing economy with over 210 million people and growing domestic demand, facing economic, environmental and climate change challenges. This paper incorporates an unconventional understanding of power in the domestic sector of Punjab, Pakistan, making up more than 52% of Pakistanis, as well as power forecasting models based on the 4597 key answers found in the 2017-18 survey, which aimed to determine who drives in need of great domestic power. These types will support future government and energy policy policy in the region, especially the transition to a low-carbon economy. Currently, 67% of Pakistan's energy demand is met with non-renewable resources. Analysis of survey data reveals the importance of energy demand for each household, the number of electrical appliances, the number of lamps, and the number of standard rooms. For individual models, drivers are important for the overall power rating of the equipment used, especially the power measurement of cooling air conditioners. Annual gas consumption, weak combinations of each family and capita are found only in the basement. The average annual consumption of electricity and gas per household is 2401 kWh and 5245 kWh respectively, with each person 391 kWh and 770 kWh. Electricity, seating, floor space, equipment rooms, electrical appliances, lamps and power measurements are predictable. In case of gas, only the floor area can be predictable (Awan and Knight, 2020).

2.3 Modelling and performance analysis of a stand-alone hybrid solar PV/Fuel Cell/Diesel Generator power system for university building

The design and operation of the off-grid PV / Fuel Cell / Diesel Generator power system in the university building was highlighted in this study. The main goal is to design an electrical system with high renewable energy components; low greenhouse gas emissions, and low energy costs. The aim is to transform a grid-powered petrol power system into a renewable and clean energy system. Hourly calculations are performed to evaluate the effectiveness of the energy and cost system using efficiency and control measures. Simulation and performance analysis showed that the proposed renewable energy system yields the best results: 73% of total energy from solar PV, 24% from petrol cells and 3% from diesel generators. The total electrical load of the building is met without a power shortage (<0.1%). The independent renewable energy system alone has the highest renewable energy percentage (66.1%), is economically viable (92 $ / MWh) and is environmentally friendly (24 kg CO_2 / MWh) (Ghenai and Bettayeb, 2019).

2.4 Optimization tools for designing Solar Photovoltaic systems

Many researchers across the globe have conducted studies of multiple software tools. Numerous software are available for sizing, analysis, optimization and simulation of renewable energy systems. This paper described multiple renewable energy systems design software's available for analyzing and optimization of the system. The paper gives a brief introduction to software like PVSyst, RETScreen and PV Sol etc. (Goel, Sharma and Lenka, 2020).

2.5 Economic analysis and impact on national grid by domestic photovoltaic system installations in Pakistan

Pakistan has been facing a growing energy crisis every year due to growing population and growing industrial areas. In addition, energy costs are very high as they come mostly from conventional energy sources. Pakistan, on the other hand, has excellent potential for solar energy production as it lies near the equator. Due to the recent decline in solar photovoltaic (PV) costs, Pakistan is moving towards these solutions in both grid and off-grid systems. Therefore, this article focuses on the behavior of the sun's rays and on the integration of a PV panel ready to harvest the great power in Pakistan. In addition, the domestic economic analysis of PV steel roof systems is done based on investment costs, payment period, reduction of electricity bills, and the choice of metering system. In addition, the impact of domestic PV systems on the power grid is assessed based on reduced electricity load. This study has the potential to encourage consumers to reap the benefits of investing in domestic PV systems by selling more energy to a local distribution company. All simulations are done in soft-sol metric sun-eye software. These simulation effects are versatile and meaningful underground conditions and events in Pakistan (Shabbir *et al.*, 2020).

2.6 Environmental impacts of solar energy systems: A review

The annual increase in land use, as well as the problems and environmental problems, play an important role in sustainable and renewable energy use. Solar energy systems are the strongest among all other renewable energy systems over the past decade. However, even renewable energy can have serious environmental consequences; therefore, continued attention and appropriate monitoring procedures should be provided. This paper discusses in detail the environmental impacts of several commercial and emerging solar energy systems on both small and medium-scale scales. The study expands on other related developments, as well as some of the key elements in their plans. This approach follows all phases, first with designs, then in all of their production phases, building materials, construction or installation, as well as past operating and removal time. Specific solutions for many programs such as waste minimization and recycling are discussed, along with other appropriate technical and environmental recommendations for mitigation (Rabaia *et al.*, 2021).

2.7 University Campus and Surrounding Residential Complexes as Energy-Hub: A MILP Optimization Approach for a Smart Exchange of Solar Energy

An effective way to increase renewable energy consumption involves creating better connections between manufacturers, consumers, and storage devices, i.e., the so-called "power hub". This poses a serious challenge, especially in urban areas where renewable energy plants are available. The paper looks at a university campus in central Lisbon that needs a large amount of electricity and natural gas to fund domestic operations. The idea is to replenish part of the compass's energy consumption with the energy provided by solar systems installed in nearby residential buildings. The aim is to find the number and type of solar panels that increase the reduction in annual energy costs for both citizens and on campus, where the campus is seen as a last resort. Performance results show that, given the 100 best-designed buildings within a distance of 500 meters around the campus, the compass can reduce annual energy costs by up to 8.61%, while residents' savings are orderly 24% to 29% , depending on the sun's rays. Sensitivity analysis also shows superior benefits for both institutions and users from the pending cost of image reduction panels (Rech *et al.*, 2020).

Chapter 3

3 Site Selection

3.1 Site analysis and conditions

NUST is located in sector H-12 of Islamabad with the location coordinates of 33.6429° N and 72.9927° E.

Islamabad has a subtropical climate having four seasons in a year.

- Spring from month of March to April
- Summer from starts in May and usually ends in August
- Autumn remains for the months of September and October
- Winter comes in November and lasts till February

June is the hottest month of the year when the average temperature exceeds 38 °C with ease. July is the wetted, with high precipitation and thunderstorms in the evening. January is the coldest month with very low temperatures across the city. Temperatures in Islamabad city varies from mild to cold, often dropping below zero. Yearly wind speed data extracted for NUST, Islamabad from RETScreen is shown in Table 1.

Table 1: Average wind speed, maximum wind and average gust from 2010 – 2020 (kmph)

Year	Avg. Wind (kmph)	Max. Wind (kmph)	Avg. Gust (kmph)
2010	7.7	12.1	13.9
2011	8.1	12.2	14.6
2012	8.8	13.4	15.4
2013	9.6	13.6	17.2
2014	8.3	12.9	15.3
2015	7.5	11.9	13.3
2016	6.9	10.8	12.1
2017	8.3	12.1	14.6

2018	7.6	10.4	12.8
2019	8.6	11.1	14.3
2020	7.3	9.8	11.5

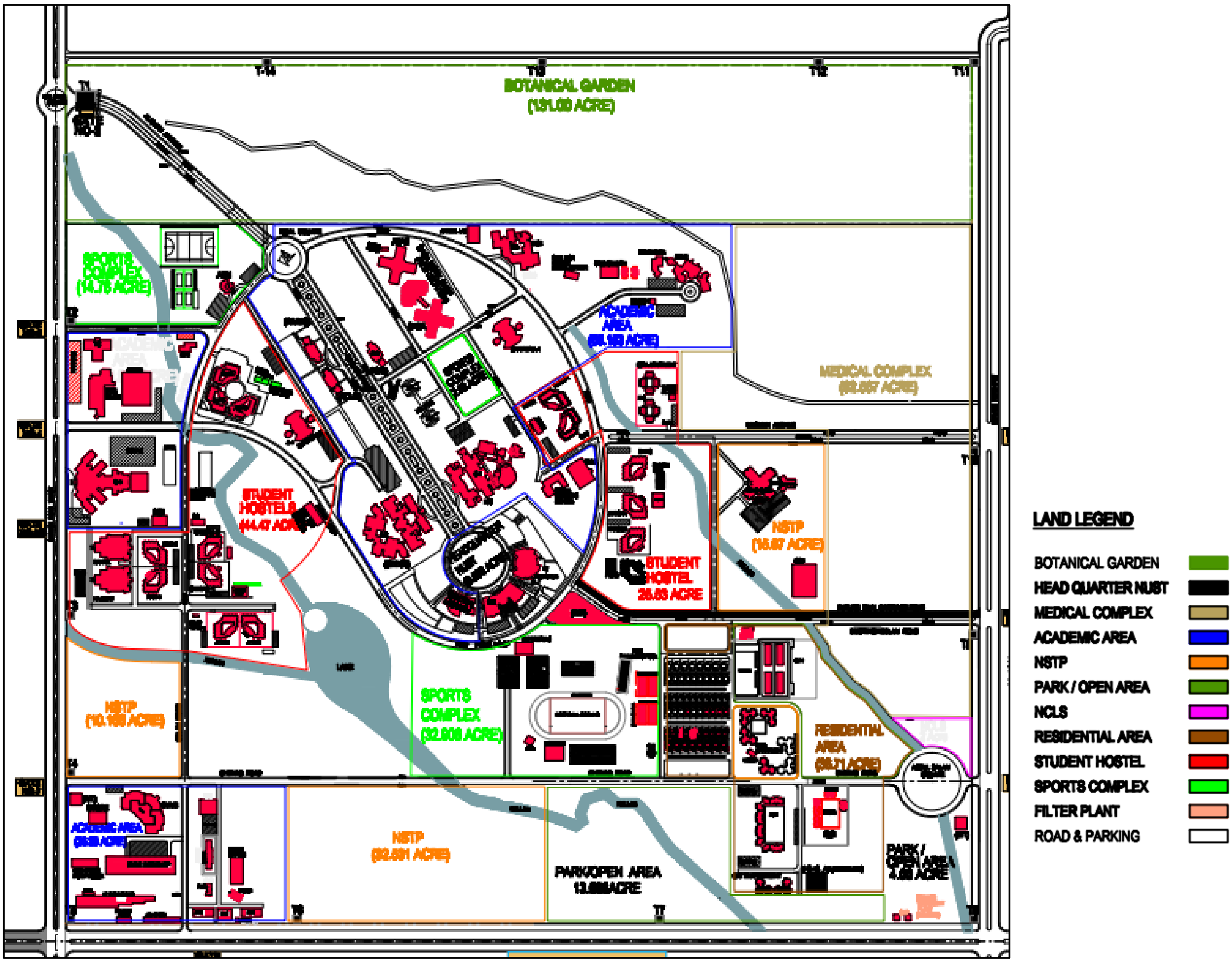
NUST H-12 Campus has an area of 2,856,987 m2 which makes 706 acre. Out of this total area provided, 416,812 m^2 is covered by vegetation. Breakdown of the 706 acre area of NUST is shown in Table 2.

Table 2: Approved and used land areas of NUST (m^2)

Sr. No.		**Approved Area**		**Proposed Area**	
		Acre	**%Age**	**Acre**	**%Age**
1	Botanical Garden	131.00	18.5	131.00	18.5
2	Academic Area	115.39	16.3	115.39	16.3
3	Roads & Parkings	141.32	20.0	141.32	20.0
4	Park/Open Area	29.60	4.2	29.60	4.2
5	STP	1.00	0.14	1.00	0.14
6	Medical Complex	84.54	11.9	60.57	8.5
7	Headquarter NUST	17.15	2.4	9.50	1.3
8	NCLS	20.27	2.8	2.00	0.28
9	Student Hostels	65.00	9.2	70.00	9.90
10	Residential Area	35.00	4.9	36.71	5.19

11	NSTP	17.84	2.5	58.36	8.26
12	Sports Complex	48.48	6.8	51.13	7.23
		706.61	100%	706.61	100%

Figure 1: Recent map of NUST



3.2 Current installations

The current installations at NUST make up a total installed capacity of 1MW altogether. Locations used for the PV setup include NICE rooftop and parking area, NSTP, USPCAS-E rooftop and parking area, SEECS rooftop and parking area, Central library Parking, Razi hostels rooftop and Ghazali Hostels rooftop.

3.3 Overview of the areas designated for PV installations:

The areas for the solarization of NUST project potentially considered for the design and installations of PV systems were identified using the NUST's master plan. The master plan helped identify the locations which are available for use, including both rooftop and parking areas. Sites that were reserved for new buildings and new constructions like the area reserved for the construction of a medical area were all omitted from the selection. Areas of each of the locations were calculated using google maps with the integrated tool to calculate area based on the edges of each building and parking lots. An overview of these areas is given in table

Table 3: Rooftops and parking areas of selected NUST sites (m^2)

Sr. No.	Building	Rooftop Area (m^2)	Parking Area (m^2)	Total Area (m^2)
1	IESE	2320	305	2625
2	SCME	1690	1420	3110
3	ASAB	2600	1870	4470
4	NBS	6200	4000	10200
5	S3H	1590	0	1590
6	SADA	2538	2960	5498
7	IGIS	1000	590	1590
8	RIMMS	500	2000	2500

9	SMME	2730	550	3280
10	SNS Block 2	585	4450	5035
11	SMME Workshop	1330	1700	3030
12	Attar Hostels	1482	640	2122
13	Ghazali Hostels	0	640	640
14	Hajveri Hostels	1250	260	1510
15	Zakriya Hostels	1250	0	1125
16	Rumi Hostels	2223	960	3183
17	Fatima Hostels	1482	640	2122
18	Khadija Hostel	741	320	1061
19	Ayesha Hostel	741	320	1061
20	Zainab Hostel	741	320	1061
21	Amna Hostel	741	320	1061
22	Maryam Block	760	375	1135
23	CIE	945	0	945
24	Exam Hall	1360	0	1360
25	Design Center	1330	0	1330
26	N'Ovative	625	0	625

27	Habib Bank Limited	240	210	450
28	Admin Block	420	700	1120
29	NSTP 1	2550	0	2550
30	NSTP 2	1720	2990	4710
31	CSD	480	1100	1580
32	NCLS	1110	680	1790
33	Iqra Apartments	1000	516	1516
34	Gym	1265	280	1545
35	PMO	280	0	280
36	IEAC	434	1590	2024
37	CIPS	2275	6290	8565
38	NUST Press	354	3500	3854
39	Bhittai Blocks	615	430	1045

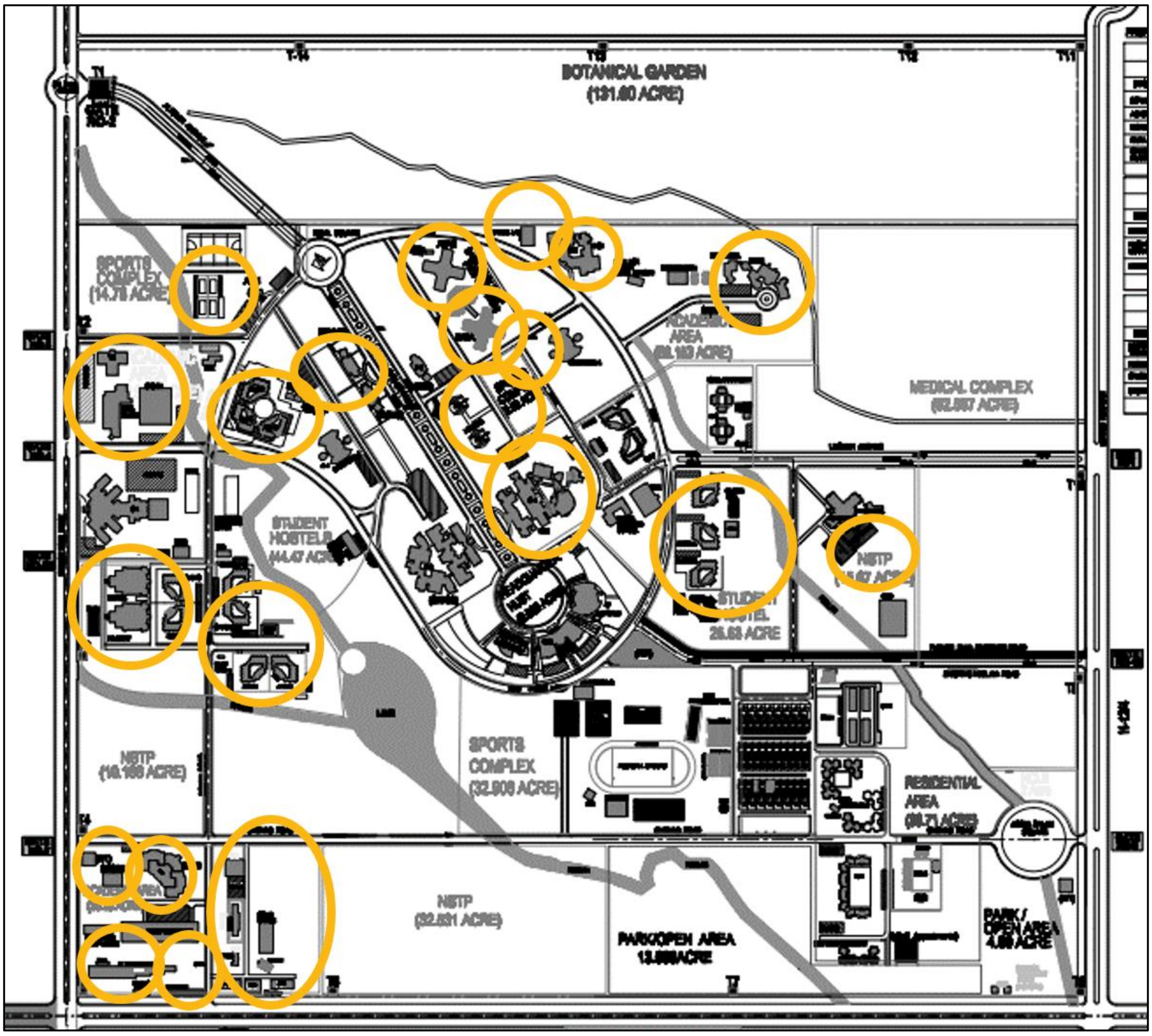
Most of these aforementioned sites have been visited and assessed to check for their eligibility. It is not expected that the terrain and site characteristics of each of these areas differ.

3.4 Site selection criteria

Suitability of each of the sites was assessed based on certain criteria while keeping the master plan in mind. The following criteria were considered when selecting area available for installations

1. Rooftops are considered because they make way for excess unused land that is currently not serving purpose through any other means.
2. Installations in parking areas can be multi-purpose as they provide shading to the parked cars.
3. Equal and solid ground and rooftop surfaces are considered to ensure that there are no disruptions in the topography and that the installation process is made easy.
4. All of the sites were assessed to check if there are no growing horticultures around the areas of installation so that no plant life or growing life is being affected by the installations
5. Since the parking lots and rooftops are not surrounded by any water bodies, it is ensured that no water body disturbances are caused by the installations.

Figure 2: Selected sites of NUST



There are two recommendations to keep in mind for the site and are listed below:

1. Plantation of shrubs around the ground mounted installations can reduce dust cover and prevent it
2. Using the same design configuration for both the ground-mounted installations and the rooftop installations can make the O&M costs much cheaper.

Chapter 4

4 Environmental conditions and resources

4.1 General climatic conditions

Monsoon and west disturbance are two key climate change initiatives in Islamabad; otherwise, the continental spirit dominates the whole season. The main factors affecting the climate of Islamabad are given below.

1. Disturbances from the west take place nearly every single month of the year in Islamabad, but they bloom in months of winter season and cause medium to heavy precipitation, with temperatures also declining.
2. Fog occurs in months of winter and lasts for the weeks to come; particularly in the Margalla Hills region.
3. Summer brings the dust storms and they peak in the months of April and May. The summer dust storms are very violent.
4. Monsoon from the southwest takes place in the summer season, starting from June to the month of September. These naturally occurring storms are naturally strong and have the potential to cause flooding situation if they come in contact with western waves.
5. The continental wind reigns at a time when there is no rain in the city.

4.2 Reference Irradiation and temperature

Data was collected for NUST over three years and this data was used to compare the conditions of irradiance with the temperature. Months and hours where irradiance is maximum are the most attractive and will yield the highest solar output. Months with high irradiance but the low temperature will yield the best output as the temperature has an effect on the efficiency of the solar panels. This can be seen as shown in Figure 3.

Figure 3: Average monthly variation at NUST of GHI (W/m²) against temperature (˚C)

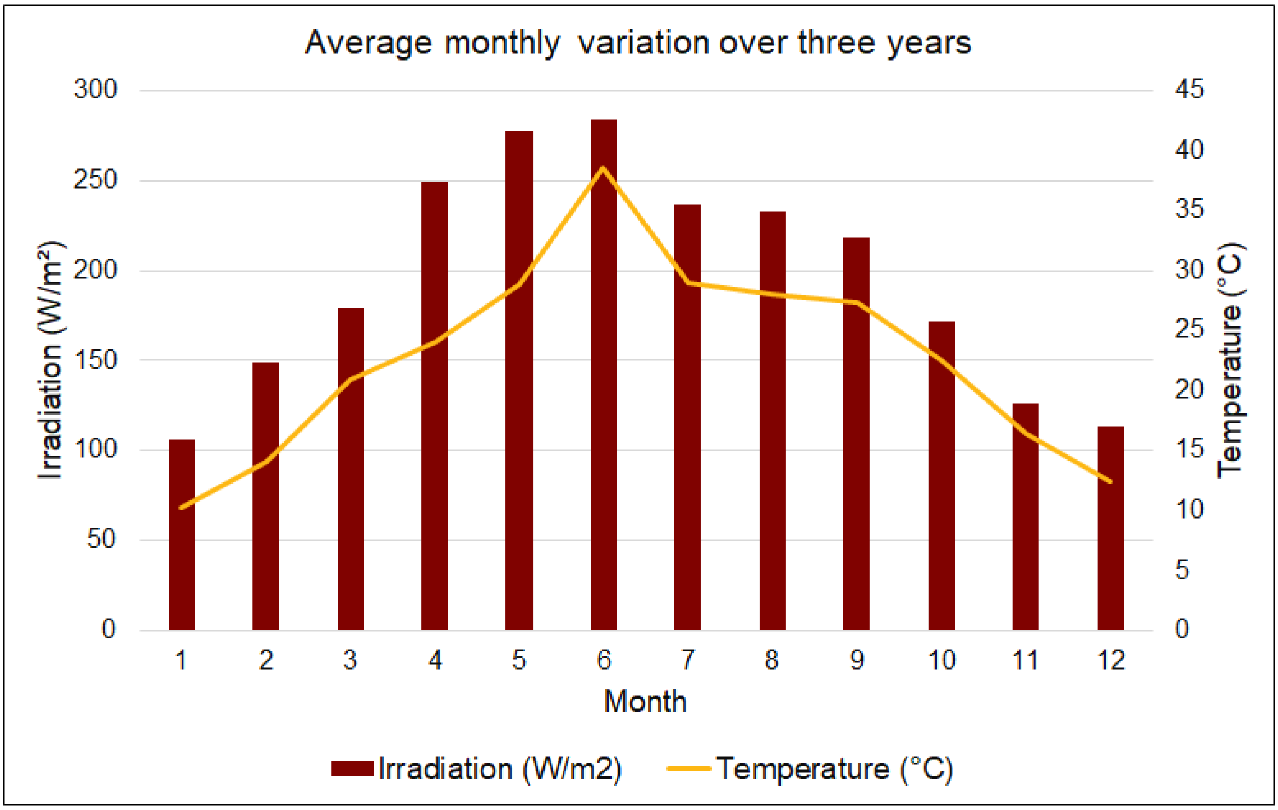


Figure 3 displays the average seasonal variation over three years at NUST. It can be observed that pre-monsoon seasons which consist of March, April and May are seen to have the high solar insolation with a relatively lower temperature as compared to Monsoon seasons which consist of June, July and August and September but have a much higher temperature comparatively.

Solar panels are strongly tested at 25˚C during the production process. The percentage of temperature measurement therefore indicates a change in efficiency as it rises or decreases in level. For example if the maximum temperature of a particular type of panel is -0.5%, then at all altitudes of 10 ℃, the maximum power of the panels will decrease by 0.5%.

So on a hot day, when the panel temperature can reach 45 ℃, a panel with a temperature of -0.5% can lead to a significant reduction in power output of 10%. On the other hand, if it were a sunny winter yesterday, the panels would actually work better.

First in the process of making panels, companies use a very hot substrate to help dissipate excess heat in the glass layer.

Your solar panel installer will also try to ensure that there is free air flow above and below the solar panels when installed, by lifting the panels a few inches from the roof. In addition it is possible to add ventilation systems or fans to your solar PV system to help facilitate air circulation around the panels.

However, it is important to make sure that you are trying to install your panels when there is a little more natural air, just another factor to consider when choosing a installation position for your solar PV (Zaini *et al.*, 2015).

Figure 4: Average seasonal variation of global horizontal irradiance (W/m²) over NUST for the last three years against average temperature variations.

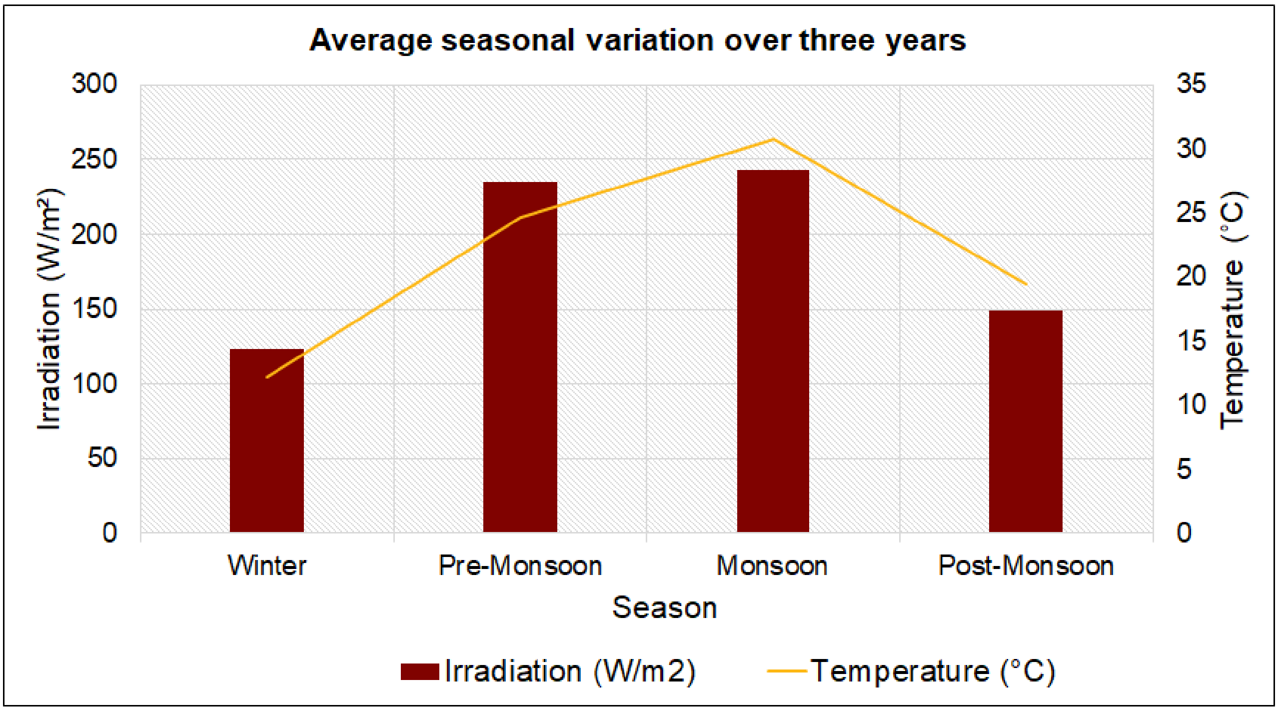
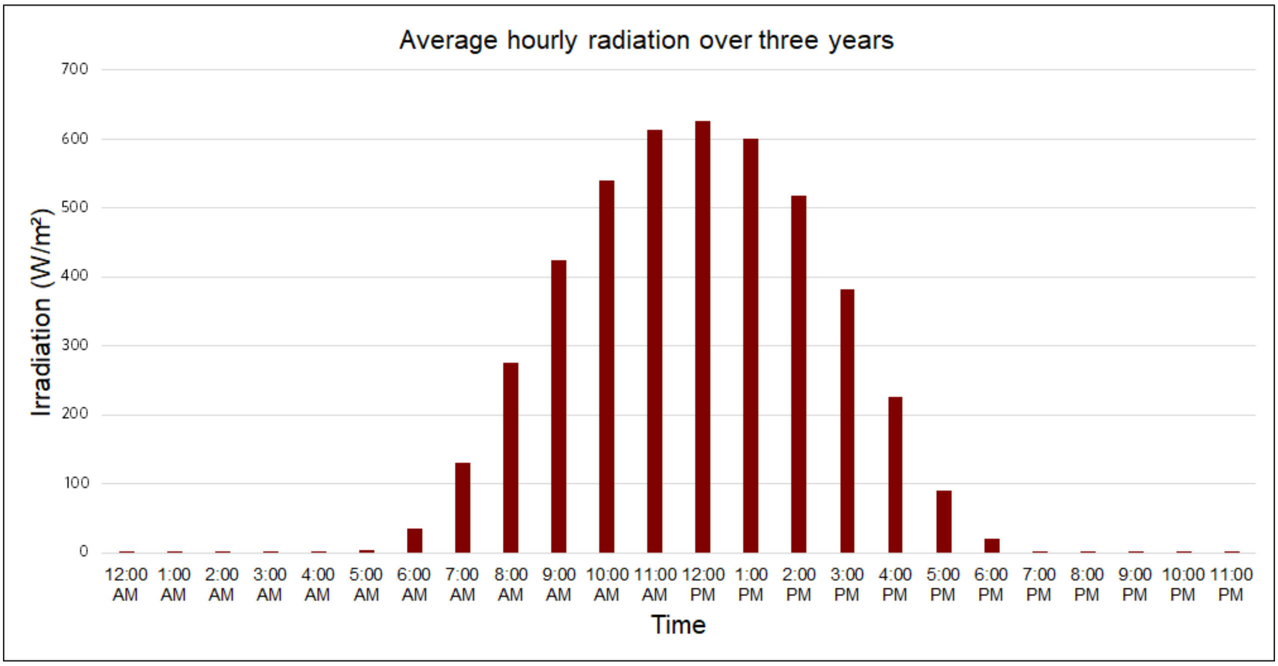


Figure 5 shows the average hourly radiation over all three years. From this data, we can interpret that maximum solar insolation will be received between 11:00 am and 1:00 pm.

Figure 5: Average hourly variation of global horizontal irradiance (W/m2) over NUST for the last three years.



Chapter 5

5 Sources of data collection

5.1 Online Tools

Global Solar Atlas is an online tool that is a ‘World Bank’ powered online tool to provide accurate solar-related data for any selected location. For our project, we selected the H-12 campus using ‘Global Solar Atlas’. It generated multiple parameters that can be used for a ground-mounted PV system. A graph was also generated which shows us the PV potential for our selected site and its expected specific yield. For our selected location the specific yield will be in the range of 1400 to 1600 kWh/kWp.

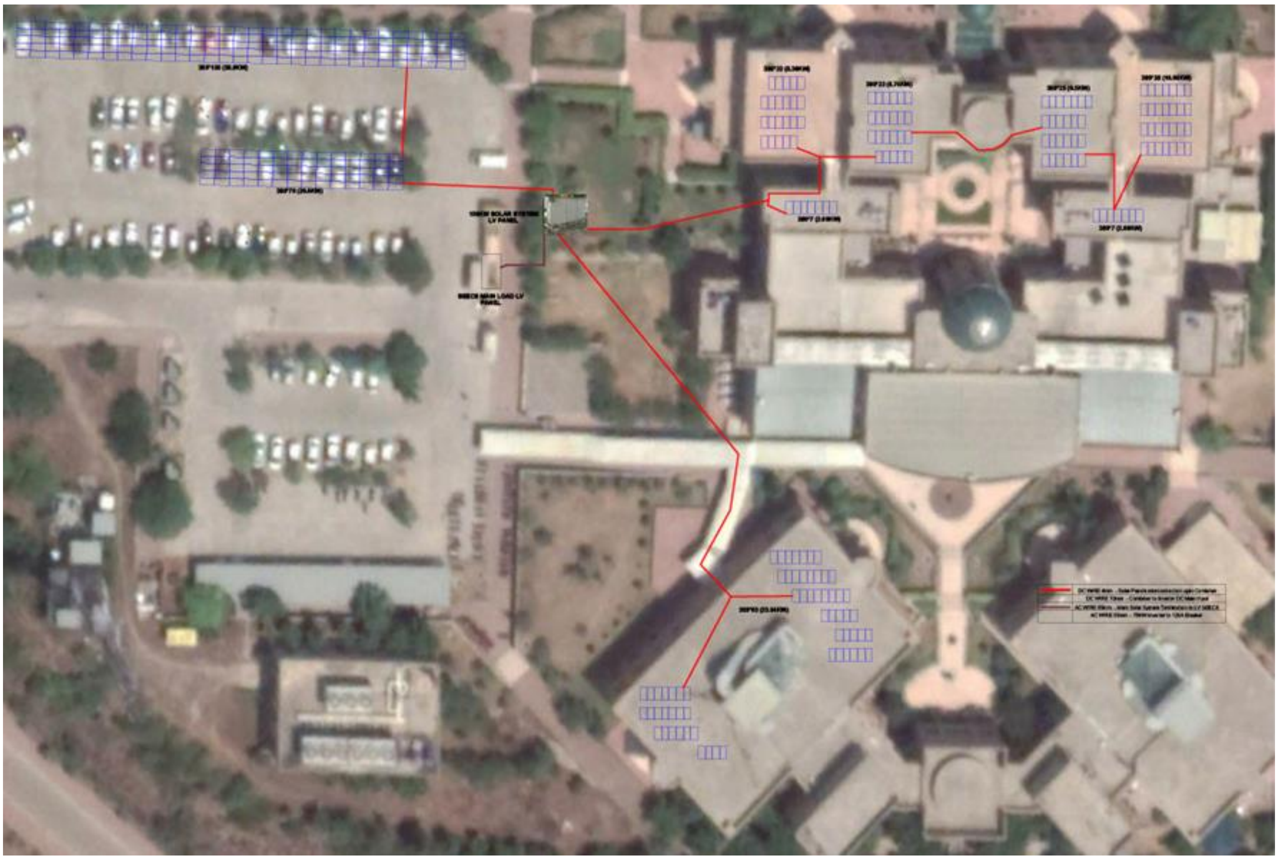
5.2 Project Management Office (PMO)

We visited PMO during the data collection phase of our project. We received the updated NUST construction master plan from PMO. It helped us select the sites for our PV installations. Apart from that, we were given the seasonal electricity load data, monthly electricity bills, etc.

5.3 U.S.-Pakistan Center for Advanced Studies in Energy (USPCAS-E)

USPCAS-E was able to provide us with the installations and layouts of the current PV setup at USPCAS-E and at SEECS along with the data sheets used to run the simulations for a 150 kW setup at SEECS. From Figure 6 we can see that both ground and rooftops have been considered for installations and interconnected.

Figure 6: Layout and the installation setup at SEECS.



Similarly, we were able to attain the layout for USPCAS-E which shows both the rooftop and parking lot setups. The total current installations at USPCAS-E are a total of 101.08 kW. Rooftop arrangements are divided into two clusters and car porch installations are also divided into two clusters. The ground-mounted installations are divided into three modules of 34 panels, 46 panels, and 52 panels each respectively.

Figure 7: Rooftop and car porch solar panel arrangements

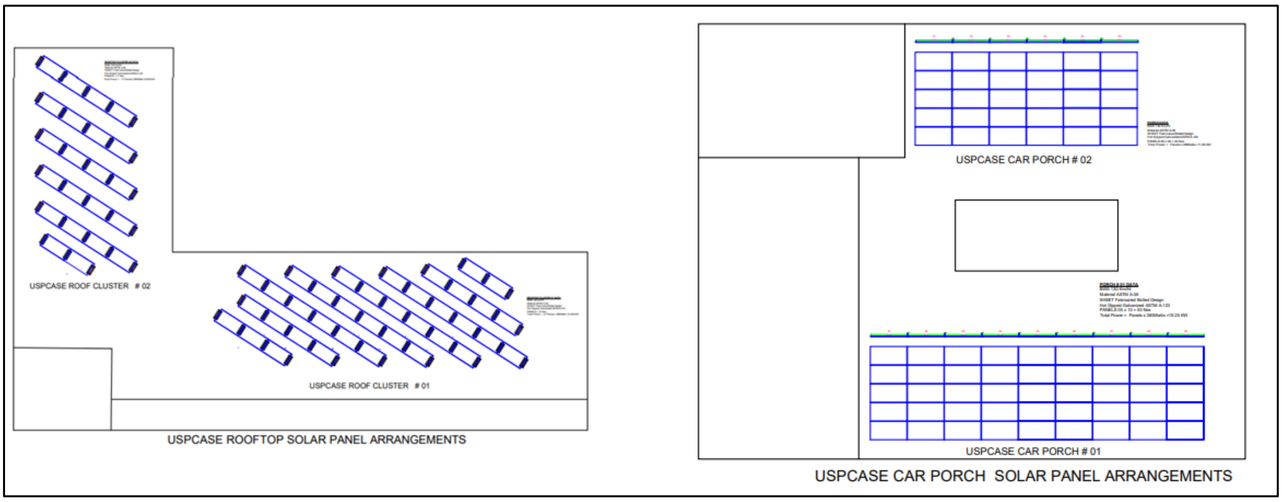
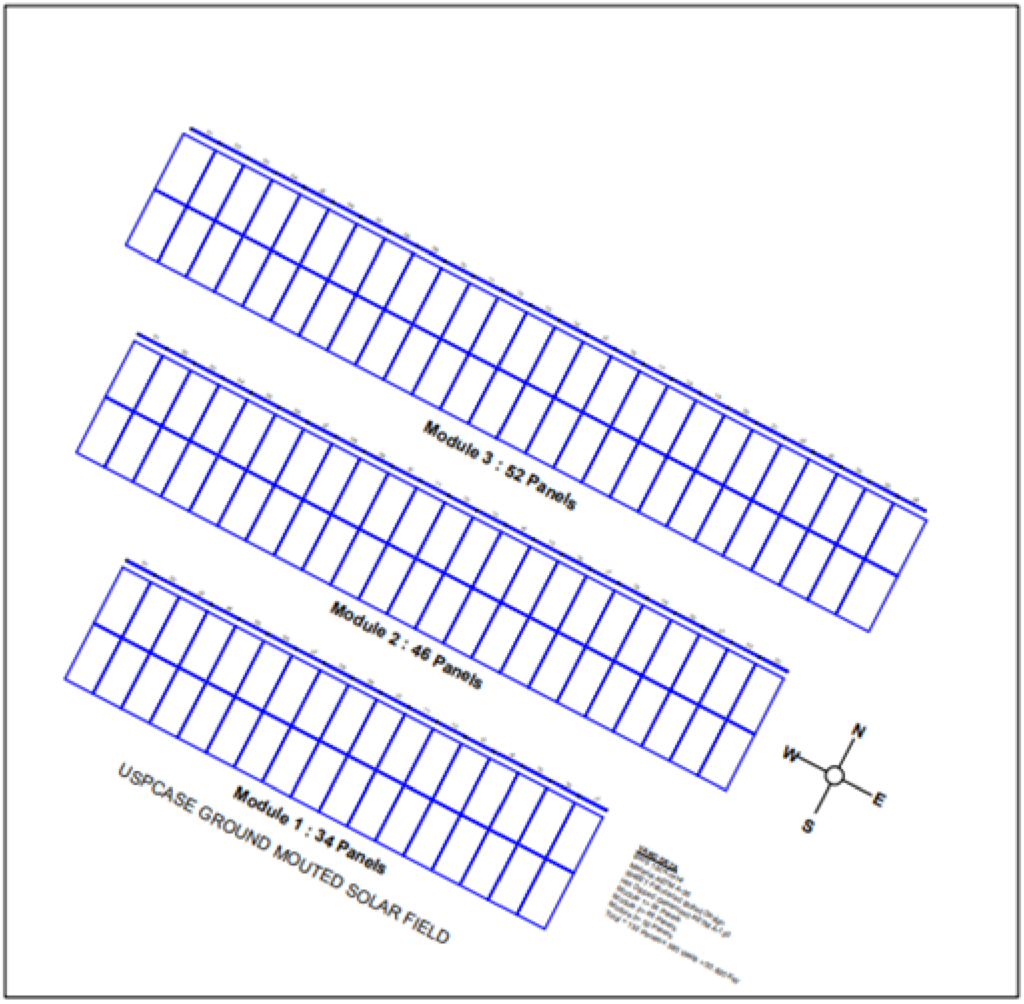


Figure 8: Ground mounted solar panels at CASEN



USPCASE GROUND MOUNTED SOLAR PANEL ARRANGEMENTS

Chapter 6

6 Software Used

To make the theoretical design more practical and realistic we used multiple modeling and simulation-based software. The software used for this process are listed below:

1. PV Syst
2. SAM
3. PV Sol
4. RETScreen

A brief description of each of the four software and their relevance to this project is given below.

6.1 PV Syst

This software is specifically designed to be used by multiple professionals like architects and engineers. Not only that, the software serves as an educational tool and has a detailed help menu to explain the models being used, and provides a user-friendly interface. PVSyst uses a meteo file database that can be imported, which is built into the system. Similarly, personal data can be imported from online sources.

This software comes with multiple tabs and features such as system sizing, system design, shading scene, grid connection, system aging, and economic evaluation. We used this software to perform the technical analysis of installations at different locations within NUST. Although this software gives us a lot of freedom, it comes on a free trial version for 30 days, after which we have to buy it to use it further. This limitation made us work on it for a short period of time.

6.2 SAM (System Advisor Model)

SAM is a software used for techno-economic modeling used mostly in the renewable energy corporations for multiple authorities and corporations. It can cater to renewable energy systems and performs tasks for

- PV Systems for large utility scale structures
- Solar power setups or electric power generation
- Wind turbines and wind farms
- Water heating systems - solar
- Marine and tidal simulations

An additional feature of SAM is that it can cater to grid-connected power systems as well in the PV system simulations. It uses an online calculator designed and approved by NREL and requires just a few basic inputs like the system losses and the required output to be able to generate the design feasibility. Additionally, you can enter financial inputs and obtain the required financial feasibility with the required economic factors catered to. Details can be chosen from a datasheet by a manufacturer or from the system’s in-built library. Online weather data files can also be obtained and input into the system or TMY files can be generated on your own to be used by the software.

6.3 PV Sol

PV Sol is an online tool for the calculation of a PV System. It is designed by the experts of the full-featured market-leading photovoltaic modeling software, this software lets us input basic data types like

- Load profile and annual energy consumption
- PV module data (manufacturer, model, orientation, quantity, etc.)
- Inverter manufacturer
- Location of our system

The automatic configuration manager of the software will then search for the optimal connection of our PV modules and then the inverter that suits best. After the simulation of the system, the results are given in the following terms:

- Annual PV energy
- Shading calculations
- Visual Design
- Performance ratio
- Solar Fraction
- Own power consumption

The visualized design and its results are attached in Appendix 2.

6.4 RETScreen

Clean Energy Management Software RETScreen (usually abbreviated as RETScreen Expert) is a software package developed by the Canadian Government. The RETScreen expert displayed the 2016 San Francisco Clean Energy Ministerial Meeting. Canadian government treasury officials use RETScreen as a greenhouse gas transfer tool for all federal emission reporting agencies.

RETScreen Expert integrates a number of databases to assist the users, including the Global Climate Database with 6,700 NASA satellite data stations; database of tests; cost database; project database; hydrological database, and product database. The program contains a wide range of integrated textbooks, including an electronic textbook. We used this software to conduct the greenhouse gas emissions analysis under the domain of climate co-benefit analysis of our project.

Chapter 7

7 Photovoltaic System

7.1 Planning target and design

For this project, the objective was to achieve a design where it is possible to achieve maximum output while using a cost-effective configuration and ensuring that maximum of the allotted and available areas are used.

The following design considerations were kept in mind when running all the simulations:

- The designed PV systems were all grid-connected. The solar panel setup would be tied to the existing network and synchronized with the IESCO supply.
- The designated ground parking lots and rooftops are all optimized so that other activities are not disturbed
- Proven, tested and appropriate technology was considered when suggesting options and running the simulations
- A maximized yield was gotten by considering the following:
  - Appropriate technologies for all the key components like solar panels, inverters, etc.
  - An optimum plant sizing while keeping into consideration all the losses in the system
  - An optimum geometry using the right tilt angles and azimuth angles.
- Ease of maintenance is provided to ensure that operation and maintenance costs can be minimal. A self-cleaning, value-added material is incorporated into the system to mitigate the dust issues and concerns.

7.2 Technology selection of the key components

The main components, which include modules and inverters are all selected in advance based on their characteristics. For instance, the crystalline silicon technology (c-Si) is considered the most appropriate based on 3 key factors - (1) they've maintained a good track record (2) the current market share of the technology (3) the average rated power of c-Si (Kumar *et al.*, 2019).

Since this technology has a higher rated capacity, it gives a much higher yield per unit area when compared to the other thin-film technologies. Any alternate technology used does not yield as high of a result as this does, which was observed when multiple simulations were run.

Multi-string inverters are regarded as the best choice for decentralized systems, being lightweight, small and easy to move around. This makes the maintenance procedures much simpler and easier. Using this inverter means that the topology formed with the PV designs can be made highly flexible.

7.3 Market survey

A market survey was conducted using both online sources and via meetings with local manufacturers around Islamabad and Pakistan. Through meetings and datasheets acquired, the following panel and inverters were selected as most apt for this solarization.

Table 4: Market survey conducted for inverters with the best-suited option 'SMA inverter'.

Parameter	SMA
Output voltage (v)	480
Operating temperature (˚c)	-20 to +50
Noise (dB)	58
Power (Kilowatt)	250 kw
Efficiency (%)	97.6%
Weight (Kg)	63

Table 5: Market survey conducted for solar panels with the best-suited option 'Canadian Solar'

Parameter	Canadian solar
Panel module	Cs3u-375|365| (iec1500v)
Country	Canada
Crystalline nature	Mono
Power (watt)	365
Area per module (m²)	1.9
Efficiency	19.1%
Price (PKR)	15,840

7.4 Possible PV Configuration

The geometry of the designated areas and the mounting structures help define the possible configuration for the entire setup. The difference in setup arises due to the difference in tilt angle and the azimuth angle used. The designated angles that were used for the first simulation were obtained from CASEN's datasheets. Two variations of the simulations were run and both were analyzed for technical and financial feasibility.

1) Variant 1 used a fixed system with a tilt angle of 30° and an azimuth angle of 0°.
2) Variant 2 used a 1 axis tracking system with an azimuth angle of 0°.

The one-axis trackers are used because they are able to provide a better yield by tracking the sun's position throughout the day. This means that this setup is able to provide much higher sunlight penetration to our solar panels thereby increasing the optimization of the system. One-axis trackers are mostly adopted in areas where the available area is large enough and is not a limiting factor. Both the variants were compared using key system indicators to select the best suited variant with the highest feasibility.

7.5 Selection of preferred PV variant

From the assessment, we have come to the conclusion that variant 2 (one-axis tracking) is the preferred variant for our design and setup. The following list summarizes the advantages of selecting this variant.

- It uses the highest installation capacity, maximizing the available area
- It produces the highest annual energy production
- The CAPEX and OPEX are considerably moderate
- Keeping financial feasibility in mind, a one-axis tracking system provides a better output and optimization

7.6 Design of the selected variant

The proposed setup of 15MW uses variant 2 design and has the following components:

- Arrays that are made up of mono-crystalline panels (Lopez-Guede *et al.*, 2017).
- A one-axis tracking system which maximizes the installed capacity and gives a high yield per area in kWh/m^2.
- 50 decentralized inverters were chosen for this purpose with AC/DC ratio being 1.2. The inverters are SMA inverters and are rated at 250,000 Watts ac. This also help avoid mismatch losses and AC inverter power clipping loss.

The 15MW plant can be divided into two sections; ground mounted and rooftops. In all cases, we ensured that the strings were designed keeping in mind that the inverter parameters that can sometimes be limiting, did not exceed their set values. Parameters like maximum and minimum MPP voltages, current, maximum system voltage and both local minimum and maximum temperatures were kept in check.

In the PVSol software, rows and columns were designed and row spacing was kept at 2.20 metres at the ground level and 1.10 metres for the rooftop level in order to avoid any of the major shadings that can occur from one row to another. This row spacing is also necessary to ensure that the work flow during installation is not disturbed and maintenance can be done with ease. These values cater to the installers moving between rows and even to drive between rows with vehicles if necessary (Alrwashdeh, 2019).

7.7 Value added technology

Although a tilt angle of 30 degrees offers a good cleaning mechanism in itself, on hot and arid days, dust accumulation can become a major concern (Ullah *et al.*, 2020).

A value added material was introduced into the analysis for the dust accumulation issue. When debris and dust accumulate in the surface, they can cause a negative effect on the performance of the panels. This is synonymous to the negative effect caused to the panels on a cloudy day. Cloudy conditions can reduce the panel's efficiency by 20% to 30% and block the absorption. The PV module cleaning device is a portable and rechargeable device which will be installed to the strings. The price of the value-added material has been incorporated into the financial analysis in chapter 10 (Khademi, Moadel and Khosravi, 2016).

Chapter 8

8 Technical Analysis

8.1 PV parameters

A standard module was selected with mono-crystalline cells for this purpose with a low temperature coefficient. The key parameters are listed in Table 6.

Table 6: Characteristics of the selected Canadian solar panel

Characteristic	Value	Unit
Nominal Power	365.238	W
Maximum Power Voltage	39.4	Vdc
Maximum Power Current	9.3	Adc
Open Circuit Voltage (Voc)	47.2	Vdc
Nominal Efficiency	19.02	%
Temperature Coefficients (Pmp)	-0.383	%/C
Temperature Coefficients (Voc)	0.138	V/C
Temperature Coefficients (Isc)	0.003	A/C
Cell type	Mono crystalline	-
Cell size	1.92	m^2

Figure 9: Module voltage (V) vs. current (A)

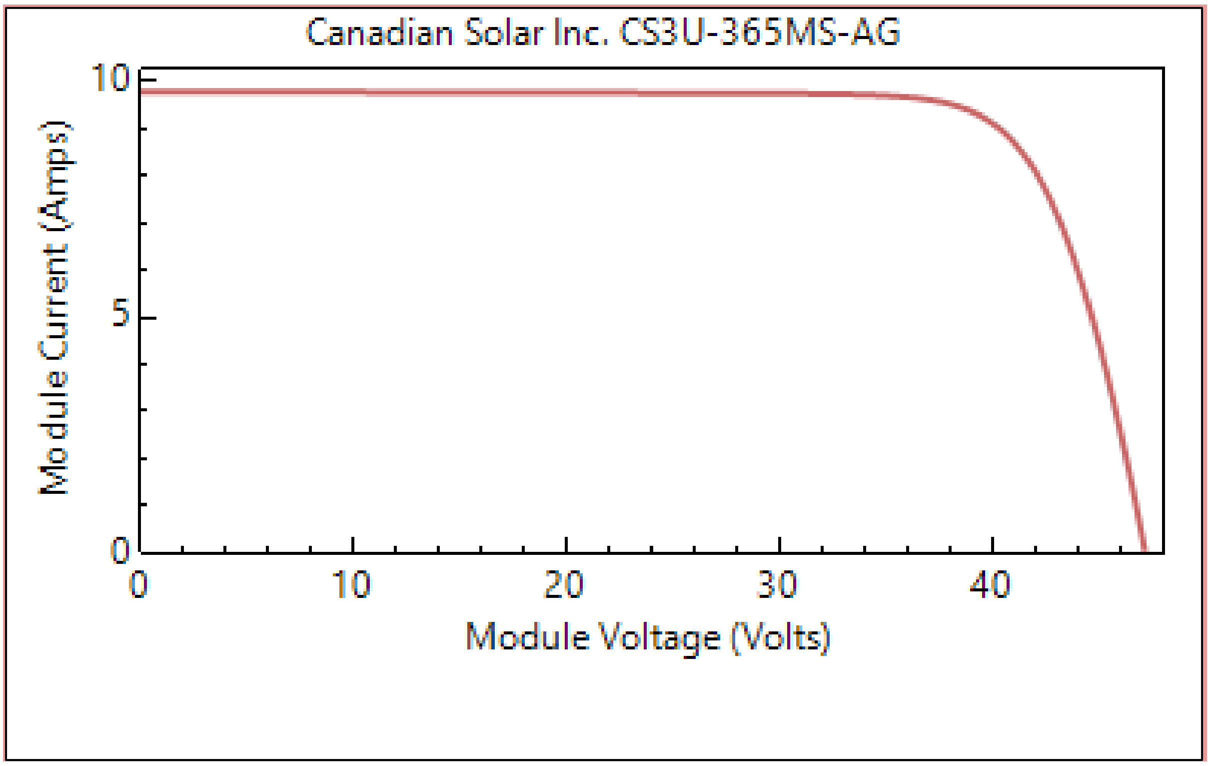
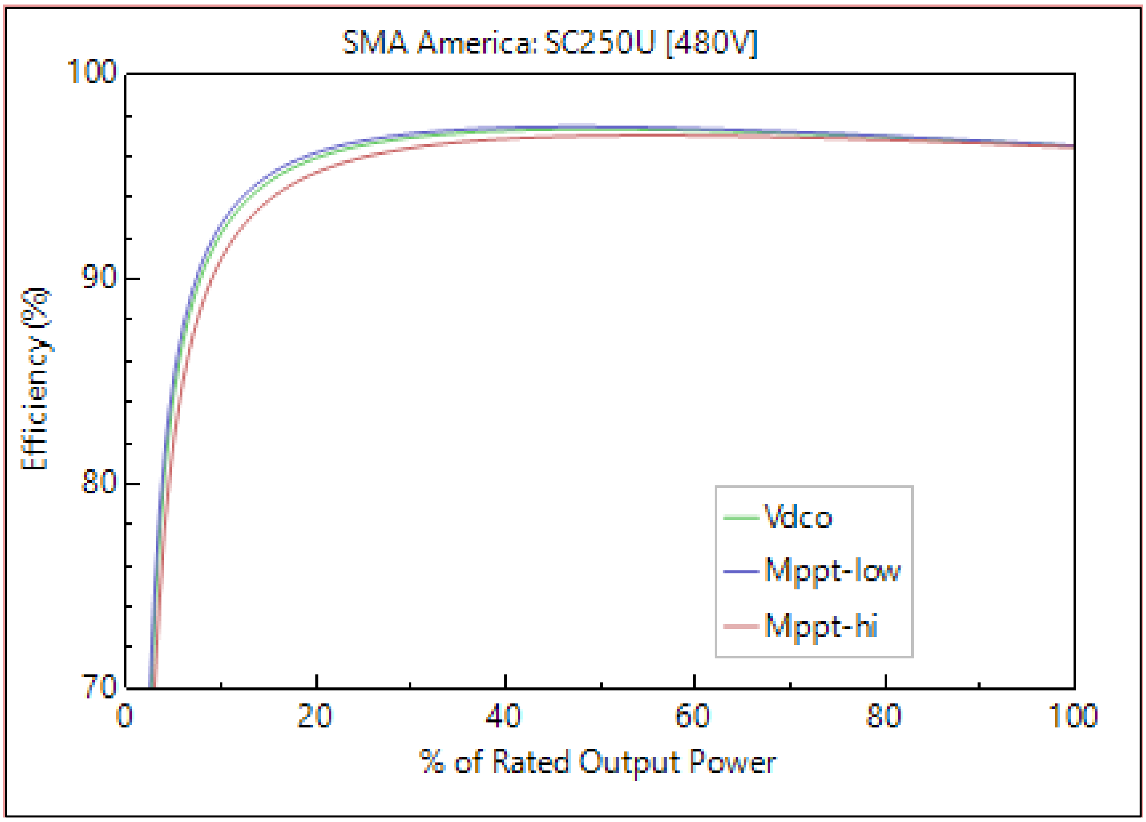


Table 7: Selected inverter module characteristics

Characteristic	Value	Unit
Maximum AC Power	250000	Wac
Maximum DC Power	259023	Wdc
Power use during operation	2064.23	Wdc
Nominal AC Voltage	480	Vac
Maximum DC Voltage	480	Vdc
Maximum DC current	700.062	Adc
Minimum DC Voltage	330	Vdc
CEC Weighted Efficiency	96.838	%
European Weighted Efficiency	96.267	%

Figure 10: % of rated power output vs. efficiency



8.2 Losses and Uncertainties:

These are few losses that have been considered during the simulations. There are losses due to the environment such as soiling losses, losses due the characteristics of the module such as LID losses, module mismatch losses, module quality losses. System losses which include DC characteristic losses, transformer loss and annual degradation. The assumed losses and uncertainties shown in Table 8 have been taken from existing data sheets and literature for the panels available.

Table 8: Losses along with their description

Parameter	Description	Loss
Irradiance loss		
Average annual soiling loss	Loss due to dirt or snow or anything else that cover the PV module surface	5%

DC losses		
Module mismatch	When solar cells experience a difference in properties and cause a mismatch loss	1%
Diodes and connections	Losses due to diodes and connections	0.5%
DC wiring	Losses due to the ohmic resistance of cables	2%
Tracking error		0.01%
Nameplate	Difference in the stated power of the module with the actual provided power	1%
Total DC power loss	Loss in conversion from dc to ac	4.440%
Transmission loss		
Transmission losses	The difference between the generated energy and the supplied energy	8.86%
Annual degradation for multi-year simulation		
Annual DC degradation rate	The degradation of PV pales over time	0.5%/year

8.3 Loss diagram:

A Sankey diagram was used to visually represent the losses in the system starting from the top of the diagram where no energy loss has occurred down to the final production by the system of 25,205,292 kWh. The loss diagram shows that there are no wide decreases in the arrows meaning no major losses are occurring anywhere in the system.

Figure 11: Loss diagram for 15 MW PV system

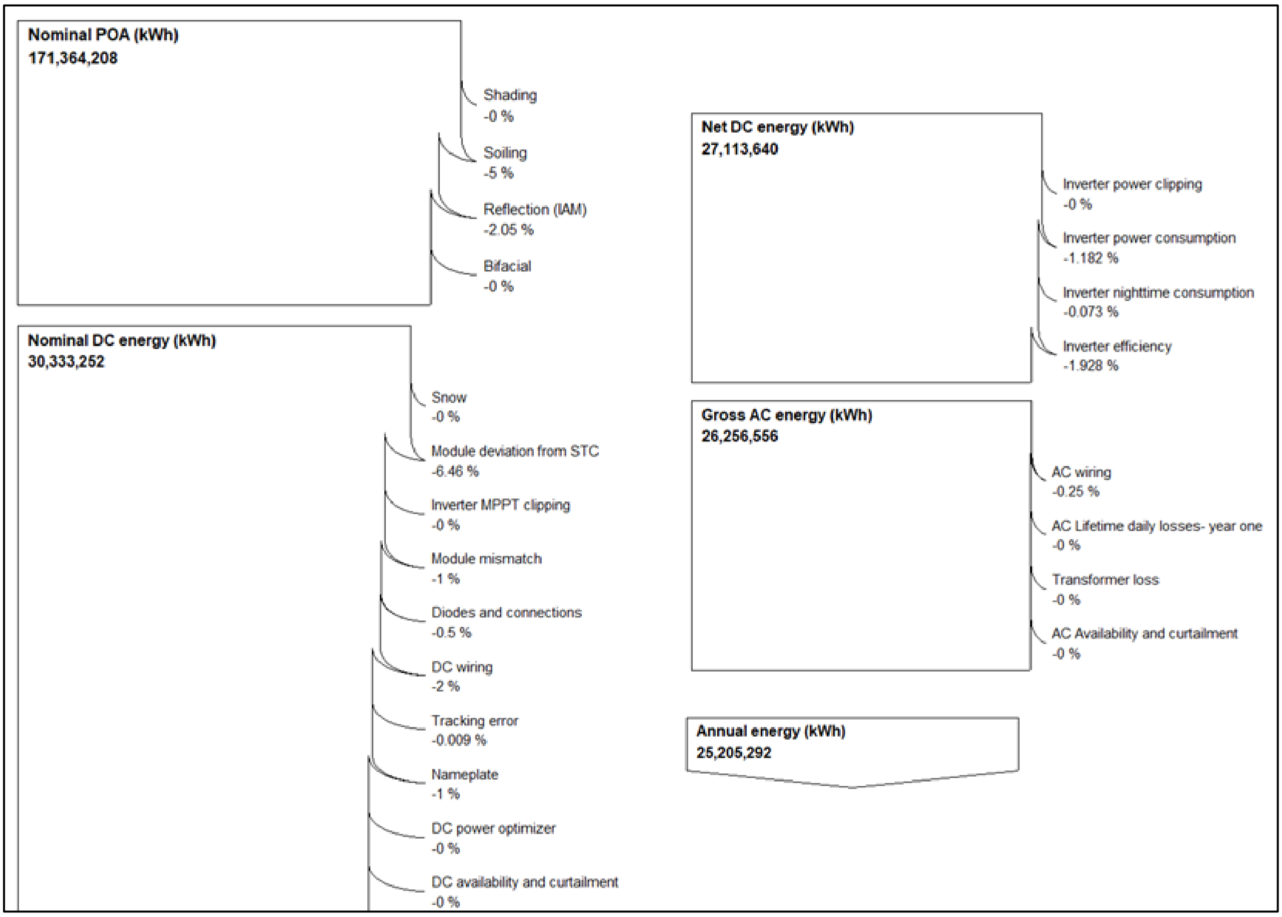
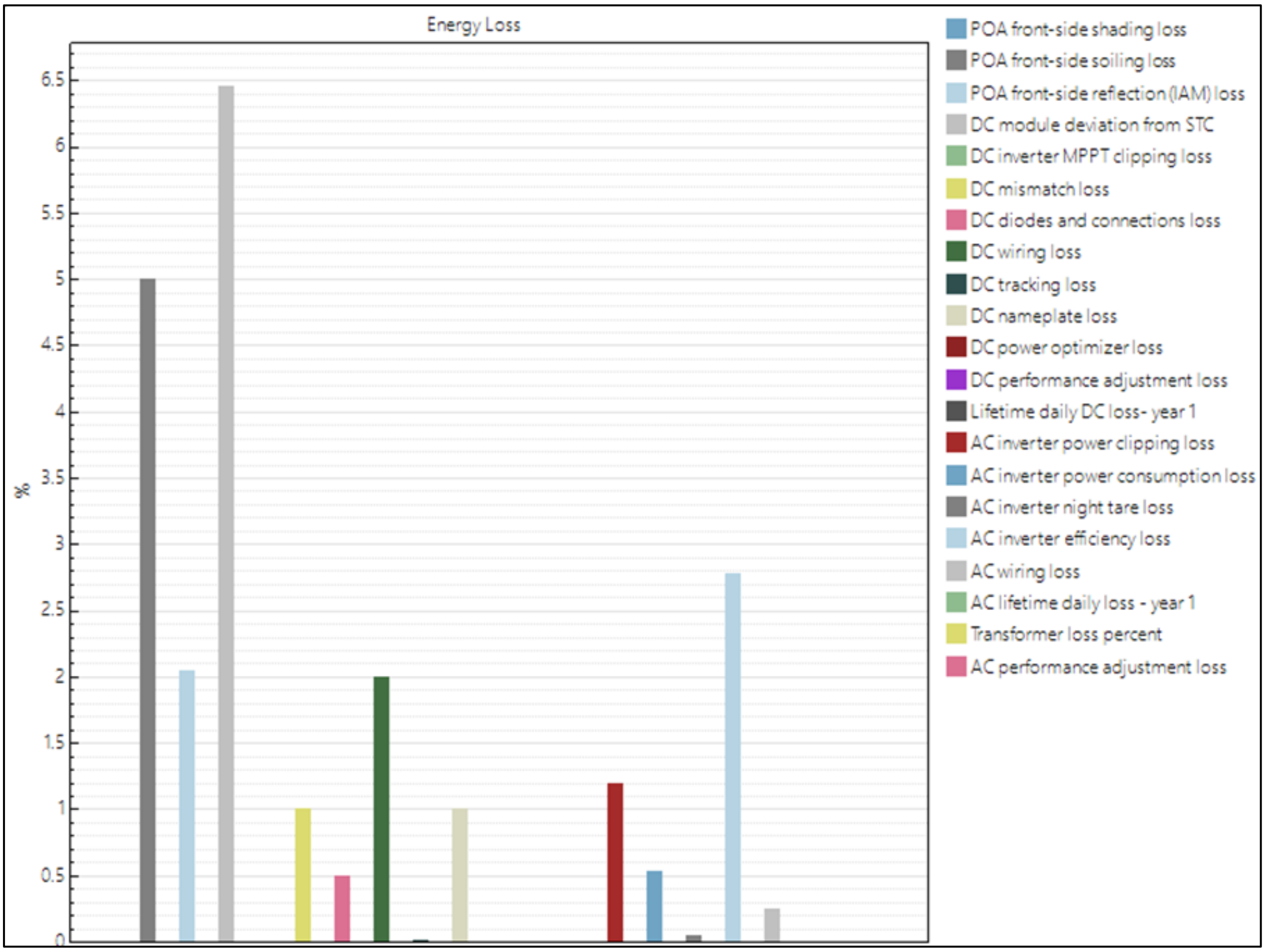


Figure 12: Energy losses in the form a graph



8.4 Expected energy production:

PVSyst simulations were run for 46 different departments of NUST, each of which has a rooftop and parking area available as seen in Table 2. First, a meteo file was imported from the software for NUST, Islamabad. The meteo file picks up the climate data within 40 km of the radius and contains hourly data of the global horizontal irradiance (GHI), diffuse horizontal irradiance (DHI), and ambient temperature. When running the simulations, we entered details of the selected solar panels, 'Canadian Solar', alongside the selected inverter 'SMA' with the product specification codes. The total available area was entered into the software. Through this data, the software allotted the number of panels needed in strings and in series and the total number of panels required altogether. A global system summary for each department was prepared which showed us the number of modules needed, the module area required, the number of inverters needed, the nominal PV power required and the maximum PV power available. Relevant losses were entered into the system from Table 8. A summary of all the simulations run is shown in Table 9. The total annual energy produced in one year is 25,205,292 Kwh with a capacity factor of 19%.

Using the hardware shown in our market survey section, we expect our on-grid decentralized installations to generate the amount of energy shown in the table below

Table 9: Summary of simulations run in PVSyst

Sr. No.	**Building**	**Total Area (m2)**	**Installation Capacity (MW)**	**Expected Production (MWh/yr)**
1	IESE	2625	0.43	688
2	SCME	3110	0.51	809
3	ASAB	4470	0.73	1176
4	NBS	10200	1.67	2673
5	S3H	1590	0.2	420
6	SADA	5498	0.75	1437
7	IGIS	1590	0.2	420
8	RIMMS	2500	0.40	651
9	SMME	3280	0.50	861
10	SNS Block 2	5035	0.75	1316
11	SMME Workshop	3030	0.45	803
12	Attar Hostels	2122	0.30	554
13	Ghazali Hostels	640	0.14	167

14	Hajveri Hostels	1510	0.20	394
15	Zakriya Hostels	1125	0.18	280
16	Rumi Hostels	3183	0.45	831
17	Fatima Hostels	2122	0.30	554
18	Khadija Hostel	1061	0.15	277
19	Ayesha Hostel	1061	0.15	277
20	Zainab Hostel	1061	0.15	277
21	Amna Hostel	1061	0.15	277
22	Maryam Block	1135	0.18	280
23	CIE	945	0.15	246
24	Exam Hall	1360	0.2	355
25	Design Center	1330	0.2	347
26	N’Ovative	625	0.10	163
27	Habib Bank Limited	450	0.06	117
28	Admin Block	1120	0.15	292
29	NSTP 1	2550	0.40	666
30	NSTP 2	4710	0.60	1230
31	CSD	1580	0.2	412

32	NCLS	1790	0.23	467
33	Iqra Apartments	1516	0.20	395
34	Gym	1545	0.20	403
35	PMO	280	0.04	73
36	IEAC	2024	0.30	528
37	CIPS	8565	1.20	2236
38	NUST Press	3854	0.60	1006
39	Bhittai Blocks	1045	0.14	206
Total		94423	15	25,205

Total installation capacity and energy output are not the numeric sum of all individual values. Rather, these results are obtained from multiple software simulations and are subjected to show some variations from one software to another.

Figure 13: Monthly power generation in kWh

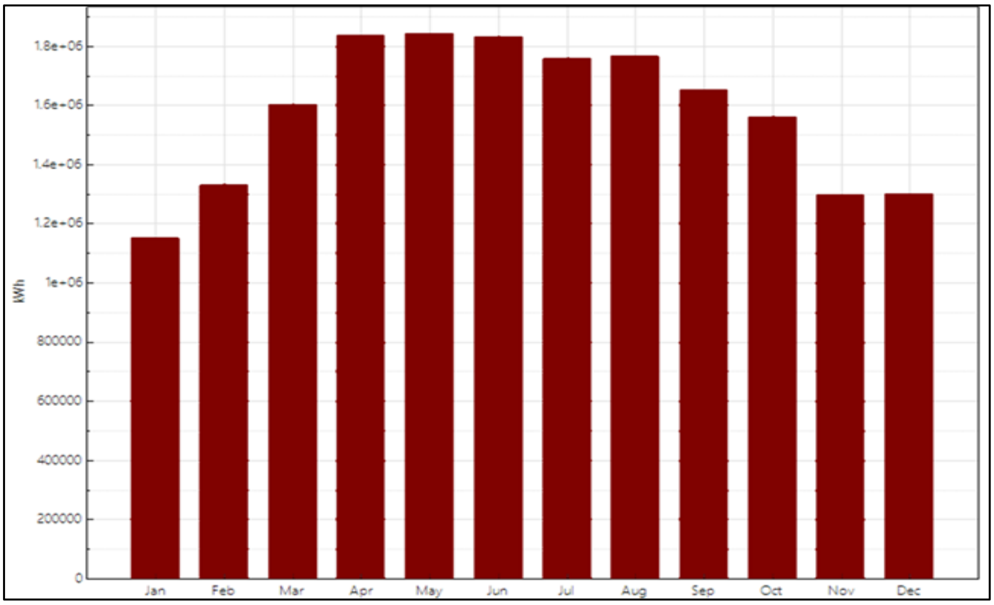
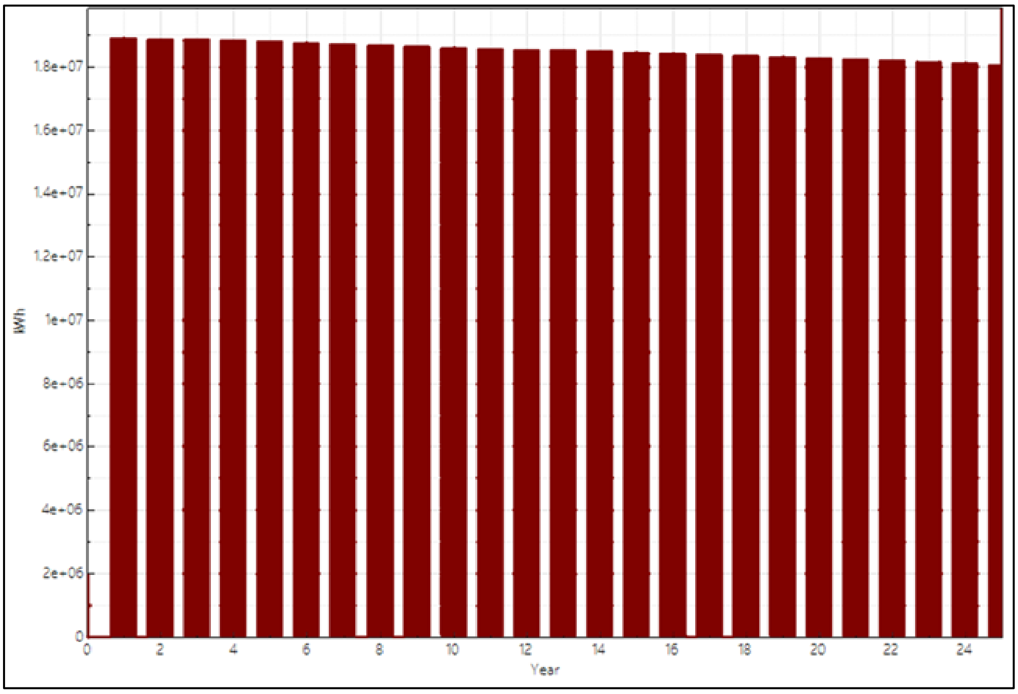


Figure 14: Annual electricity production for 25 years



Chapter 9

9 Environmental Assessment

9.1 Current GHG emission scenario of Pakistan

Currently almost every developing country is facing a major threat of environmental degradation. Mostly the side effects of any kind of action or activity are ignored and we face major consequences that do not get enough recognition. An ARDL study was conducted and its results showed us that any economic activity leads to an increase in the CO2 emissions in Pakistan. It is highly advisable to promote and encourage the use of renewable energy which can meet the growing energy demand. These practices can consequently reduce the CO2 emissions and provide economic growth in the long run.

367 tonnes of CO2 equivalent were reported to be produced as a result of GHG emissions in 2012. Different sectors like the energy sector and the agriculture sector were at 89% of the GHG annual production capacity. Other processes and activities like industrial waste, land use and forestry all contribute to 11% GHG emissions. Between 1994 and 2012, a comparison was made and it was observed that a rise of 4.1% has been observed and was expected to keep rising in order to meet the national development goals even if the per capita exports remain low when compared to the global average (Khan, Khan and Rehan, 2020).

It can also be seen that the total fuel consumption in 2012 was 47.96 Mtoe and this does not include the 14.19 Mtoe that were consumed by the electricity sector, the 13.26 Mtoe by the manufacturing sector and the 10.06 Mtoe by the transport sector (Mir, Purohit and Mehmood, 2017).

9.2 GHG Emission Analysis through RETScreen

The GHG emission analysis was conducted using RETScreen software. The software uptakes values of the current electricity consumption in kWh and uses that as its base case value. Under the energy section of the software, the power method is selected as PV technology and the details of the PV technology are entered. Through the software, we were able to pick our PV panels of choice and enter them into the database along with the planned power generation of 15MW. A capacity factor of 19% was also entered into the system when selecting the PV technology. Once the PV system was established, a GHG emission analysis was conducted by the software. In order to carry out this analysis, the software required entry of transmission and distribution losses. Transmission and distribution losses in Pakistan amount to 8.86% for the IESCO division (*Performance Evaluation Report*, 2018).

Once the details were entered into the system the software also picked up on a GHG emission factor of 0.409 tonnes of CO_2 reduced per MWh of electricity generated. The gross annual GHG emission reduction was calculated as 10,308.5 tonnes. This value is equivalent to 1888 cars and trucks not used, 4,428,106 tonnes liters of gasoline not consumed, 2342 acres of forest absorbing carbon, 3554 tonnes of waste recycled, 23,967 barrels of crude oil not consumed.

Chapter 10

10 Economic and financial analysis

10.1 Direct Capital Costs

The values were all taken from manufacturer data sheets and through local meetings with manufacturers. The total estimated cost is equal to USD $9,085,819 where 41,440 units of solar panel modules are used and 50 inverter units are employed. This means that each module is worth 0.1$/Wdc and the inverter cost is 0.3$/Wdc. Balance of system equipment, installation labor, and installer marginal overhead values are 0.10, 0.06 and 0.04$/Wdc respectively. Contingency is kept as 0.05% of the entire subtotal.

10.2 Indirect Capital Costs

Permitting and environmental studies, engineering and developer overhead are 0.03 and 0.07 each respectively. The total indirect capital costs come up to be $1,513,546.

10.3 Total Installed Costs

The total installed costs come up to $10,599,365 and the total installed cost per capacity is equal to 0.7$/Wdc. The operation and maintenance costs are kept fixed at $10,000 per year. The analysis period is kept as 25 years with the inflation rate as 10% per year and the real discount rate as 7% per year.

10.4 Net Metering

Net metering is a method of charging the electricity which permits users who make the electricity for their full or partial consumption at any given time. Net metering regulations can differ greatly from a country to its states or provinces. Many net metering rules include the monthly transfer of kWh credits, a nominal monthly connection fee, and require a monthly payment.

Net metering permits and encourages its users to generate their own electricity at any given time of a day and that energy can be utilized during night. Besides that it gives us the perks to roll over the excessive energy to use in upcoming months. And this energy can also be utilized in winter when the daily sunshine hours decrease.

Similarly the research in this domain also supports the incorporation of net metering to the grid system. The concept of net metering has been supported in the IEEE 15th International Conference on Environment and Electrical Engineering (EEEIC) (Sajjad *et al.*, 2015).

Keeping all the pros and cons in mind, we have decided to include net metering in our solarization system. We carefully studied the net metering guidelines from NEPRA and aligned them with our project and its finances. Currently, the solar feed in tariff for the northern region of Pakistan is 0.1394 USD/kWh. Applying net metering made our payback time smaller and it came to be around 11 years. Total expected generation of electricity is around 20,139 MWh annually out of which 11,950 MWh will be consumed to meet the NUST electricity demands and the excess energy of 8,189 MWh will be transmitted to the national grid through net metering.

10.5 Economic factors

Using all the information collected and entered into the system, an economic review was conducted of the solarization of NUST H-12 campus. The following inputs, as mentioned earlier in this chapter, have been considered:

10.5.1 Global data:

Assessment period: 20 years

First year of assessment: 2022

10.5.2 Specific financial parameters:

Discount rate: 7%/year

Inflation rate: 10%/year

10.5.3 Levelized cost of electricity (LCOE)

The levelized cost of electricity was obtained from the formula below:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

Where LCOE is the levelized cost of electricity in $/kWh. The formula was used by the software itself to give us the LCOE value of 3.81 cents/kWh. The LCOE takes into account the investment over the lifetime while keeping the discount rate in check. The LCOE is quite low when compared to other solar project installations. A solar power plant usually has an LCOE value of 8.3 cents/kWh. Since our value is way below the stated value, it means that the investment can be considered as good. (Hussein *et al.,* 2016)

10.5.4 Net present value (NPV)

Net present value of a system shows the profitability of the investment. It tells us about how feasible the project will be in the long run. A positive value is an indication that the performance of the system is good and that the project can be considered as economically feasible whereas a negative value is an indication that the project should not be continued. The net present value of this project comes out to be a highly positive value of $516,785, which indicates that the project can be continued further and the investment is encouraged (Abdelhady, 2021).

10.5.5 Payback period

Payback period tells us the time needed to reach a break-even or to cover the initial investment costs and begin to receive a profit on the invested costs. The simple payback period of our investment is expected to be 11.1 years. Meaning that out of the total project lifetime of 2 years, we are expected to start receiving profit after half of the stated lifetime.

Chapter 11

11 Conclusion and recommendations

11.1 Technical and financial feasibility of the system:

From the simulations we have analysed that the 15MW system can easily be installed on NUST rooftops and parking areas that are available. The system catered to the losses and simulated an energy output of 25,205,292 kWh per year. The demand for NUST is 11,959,000 kWh which means that excess energy is produced by the system that is set up. This excess energy produced is supplied to the grid and when a feed-in tariff rate is applied, the excess energy can produce income for NUST and prove to be extremely beneficial and feasible in the long run.

Table 10 shows a financial summary of all the calculations done by the software. From this we have analyzed that the system is feasible however the expected payback period is a little high. With low values of LCOE and a positive value for NPV, it can be deduced that the system would perform well in NUST and give it a good return on investment in the long term.

Table 10: Financial summary of the analysis using SAM

Parameter	Value	Unit
LCOE	3.81	Cents/kWh
Electricity bill without system for 1 year	1.5 million	USD
NPV	$516,785	USD
Simple payback period	11.1	Years
Net capital costs	10,599,365	USD

Cash flows are generated in an excel sheet and can be seen to have reduced cash flows over time. The cash flows are used for payback values calculations. A discounted payback period is calculated with the values. Project cash flows can be seen to reduce over the lifetime of the PV plant. Cash flows in the first year are negative due to the high initial cost of investment.

11.2 Environmental Benefits

Pakistan is not just suffering from an energy crisis but also an environmental one. NUST aims to make all of its campuses carbon neutral and in order to do that, NUST has already implemented a 1 MW of installation on the H-12 campus. Our project proposes an additional 15 MW installation that can favor NUST's clean energy goal and provide benefit to not just the campus but also Pakistan in the long run. Not only is the installation of solar panels an adoption of green technology practices, it also helps minimize and mitigate the impacts of CO2 emissions that contribute to climate change problems.

From the conducted analysis we have found that 10,305.8 tonnes of CO2 emissions can be prevented through these installations. This equates to a total of 1888 cars and trucks not used, 4,428,106 tonnes litres of gasoline not consumed, 2342 acres of forest absorbing carbon, 3554 tonnes of waste recycled, 23,967 barrels of crude oil not consumed.

11.3 Critical analysis and recommendations

General recommendations for the analysis of this project are as follows. These recommendations can help conduct a stronger analysis and cater to any minor disparities.

1. High initial costs of investment are needed for this project - Strong convincing power will be required and the need for NUST to focus on the consumer value and environmental benefits.
2. Lack of some specific data availability from NUST - Building-wise data of specific energy usage limited software like RETScreen
3. A completely on-grid system has been proposed from our side - A battery based system can be incorporated into the analysis in the future.
4. Fluctuations have to be catered to in the technical analysis - A capacity bank can be included and accounted for in the financial section.
5. Fixed mode system was seen to be non-financially feasible. NUST should focus on a tracking based system which is shown to give a better financial return and output.
6. Software like PVSyst were expensive and were used in a trial mode which limited the available time for the analysis.

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Appendix 1

Screenshots of simulations

Figure 16: Simulations for every department on PVSyst

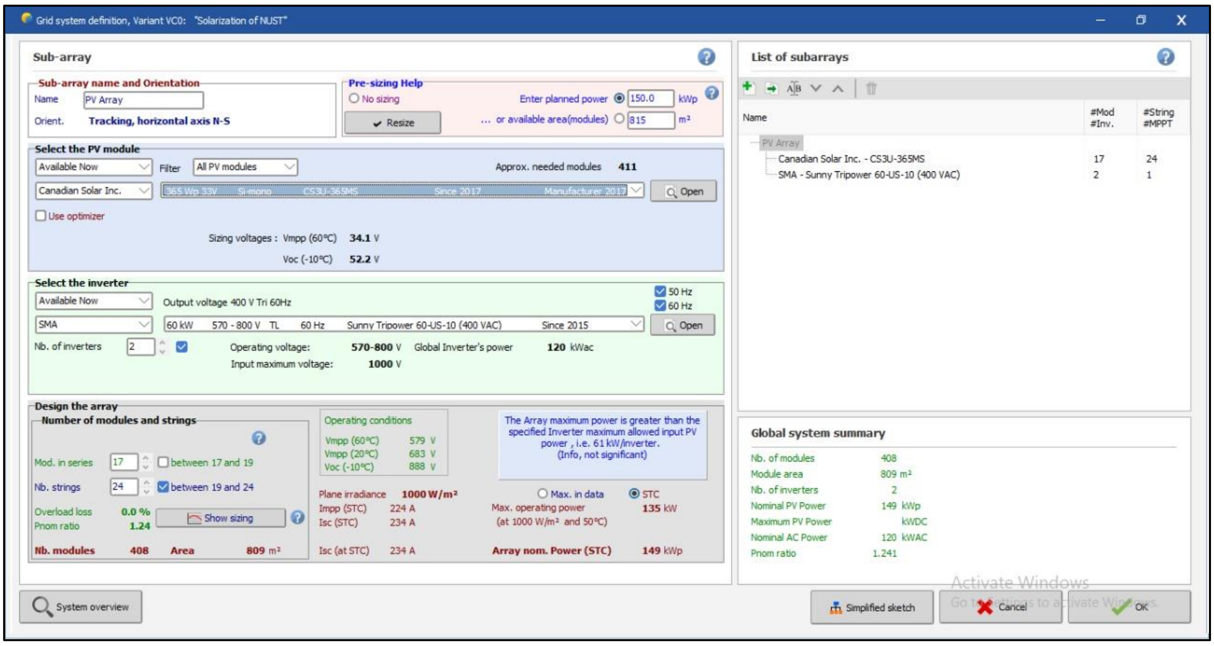


Figure 15: Losses entered into PVSyst

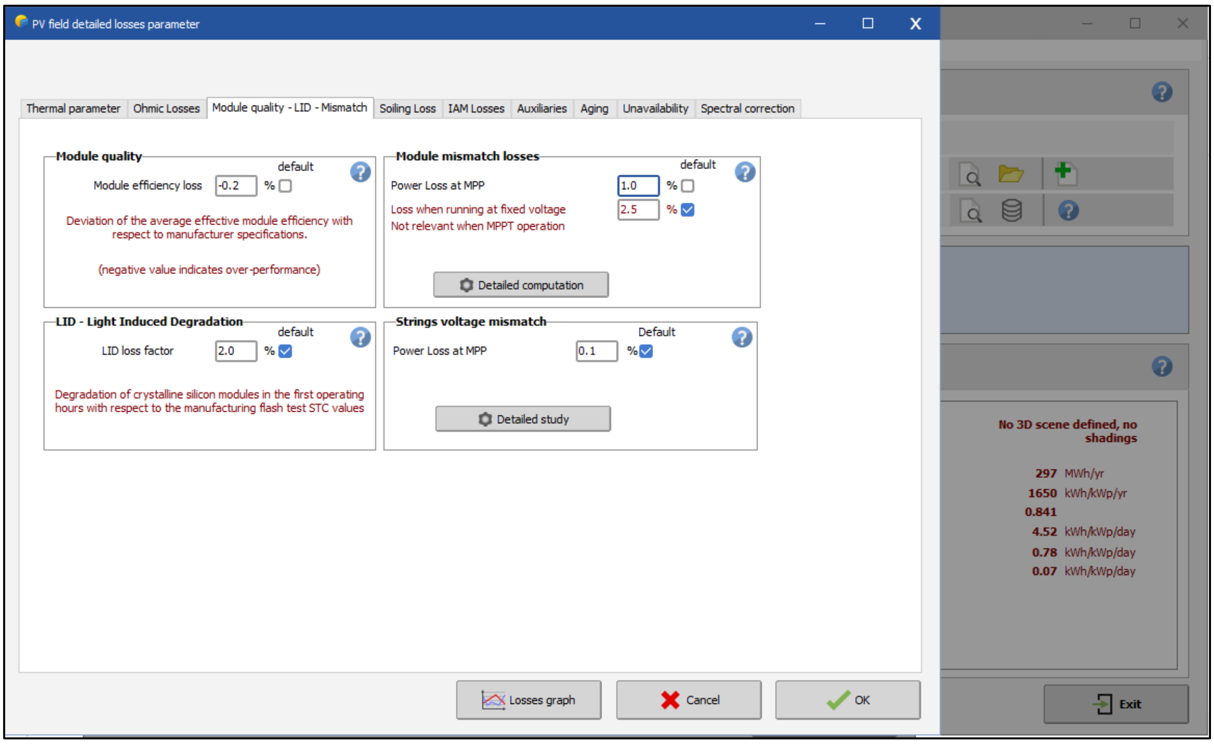
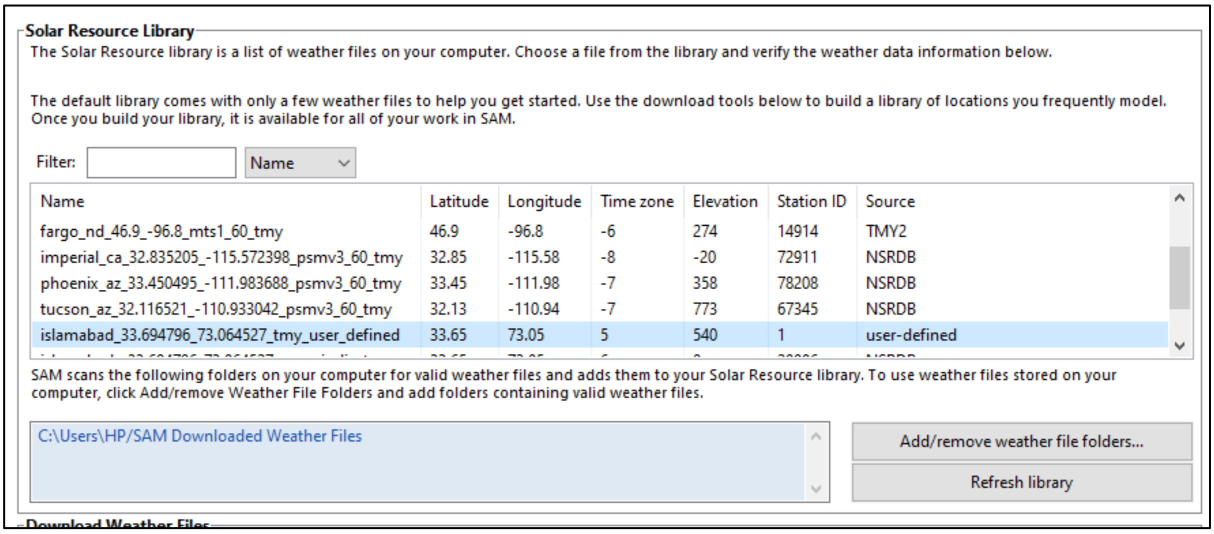


Figure 19: Source resource library on SAM



Solar Resource Library

The Solar Resource library is a list of weather files on your computer. Choose a file from the library and verify the weather data information below.

The default library comes with only a few weather files to help you get started. Use the download tools below to build a library of locations you frequently model. Once you build your library, it is available for all of your work in SAM.

Filter: Name

Name	Latitude	Longitude	Time zone	Elevation	Station ID	Source
fargo_nd_46.9_-96.8_mts1_60_tmy	46.9	-96.8	-6	274	14914	TMY2
imperial_ca_32.835205_-115.572398_psmv3_60_tmy	32.85	-115.58	-8	-20	72911	NSRDB
phoenix_az_33.450495_-111.983688_psmv3_60_tmy	33.45	-111.98	-7	358	78208	NSRDB
tucson_az_32.116521_-110.933042_psmv3_60_tmy	32.13	-110.94	-7	773	67345	NSRDB
islamabad_33.694796_73.064527_tmy_user_defined	33.65	73.05	5	540	1	user-defined

SAM scans the following folders on your computer for valid weather files and adds them to your Solar Resource library. To use weather files stored on your computer, click Add/remove Weather File Folders and add folders containing valid weather files.

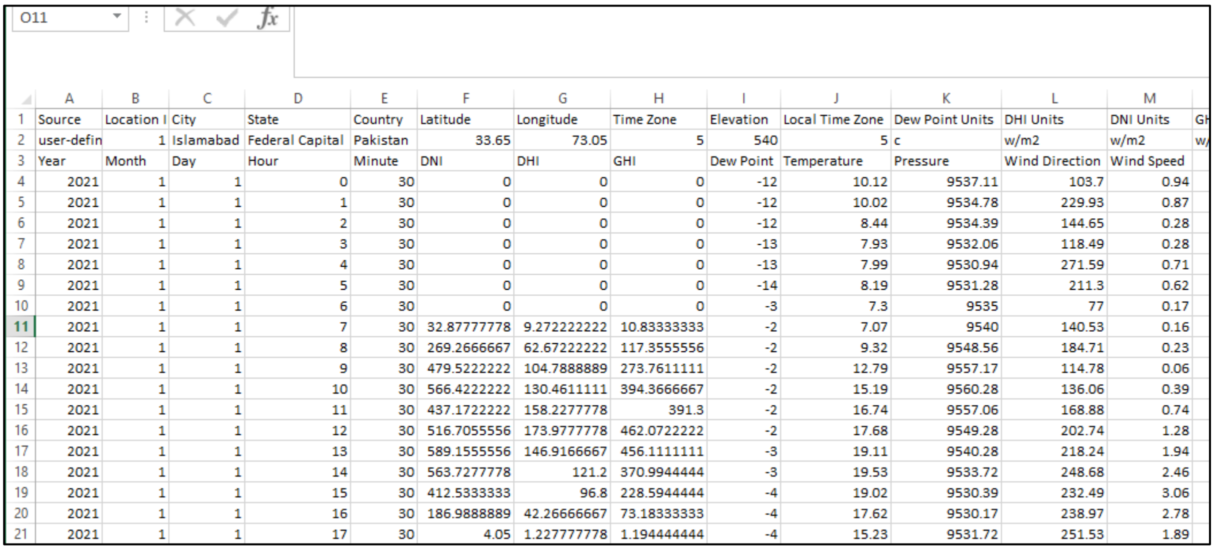
C:\Users\HP/SAM Downloaded Weather Files

Add/remove weather file folders...

Refresh library

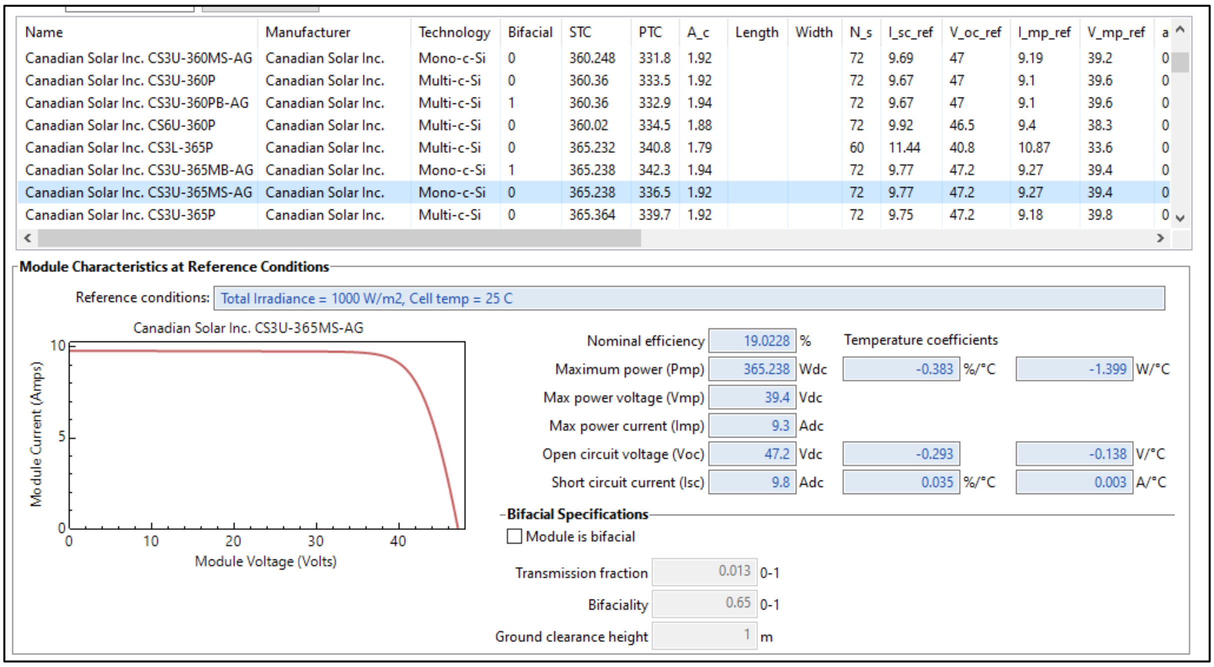
Download Weather Files

Figure 18: TMY file generated for NUST



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Source	Location I	City	State	Country	Latitude	Longitude	Time Zone	Elevation	Local Time Zone	Dew Point Units	DHI Units	DNI Units
2	user-defin	1	Islamabad	Federal Capital	Pakistan	33.65	73.05	5	540	5	c	w/m2	w/m2
3	Year	Month	Day	Hour	Minute	DNI	DHI	GHI	Dew Point	Temperature	Pressure	Wind Direction	Wind Speed
4	2021	1	1	0	30	0	0	0	-12	10.12	9537.11	103.7	0.94
5	2021	1	1	1	30	0	0	0	-12	10.02	9534.78	229.93	0.87
6	2021	1	1	2	30	0	0	0	-12	8.44	9534.39	144.65	0.28
7	2021	1	1	3	30	0	0	0	-13	7.93	9532.06	118.49	0.28
8	2021	1	1	4	30	0	0	0	-13	7.99	9530.94	271.59	0.71
9	2021	1	1	5	30	0	0	0	-14	8.19	9531.28	211.3	0.62
10	2021	1	1	6	30	0	0	0	-3	7.3	9535	77	0.17
11	2021	1	1	7	30	32.87777778	9.272222222	10.83333333	-2	7.07	9540	140.53	0.16
12	2021	1	1	8	30	269.2666667	62.67222222	117.3555556	-2	9.32	9548.56	184.71	0.23
13	2021	1	1	9	30	479.5222222	104.7888889	273.7611111	-2	12.79	9557.17	114.78	0.06
14	2021	1	1	10	30	566.4222222	130.4611111	394.3666667	-2	15.19	9560.28	136.06	0.39
15	2021	1	1	11	30	437.1722222	158.2277778	391.3	-2	16.74	9557.06	168.88	0.74
16	2021	1	1	12	30	516.7055556	173.9777778	462.0722222	-2	17.68	9549.28	202.74	1.28
17	2021	1	1	13	30	589.1555556	146.9166667	456.1111111	-3	19.11	9540.28	218.24	1.94
18	2021	1	1	14	30	563.7277778	121.2	370.9944444	-3	19.53	9533.72	248.68	2.46
19	2021	1	1	15	30	412.5333333	96.8	228.5944444	-4	19.02	9530.39	232.49	3.06
20	2021	1	1	16	30	186.9888889	42.26666667	73.18333333	-4	17.62	9530.17	238.97	2.78
21	2021	1	1	17	30	4.05	1.227777778	1.194444444	-4	15.23	9531.72	251.53	1.89

Figure 17: PV module selected



Name	Manufacturer	Technology	Bifacial	STC	PTC	A_c	Length	Width	N_s	I_sc_ref	V_oc_ref	I_mp_ref	V_mp_ref	a
Canadian Solar Inc. CS3U-360MS-AG	Canadian Solar Inc.	Mono-c-Si	0	360.248	331.8	1.92			72	9.69	47	9.19	39.2	0
Canadian Solar Inc. CS3U-360P	Canadian Solar Inc.	Multi-c-Si	0	360.36	333.5	1.92			72	9.67	47	9.1	39.6	0
Canadian Solar Inc. CS3U-360PB-AG	Canadian Solar Inc.	Multi-c-Si	1	360.36	332.9	1.94			72	9.67	47	9.1	39.6	0
Canadian Solar Inc. CS6U-360P	Canadian Solar Inc.	Multi-c-Si	0	360.02	334.5	1.88			72	9.92	46.5	9.4	38.3	0
Canadian Solar Inc. CS3L-365P	Canadian Solar Inc.	Multi-c-Si	0	365.232	340.8	1.79			60	11.44	40.8	10.87	33.6	0
Canadian Solar Inc. CS3U-365MB-AG	Canadian Solar Inc.	Mono-c-Si	1	365.238	342.3	1.94			72	9.77	47.2	9.27	39.4	0
Canadian Solar Inc. CS3U-365MS-AG	Canadian Solar Inc.	Mono-c-Si	0	365.238	336.5	1.92			72	9.77	47.2	9.27	39.4	0
Canadian Solar Inc. CS3U-365P	Canadian Solar Inc.	Multi-c-Si	0	365.364	339.7	1.92			72	9.75	47.2	9.18	39.8	0

Figure 21: DC Sizing and Configuration

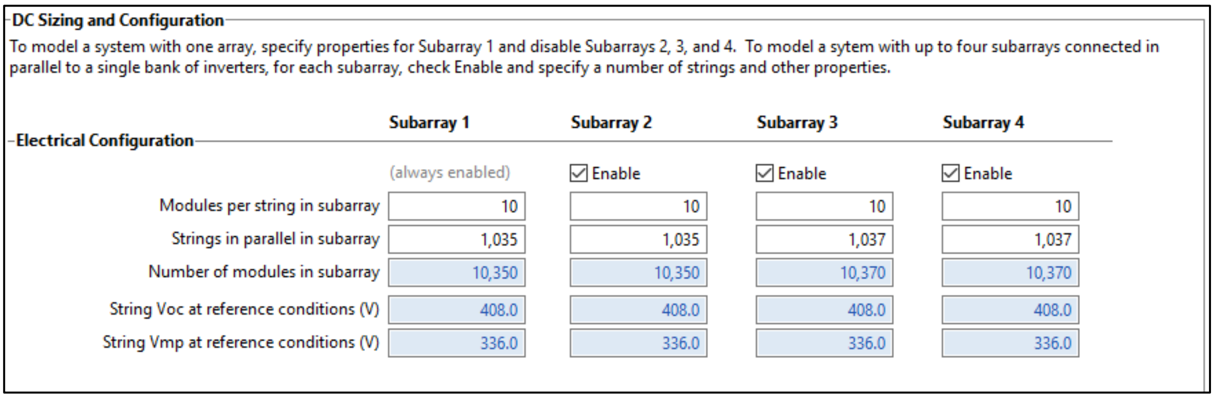


Figure 20: Direct capital costs

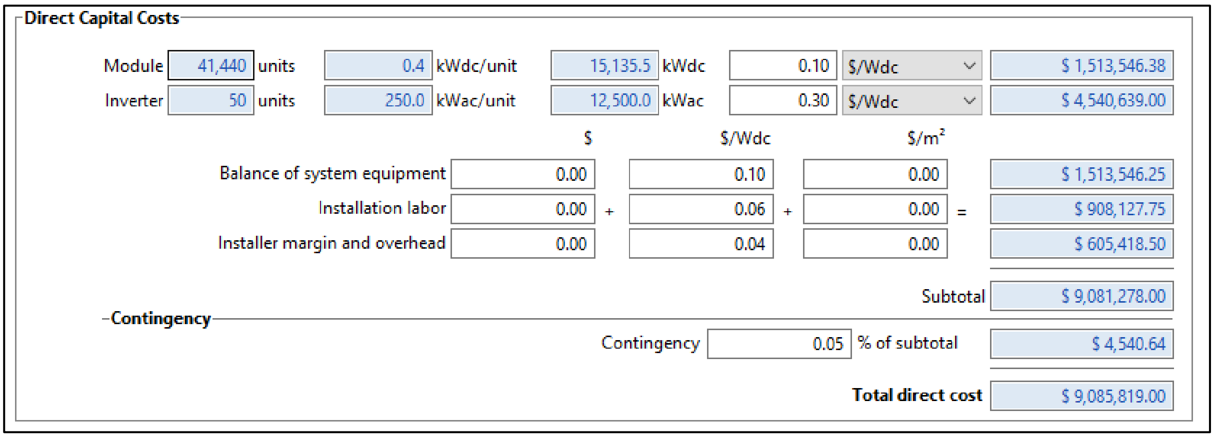


Figure 22: Indirect capital costs

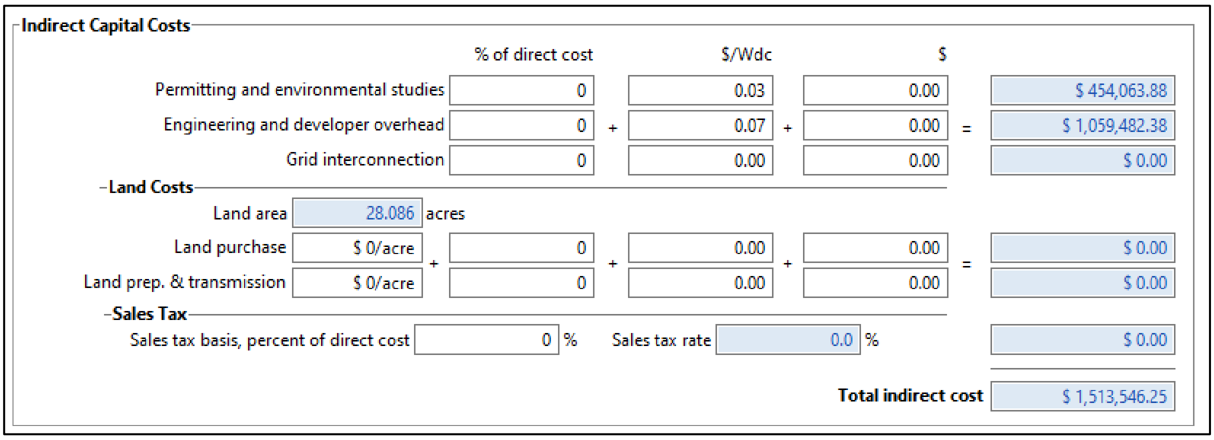


Figure 24: Total installed cost

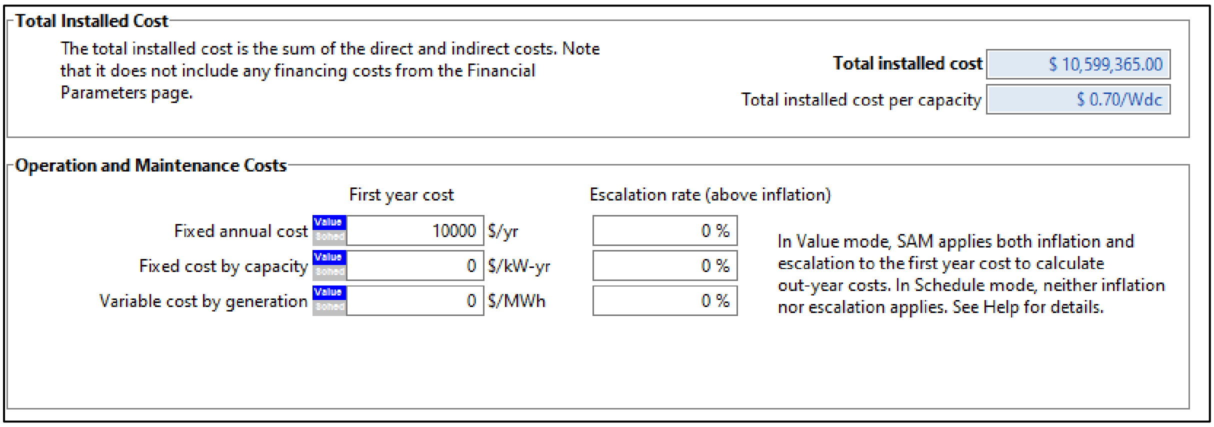
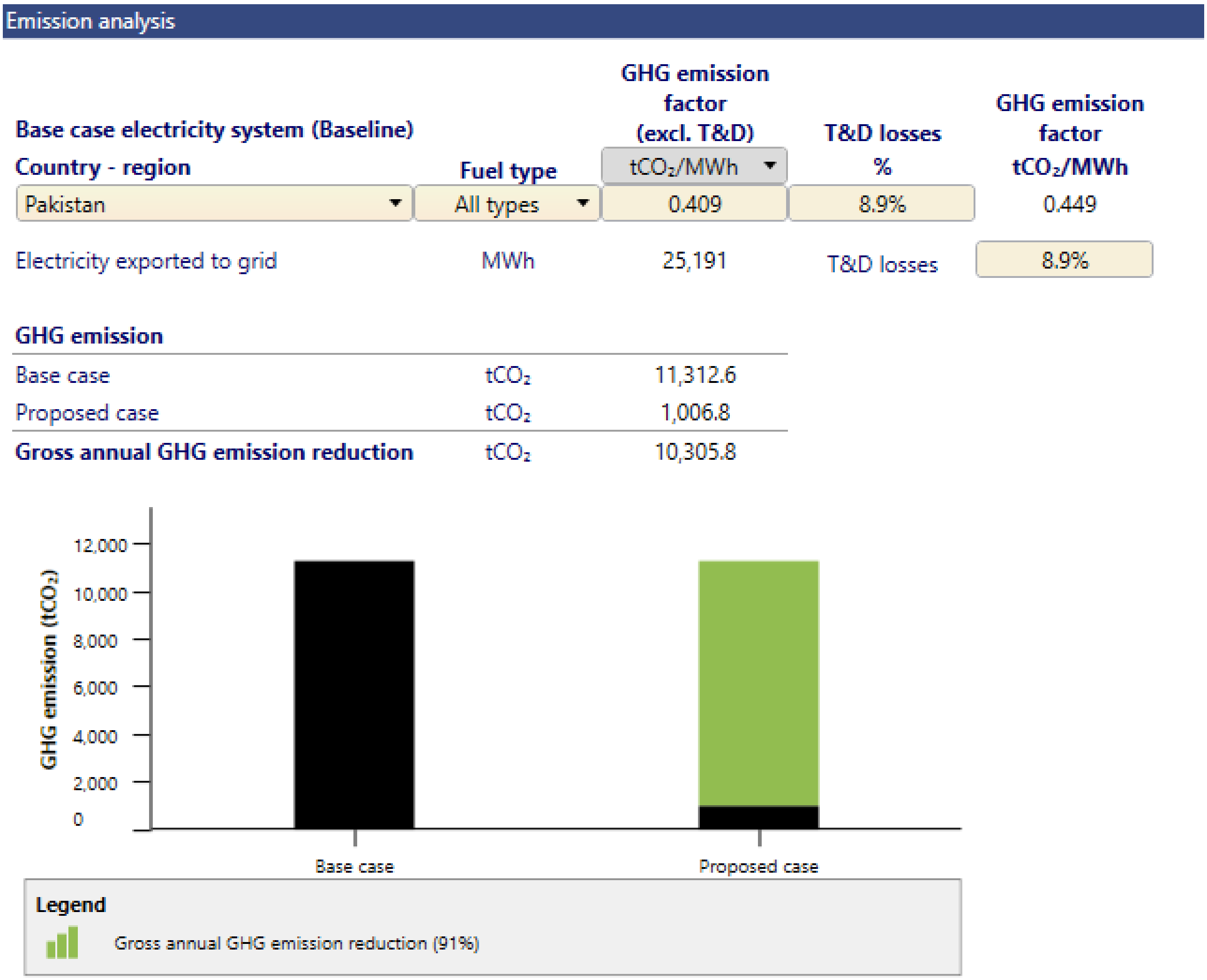


Figure 23: GHG Emission analysis



Appendix 2

Data tables and drawings

Table 11: Monthly irradiation values (W/m^2) vs temperature (˚C)

Month	Irradiation (W/m²)	Temperature (°C)
1	106.04	10.26
2	149.12	14.04
3	179.10	20.97
4	248.88	24.09
5	277.15	28.80
6	283.58	38.52
7	236.68	28.99
8	233.19	28.06
9	218.03	27.33
10	172.12	22.56
11	126.42	16.43
12	113.80	12.42

Table 12: Seasonal variation in irradiation (W/m^2) and temperature (˚C)

Season	Irradiation (W/m²)	Temperature (˚C)
Winter	122.99	12.24
Pre-Monsoon	235.04	24.62
Monsoon	242.87	30.72
Post-Monsoon	149.27	19.49

Table 13: Hourly variation in irradiance (W/m^2)

Time	GHI (W/m2)
12:00 AM	0.004103123
1:00 AM	0.006463326
2:00 AM	0.005228758
3:00 AM	0.004956427
4:00 AM	0.002904866
5:00 AM	2.900382462
6:00 AM	34.97725781
7:00 AM	129.6254741
8:00 AM	276.2661814
9:00 AM	423.8343495
10:00 AM	540.8192861
11:00 AM	613.3893802
12:00 PM	626.9859256
1:00 PM	601.0979899
2:00 PM	517.2033471
3:00 PM	381.5905699
4:00 PM	226.6463177
5:00 PM	90.59659114
6:00 PM	19.82533744
7:00 PM	0.795926725
8:00 PM	0.006503486
9:00 PM	0.004502542
10:00 PM	0.008769063
11:00 PM	0.006190995

Figure 25: Simulations run for every department on PVSyst

	Building	Type	Rooftop Area (Sqm)	Parkings	Total	Active Area	Panel Area	Total Panels	Watts per panel	IC (Watts)	IC (kW)	Invertor (KW)	No of invertors	Invertor	Series	Strings	IC (MW)
1	IESE	Academic	2320	305	2625	2362.5	2	1181.25	365	431156.25	431.15625	100	4	400	19	62	0.43115625
2	SCME		1065	500	1565	1408.5	2	704.25	365	257051.25	257.05125	100	2	200	19	37	0.25705125
3	SCME 2		625	920	1545	1390.5	2	695.25	365	253766.25	253.76625	100	2	200	18	39	0.25376625
4	ASAB		2600	1870	4470	4023	2	2011.5	365	734197.5	734.1975	100	6	600	19	106	0.7341975
5	NBS		6200	4000	10200	9180	2	4590	365	1675350	1675.35	800	2	1600	17	270	1.67535
6	S3H		1590	0	1590	1431	2	715.5	365	261157.5	261.1575	100	2	200	18	40	0.2611575
7	SADA		2538	2960	5498	4948.2	2	2474.1	365	903046.5	903.0465	150	5	750	26	95	0.9030465
8	IGIS		1000	590	1590	1431	2	715.5	365	261157.5	261.1575	100	2	200	18	40	0.2611575
9	RIMMS		500	2000	2500	2250	2	1125	365	410625	410.625	100	4	400	18	62	0.410625
10	SMME		2730	550	3280	2952	2	1476	365	538740	538.74	100	5	500	18	82	0.53874
11	SNS 2		585	4450	5035	4531.5	2	2265.75	365	826998.75	826.99875	150	5	750	28	81	0.82699875
12	Workshop		1330	1700	3030	2727	2	1363.5	365	497677.5	497.6775	150	3	450	28	49	0.4976775
13	Attar 1	Hostels	741	320	1061	954.9	2	477.45	365	174269.25	174.26925	150	1	150	28	17	0.17426925
14	Attar 2		741	320	1061	954.9	2	477.45	365	174269.25	174.26925	150	1	150	28	17	0.17426925
15	Ghazali 1		0	320	320	288	2	144	365	52560	52.56	17	4	68	18	8	0.05256
16	Ghazali 2		0	320	320	288	2	144	365	52560	52.56	17	4	68	18	8	0.05256
17	Hijveri		1250	260	1510	1359	2	679.5	365	248017.5	248.0175	100	2	200	18	38	0.2480175
18	Zakria		1250	0	1250	1125	2	562.5	365	205312.5	205.3125	100	2	200	18	31	0.2053125
19	Rumi 1		741	320	1061	954.9	2	477.45	365	174269.25	174.26925	75	2	150	17	28	0.17426925
20	Rumi 2		741	320	1061	954.9	2	477.45	365	174269.25	174.26925	75	2	150	17	28	0.17426925
21	Rumi 3		741	320	1061	954.9	2	477.45	365	174269.25	174.26925	75	2	150	17	28	0.17426925
22	Fatima 1		741	320	1061	954.9	2	477.45	365	174269.25	174.26925	75	2	150	17	28	0.17426925
23	Fatima 2		741	320	1061	954.9	2	477.45	365	174269.25	174.26925	75	2	150	17	28	0.17426925
24	Khadija		741	320	1061	954.9	2	477.45	365	174269.25	174.26925	75	2	150	17	28	0.17426925
25	Ayesha		741	320	1061	954.9	2	477.45	365	174269.25	174.26925	75	2	150	17	28	0.17426925
26	Zainab		741	320	1061	954.9	2	477.45	365	174269.25	174.26925	75	2	150	17	28	0.17426925
27	Amna		741	320	1061	954.9	2	477.45	365	174269.25	174.26925	75	2	150	17	28	0.17426925
28	Bhittai 1		360	430	790	711	2	355.5	365	129757.5	129.7575	100	1	100	18	20	0.1297575
29	Bhittai 2		255	0	255	229.5	2	114.75	365	41883.75	41.88375	9	4	36	9	12	0.04188375
30	Maryam Block		760	375	1135	1021.5	2	510.75	365	186423.75	186.42375	75	2	150	17	30	0.18642375

31	CIE		945	0	945	850.5	2	425.25	365	155216.25	155.21625	75	2	150	17	25	0.15521625
32	Exam Hall		1360	0	1360	1224	2	612	365	223380	223.38	100	2	200	18	14	0.22338
33	Design Center		1330	0	1330	1197	2	598.5	365	218452.5	218.4525	100	2	200	19	32	0.2184525
34	N'Ovative		625	0	625	562.5	2	281.25	365	102656.25	102.65625	100	1	100	19	15	0.10265625
35	Bank		240	210	450	405	2	202.5	365	73912.5	73.9125	20	3	60	17	12	0.0739125
36	Admin Block		420	700	1120	1008	2	504	365	183960	183.96	150	1	150	28	18	0.18396
37	NSTP 1		2550	0	2550	2295	2	1147.5	365	418837.5	418.8375	100	4	400	18	64	0.4188375
38	NSTP 2	MISC	1720	2990	4710	4239	2	2119.5	365	773617.5	773.6175	150	4	600	28	76	0.7736175
39	CSD		480	1100	1580	1422	2	711	365	259515	259.515	100	2	200	18	40	0.259515
40	NCLS		1110	680	1790	1611	2	805.5	365	294007.5	294.0075	75	3	225	18	45	0.2940075
41	Iqra apartment		1000	516	1516	1364.4	2	682.2	365	249003	249.003	100	2	200	19	36	0.249003
42	GYM		1265	280	1545	1390.5	2	695.25	365	253766.25	253.76625	100	2	200	18	49	0.25376625
43	PMO		280	0	280	252	2	126	365	45990	45.99	11	4	44	11	11	0.04599
44	IEAC		434	1590	2024	1821.6	2	910.8	365	332442	332.442	150	2	300	26	35	0.332442
45	CIPS		0	6290	6290	5661	2	2830.5	365	1033132.5	1033.1325	150	8	1200	26	148	1.0331325
46	NUST Press		354	3500	3854	3468.6	2	1734.3	365	633019.5	633.0195	150	4	600	28	62	0.6330195
					92148	82933.2	2	41466.6	365	15135309	15135.309			13551			15.135309

Figure 26: Visual of solar installations on SADA by PVSol

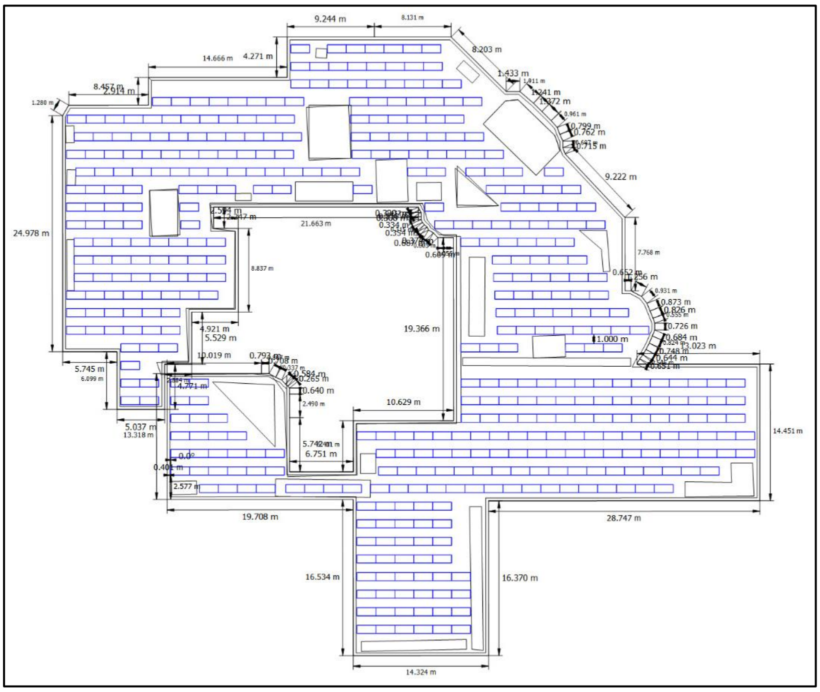


Figure 27: Visual of solar installations on IESE by PVSol