DESIGN STRATEGIES FOR SOLAR CAR PARKS: A CASE STUDY FOR IZTECH LIBRARY PARKING LOT

A Thesis Submitted to the
Graduate School of Engineering and Sciences of
İzmir Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in Photonics Science and Engineering

by
Enes Bursa

July 2022

İZMİR

ACKNOWLEDGEMENT

I would like to thank my esteemed advisor Dr. Emre SARI, who was always friendly to me and from whom I learned a lot, for his help and support throughout designing this project and writing my master's degree study. I would also like to thank Assoc. Prof. Dr. Aziz GENÇ and Assoc. Prof. Dr. Serhat TOZBURUN for their kindness to participate in my thesis defense and for their contribution to the finalization of my thesis with their valuable comments.

I would like to thank my mother, Neriman BURSA, who helped me along the way and whose support I felt constantly, my brother Burak BURSA and my brother's wife Gülcan BURSA for their unwavering support, and my nephew Ali BURSA who was my biggest help in fighting against stress with his cuteness during this process.

I would like to thank my friends with whom I shared my troubles and worries, laughed, and had fun together, and supported me under all circumstances.

ABSTRACT

DESIGN STRATEGIES FOR SOLAR CAR PARKS: A CASE STUDY FOR IZTECH LIBRARY PARKING LOT

The world's need for renewable resources is growing as a result of the global climate crisis. In order to overcome this issue. The Paris Agreement was signed by the nations as a step for solution to this issue. In it, targets for future were set, and the nations pledged to meet these targets. Nowadays investments in energy production from renewable sources are increasing. When compared to 2019, the amount of energy produced from renewable sources grew by 12.5% in 2020. Photovoltaic systems are receiving more investment as a result of their growing efficiency. In 2020, photovoltaic system production climbed by 20.5 percent.

Turkey is increasing their investment in photovoltaic systems. It is crucial for universities to be pioneers in energy production from renewable sources. The studies carried out by universities should be taken into account in terms of both increasing knowledge in this area and having people resource who are trained in it.

In this study, the open parking area of the library building of the Izmir Institute of Technology were covered with a roof in order to simulate and analyze the installation of photovoltaic solar panels on the roof. These simulations and calculations were done using software called Enact Systems. PVWatts is utilized by Enact system for climate and photovoltaic calculations infrastructure. 560 panels have been installed on the 835 m^2 covered parking lot. The installed power of the panels is 224 kW, and they can generate about 302 gWh of electricity annually. This amount is equal to 51% of library consumption. With this production, the amortization period of the investment is calculated as 8 years.

ÖZET

GÜNEŞ ENERJİLİ OTOPARK TASARIM STRATEJİLERİ: İYTE KÜTÜPHANE OTOPARK ALANI İÇİN BİR VAKA ÇALIŞMASI

Dünyanın yaşamış olduğu küresel iklim krizinden dolayı yenilenebilir kaynaklara olan ihtiyaç günden güne artmaktadır. Bu sorunu aşmak için ülkeler birleşmiş Paris Anlaşması diye adlandırılan, ileri tarihlere yönelik hedeflerin belirlendiği anlaşmaya imzacı olup bu hedeflere uyma taahhüdünde bulunmuşlardır. Günümüzde yenilenebilir kaynaklardan enerji üretimine yatırım artmaktadır. 2020 yılında yenilenebilir kaynaktan enerji üretimi bir önceki yıla göre %12.5 oranında artmıştır. Fotovoltaik sistemlerin giderek daha verimli olmasından dolayı aldığı yatırım da giderek artmaktadır. 2020 yılında fotovoltaik sistemlerden yapılan üretim %20.5 artmıştır.

Türkiye de fotovoltaik sistemlere yatırımların arttığı ülkelerden biridir. Güneş enerjisi kapasitesi ve enerji ihtiyacı itibariyle de yatırım yapılmasının elzem olduğu söylenebilir. Üniversiteler yenilenebilir kaynaklardan enerji üretiminde öncü olmaları son derece önemlidir. Üniversitelerin yaptığı çalışmalar hem bu alanda bilinç kazanılması hem de bu alanda yetişmiş insan kaynağı olması açısından ele alınmalıdır.

Bu bağlamda bu çalışmada İzmir Yüksek Teknoloji Enstitüsü'nün kütüphane binasının açık otopark alanlarının üzeri çatı ile kapatılarak, çatı üzerine fotovoltaik güneş paneli yerleştirilmesinin simülasyonu ve analizi yapılmıştır. Bu simülasyon ve hesaplama Enact adlı yazılım kullanılarak yapılmıştır. Enact sistemi iklim ve üretim hesaplama altyapısı olarak PVWatts yazılımını kullanmaktadır.

Üzeri kapatılan otopark alanı 835 m2 olup bu alana 560 adet panel yerleştirilmiştir. Panellerin kurulu gücü 224 kW olup senede yaklaşık 302 gWh elektrik üretim kapasitesine sahiptir. Bu miktar kütüphane tüketiminin %51ine eşittir. Bu üretim ile yatırımın amorti süresi 8 yıl olarak hesaplanmıştır.

Dedicated to the memory of my father, Kadir BURSA, who always loved me...

TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

Figure **Page**

LIST OF TABLES

Table **Page**

ABBREVIATIONS

IEA **:** International Energy Agency

GDP **:** Gross Domestic Product

Mtoe : Million tons of oil equivalent

TFC : Total final consumption

NREL **:** National Renewable Energy Laboratory

NSRDB **:** National Solar Radiation Database

SPR **:** Solar Production Ratio

CHAPTER 1

INTRODUCTION

1.1 Renewable Energy

All the machines that we use, every technological device that we know, and many more systems that we know or not work with energy. Without energy civilization cannot move forward even cannot exist. In the light of this information, it can be said that energy is and indispensable necessity for humanity. If we do not count specific times such as covid pandemic, energy consumption tends to increase by year. This information infers civilization is developing. It really is but there is an unfortunate tradeoff. This tradeoff is hidden in methods of producing energy.

There are lots of ways to obtain energy, but it can be separated in two ways. These are renewable and nonrenewable resources. Most of the energy that used by humanity producing from nonrenewable resources. Countable nonrenewable energy resources are Oil, Natural Gas, Coal, and Nuclear Power. Oil, natural gas and coal counts as fossil fuels and fossil fuels can be said that the locomotive of the energy sector.

As Figure1 shows, about 84% of the primary global energy consumption in 2019 supplied from fossil fuels. [1] Primary energy is the energy that can be directly exploited or imported directly from nature without any energy conversion. Fossil fuels the most important energy sources but as before referred there is a tradeoff. It is easy and cheap, but it releases lots of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) which are named as “greenhouse gases”. They cause greenhouse effect, and it effects as global temperature rising with unnaturally. The problem is getting serious day by day. It evolved as global climate crisis and according to some research the world is at the border of unrecoverable damage. [2] To avoid disaster immediate precautions must take. Greenhouse gas emissions must be drastically reduced. Obtaining energy from fossil fuels is the main reason of this problem, as humanity we must change our primary energy sources.

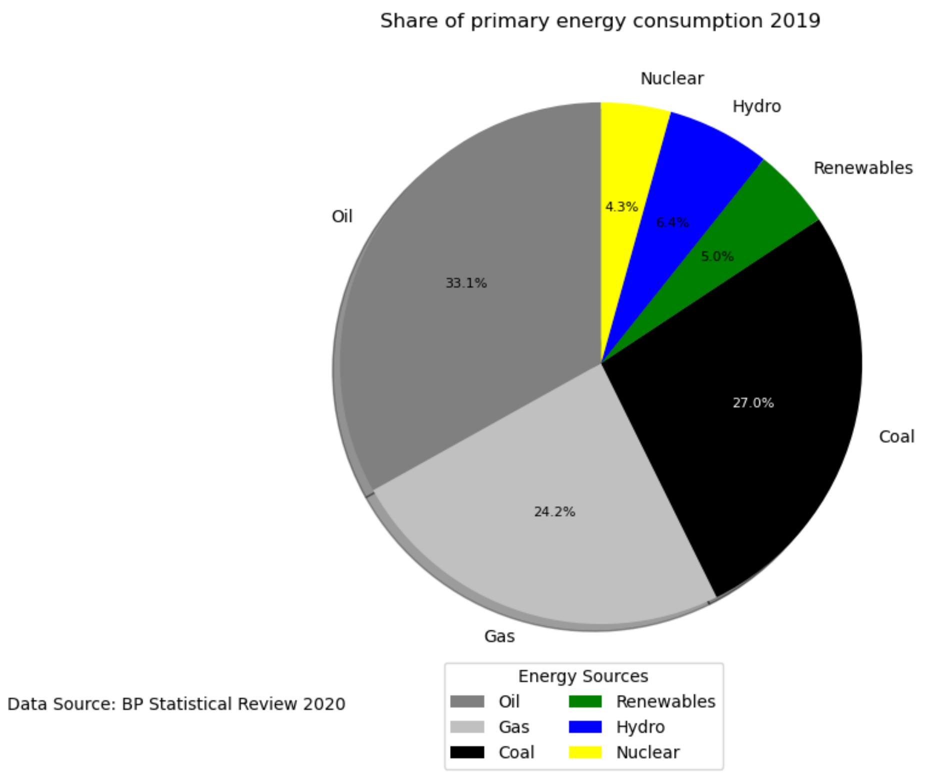

Figure 1: Global primary energy consumption by source

Of course, obtaining energy is not limited with fossil fuels, there are some other ways. Renewable energy sources and nuclear energy are alternatives to the fossil fuels. This transformation has to be done, it is crucial for whole life in this World.

There five major renewable energy sources these are:

- Solar energy
- Wind energy
- Hydropower
- Biomass
- Geothermal energy

According to the International Energy Agency Global Energy Review 2019 report Renewables are around 14% of the total consumed energy is produced from renewable sources. [3] On the other hand, according to the BP Statistical Review of World Energy 2021 report 27.75% of electricity production is from renewable sources. It was 25.98% in 2020 report. [1]

Recently almost every government encouraging the renewable energy sources and most of them are subsidize it. They started to taking responsibility for this and they already determined their roadmap to handle it.

Paris Agreement can count as the most comprehensive and the most serious one. It also referred as Paris Climate Accords. It adopted in 2015 and it includes climate change mitigation, adaptation, and finance subtext. It signed by 193 United Nations member countries. That makes this agreement is global climate change agreement. This agreement's sharp objective is net-zero CO_2 emissions until 2050. [4] Under all of these developments contribution of renewables to energy production is increasing.

According to the International Energy Agency "Renewables 2021 Analysis and forecast to 2026" report they forecast to in the end of 2026 global renewable electricity capacity will exceed up to 60% of 2020 levels. For the sake of comparison this amount is almost equal to the total electricity production from fossil fuels and nuclear energy combined in 2021. In same report 95% of the total increase in global power capacity through 2026 will come from renewables. Half of this increase will be met by photovoltaic energy alone. [5] These predictions are based on strong government support and decisions taken at serious clean energy summits. One of example of these summit is United Nations Climate Change Conference 2021 which also known as COP26. [6]

1.2 Solar Energy

Solar energy has huge potential when compare with energy demand of the world. This situation makes solar energy popular and best option in renewable energy sources. Solar energy source the Sun emits energy at a rate of $3.8*10^{23}$ kW and approximately $1.8*10^{14}$ kW is intercepted by earth. About 60% of this amount reaches to the earth which is about $1.08*10^{14}$ kW. The rest 40% of this energy is reflected to the back and absorbed by the atmosphere. The energy of the Sun, which hits the earth in less than 80 minutes, is as much as the energy used by the whole world throughout the year. [7]

Solar energy is travelling as a light, and it is continuous, not exhaustible. Solar PV efficiency is increasing by year. It also means decreasing price per kWh. The global weighted average levelized cost of electricity PV module prices decreased by 85% since

2010 to 2020 from $0.381/kWh to $0.057/kWh [8]. One of the reasons for this can be shown as the cheapening of PV technology products and the increase in the efficiency of PV modules.

Solar radiation not distributed uniformly on earth. Some countries are luckier than others. It is highly correlated with the latitude. Solar radiation decreases towards the poles and increases towards to the equator. [9] It shown in Figure 2.

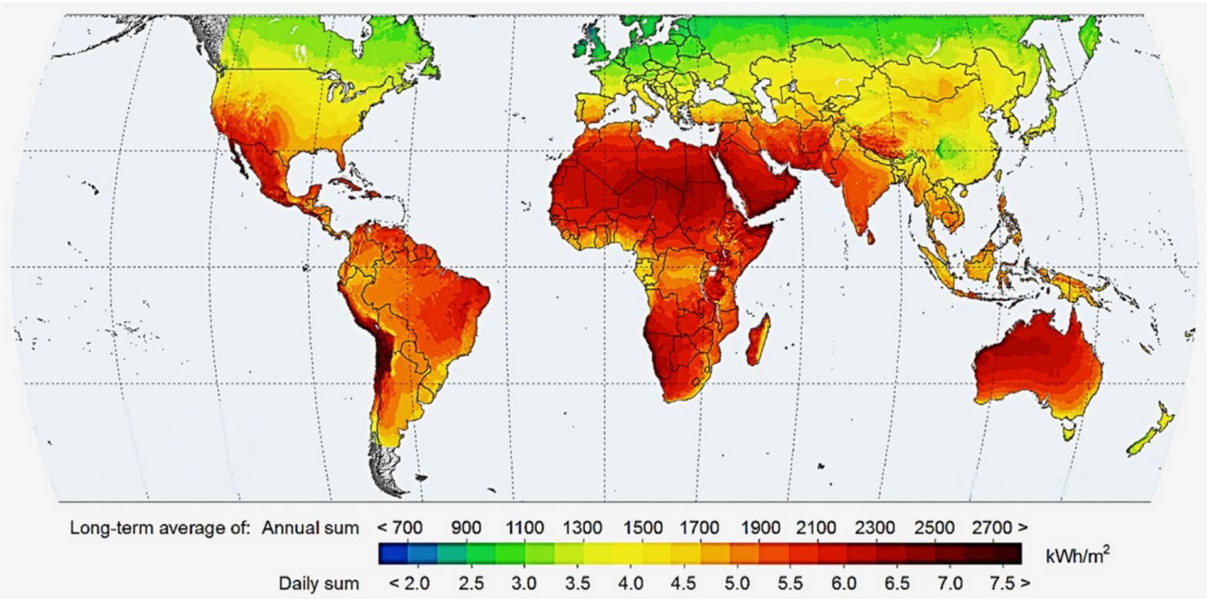

Figure 2: Solar radiation distribution on earth [9]

1.3 Solar Energy in Turkey

Turkey is a Mediterranean country located between 36-42° North parallels and 26-45° East meridians. Turkey is one of the countries that can be considered lucky in terms of solar energy potential. Considering the countries that have less solar energy potential and produce more solar energy than Turkey, it can be predicted that Turkey's efforts and investments in the field of solar energy will increase. [3] More investment in solar energy will reduce energy dependency on foreign countries. To achieve these goals, incentive and subsidy packages for renewable energy have been announced since 1984 [11]. In this context, Turkey's solar energy capacity has increased by 104.4% in the 10-year period between 2009-2019. [1]

1.3.1 Insolation

Turkey's solar energy capacity is considerably good, especially in southern cities. The duration of sunshine in Turkey varying between 1750 hours and 3000 hours per year. [10]

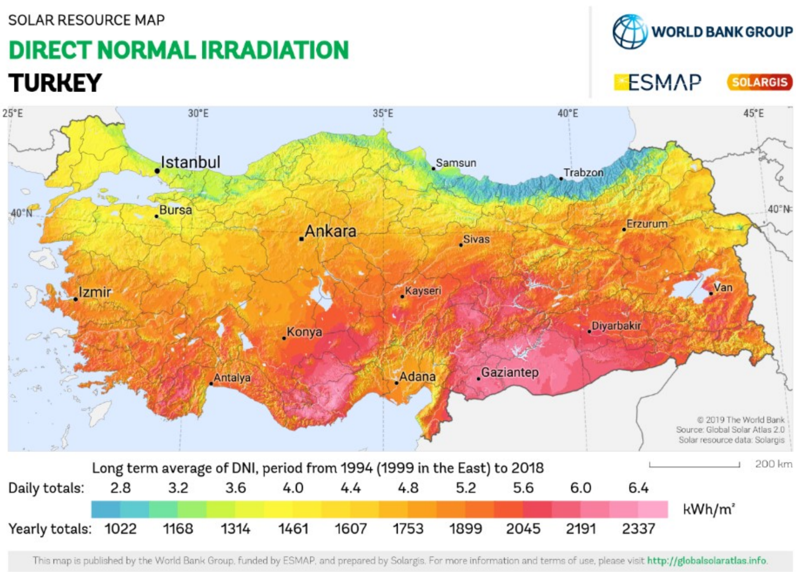

Figure 3 : Turkey's solar power potential map (Source: URL1)

Figure 3 shows the solar power potential map of Turkey. Geographically Mediterranean region and Southeast region have the most potential. According to this map, more than half of Turkey is a reasonable candidate for solar energy investments. Although Germany is located in northern latitudes compared to Turkey, their solar energy capacity has exceeded 50 gigawatts (GW) as of 2020, and they increased their investment by 10% on an annual basis in the same year. [1] From this it can be deduced all area of Turkey is reasonable for solar energy investment.

Figure4 shows average sunshine duration of Turkey per day by years. Overall Turkey average sunshine duration is about 2500 hours per year.

When comparing sunshine duration Turkey's most effective times are summer months. Especially July is the shiniest month according to the Turkish State Meteorological Service Official website data which shown in Figure 5.

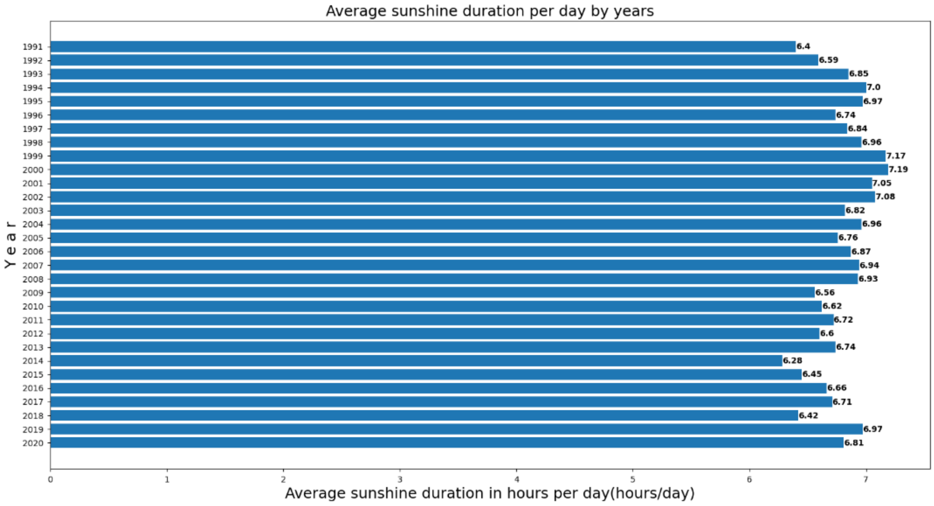

Figure 4: Average sunshine duration of Turkey per day by years (Data Source: URL2)

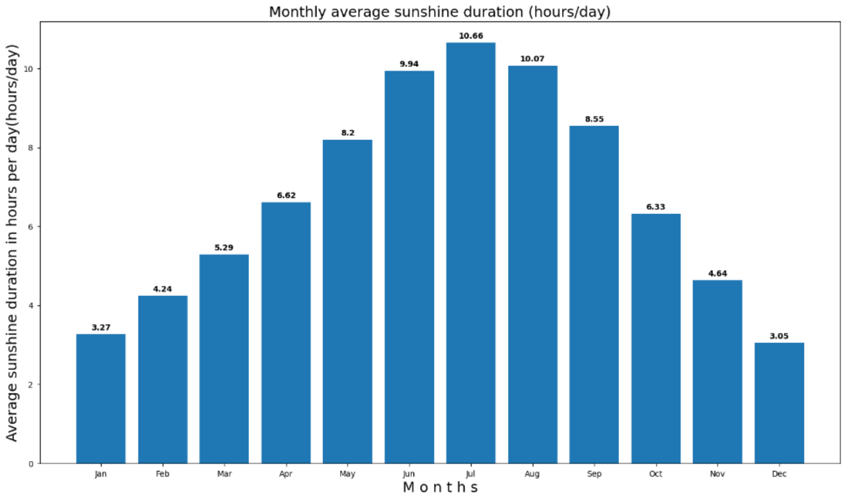

Figure 5: Monthly average sunshine duration of Turkey (Data Source: URL2)

1.3.2 Policies and Laws

In Turkey, energy production and distribution were legally monopolized by the state until 1984. In 1984 a law published (Law No. 3096) and this law is about to the letting the private sector was allowed to build power plants and sell it to the Turkish state. [11] This law was the first step then after many laws and government incentives, renewable energy initiatives in Turkey have increased significantly.

Table 1: Turkish State incentive for PV energy announced by Law No. 7257 [12]

II Sayılı Cetvel (29/12/2010 tarihli ve 6094 sayılı Kanunun hükmüdür.)		
Tesis Tipi	Yurt İçinde Gerçekleşen İmalat	Yerli Katkı Fiyatları (ABD Doları cent/kWh)
C- Fotovoltaik güneş enerjisine dayalı üretim tesisi	1- PV panel entegrasyonu ve güneş yapısal mekaniği imalatı	0,8
	2- PV modülleri	1,3
	3- PV modülünü oluşturan hücreler	3,5
	4- İnvertör	0,6
	5- PV modülü üzerine güneş ışınını odaklayan malzeme	0,5

The photovoltaic energy support program established in the Official Gazette of Turkey on 2 December 2020 shown in Table 1. [12] For the investment up to one megawatt installed power, the service fee from government offices is not charged. [13] Such incentives, tax reductions, fee cuts are specified in the same law. [13] Under YEKDEM (Renewable Energy Support Mechanism) Turkey applying feed-in tariffs for renewable power plants. The feed-in tariffs are currently $0.133 per kWh.

1.4 Usage of Solar Power and Solar Energy Economics

There are two types of solar energy according to its usage:

1. Passive Solar Energy
2. Active Solar Energy

Passive solar energy can be described as the taking advantage of solar energy without using any mechanical devices. Using windows in homes to get natural lighting and heat can count as an example of passive solar energy.

Active solar energy is the process of transforming solar energy into useful energy through mechanical equipment, as well as the collection, storage, and distribution of energy for future use. Active solar energy can be examined under three different headings. These are:

- Concentrating Solar Power
- Solar Thermal Energy
- Photovoltaic Solar Power

Concentrating solar power is used to generate electricity. It is often used for large scale energy production. This system works as through mirrors spread over a vast area, these mirrors focus the sunlight to a specific point and converts the solar light energy into heat energy. That heat energy is boiling the water and turning the tribune with the motion of its steam through a conventional generator. These are the process of generating electricity by concentrating sunlight with mirrors. (Figure 6)

Solar thermal energy is a type of energy that uses solar radiation to generate thermal energy for use in industry, as well as in residential and commercial buildings. (Figure 7)

Photovoltaic solar power is converting solar energy into electricity by using photovoltaic solar cells. This system is the most widely used type of solar power because PV solar power has lots of benefits with compared to others. Solar light is hitting on a semiconductor and excite the electron then current occurs. The electricity which generated with using solar PV can directly be used as direct current or can be stored and utilized later, it also can be convert alternating current with using an inverter.

The first installed power generation with solar energy in Turkey started in 2014. As of April 2022, there are 8566 solar power plants in Turkey, 37 of them are licensed and 8529 of them are unlicensed. The installed power of these 8566 power plants is 8084.9 MW. [14] In 2020 solar PV electricity generation has increased to 10.8 terawatt-hours. [1] Distribution of solar energy power plants in Turkey cities shown in Figure 8.

Figure 6: Concentrated solar power plant (Source: URL3)

Figure 7: Thermosiphon uses sunlight to heat water (Source: URL4)

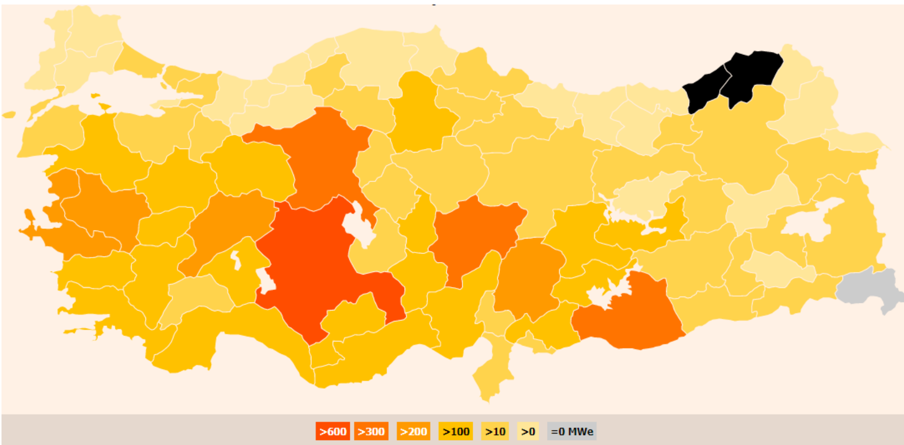

Figure 8: Distribution of solar energy power plants in Turkey (Source: URL5)

Turkey's construction sector is growing rapidly by years. As growing economies, the urbanization rate is high. The construction sector one of the locomotive sectors because it accounts between 5% and 6% of total Gross Domestic Product (GDP) and approximately employs 2 million people. [15,16] According to the IEA report Turkey's residential sector consumed 20.5 Mtoe (million tons of oil equivalent), accounting for 21% of TFC (total final consumption) in 2018. [17] The total energy demand of buildings is expected to increase year by year due to the rapid growth of urbanization and population. [18] According to this conjuncture, energy efficiency policies can be developed. One of the prominent solutions in terms of energy efficiency in buildings is the application of rooftop solar energy systems. Since rooftop solar panel applications will reduce the electricity requirement of the buildings from the grid, then the grid will be less loaded, due to the less load a more effective grid network will be achieved and a fair amount of the distribution losses will be prevented.

Table 2: Distribution of billed electricity consumption by consumer type (Source: URL6)

	2022 February	
Consumer Type	**Amount (MWh)**	**Share (%)**
Illumination	480.653,99	2,26
Dwelling	5.493.935,17	25,87
Industry	9.070.253,89	42,71
Irrigation	1.075.376,93	5,06
Commerce House	5.118.512,63	24,10
Final Total	**21.238.732,61**	**100**

In Table 2, the distribution of billed electricity consumption by consumer type of Turkey is given. It can be concluded that approximately 92.5% of billed consumption, excluding irrigation and illumination occurs in buildings. In the report dated 2020 which mentions Turkey's rooftop solar energy potential, it states that Turkey's technical rooftop PV potential is 14.9 gigawatts. There are studies in the literature about the use of this potential in Turkey. These studies were carried out for university buildings, commercial buildings, and residential buildings. [19–26]

1.5 The Purpose of The Thesis

The World is inevitably changing the energy resources and will have to increase rate of this change. This transformation is from fossil fuels to renewable sources. As in every development, energy transformation takes place with the light of science and the guidance of scientists. It is essential that universities take the lead role in this change as institutions that produce, develop and present scientific solutions to the society.

In this context İzmir Institute of Technology campus has broad area to build renewable energy infrastructure. By using this area, the renewable energy production capacity of the campus can be increased and the energy load on the grid can be reduced. When IZTECH benefit from this opportunity with PV investment, it can produce electricity as much as a significant part of its consumption from PV solar panels and become one of the leading universities in Turkey in renewable energy field. With the demonstration that this study is feasible, it can be possible to create public opinion and reduce the carbon emission of campuses in Turkey with the proposal of green campus support packages. It is aimed that this study will be pioneer to all these ambitions.

In this study, a case study of the solar photovoltaic solar panel system was made for the parking lot of the library building on the İzmir Institute of Technology campus. At the end of the study, it was concluded that this project is economically feasible. With this result, it is aimed to be a guiding study for the increase of PV system applications especially in the IZTECH campus and then in all other campuses.

CHAPTER 2

SOLAR DESIGN AND MANAGEMENT SOFTWARE PROGRAMS

There are already lots of software package programs developed for solar and photovoltaic systems. All these systems designed for,

- Estimate solar energy capacity and potential for specified purpose and specific location
- Calculate the shadow effects, available areas for PV installation
- Design the PV installation to meet the required energy
- Create engineering reports, feasibility analysis and reports [27]

The parts that make up the difference between them can be listed as calculation methods, data sources that they use, and some other methodologies usage. These software packages also have separate features as paid, free, web-based, installed, etc. Investigate some of the popular photovoltaic solar energy design software programs.

AURORA is a paid service, web-based software. It has 2D/3D design options, and it allows to prepare the entire engineering design.

PVSYST is a paid service Windows-based software package. It has an easy-to-use interface. Detailed studies can be done, it can make an hourly analysis, it can give report as an output. It also offers create project proposal. These features make it one of the most used software.

HELLIOSCOPE offers a paid, web-based service. It is also a popular one and it has several features. It has 3D design opportunity, can work in integration with CAD programs, shade analysis, unlimited amount of design opportunity, fast prepared proposals, and simulate the designed project.

PYLON is web-based software its payment method is interesting which receives the payment per project and pricing policy is relatively cheaper. It has a user-friendly interface, its features are high resolution imaging tool, 3D design, shadow analysis, financial analysis, and proposal preparation.

HOMER is a paid program that provides Windows-based or web-based services. It offers more comprehensive service compared to others. It can be used not only for solar PV systems but also for the design and analyze of hybrid energy systems. Since it is a program on hybrid energy, it may not output as detailed as other PV specific programs.

SOLAREDGE is a free web-based PV design software package. It has advanced 3D design tool, has options to use custom image or satellite imagery to design the project, prepares proposals, offers of an integrated project design from start to end.

PV*SOL is either web-based or installed on Windows versions are available and has both free and premium options. Its top features are 3D shading analysis, battery storage systems, maps import, electric vehicles, configurable project report, predefined load profiles and up-do-date database and 2D, 3D visualization options.

PV F-CHART is paid Windows-based installed software package. Its features can be listed as extremely fast executions, hourly load profiles for each month, cost differences, life cycle economics. No option to import weather data from outer sources, no option for module or inverter data entrance.

RETSCREEN is paid and installed on Windows system. This software created by Canada state. Its general purpose is on clean energy management. It offers feasibility report, takes climate data from NASA, 36 language options, can use institutional buildings, factories, power plants and individual homes.

SAM (System Advisor Model) is an open source, free software and it is available on Windows, macOS, Linux. It developed US Department of Energy and National Renewable Energy Laboratory. It creates a model which calculates grid-connected system's, detailed losses due to temperature effect on module, shading and other losses. It is not user-friendly because it needs many manual data entrance.

SOLARIUS is a subscription based paid service and it works on Windows. This software package, which specializes in systems installed on buildings, can work in integration with the Building Information Modelling (BIM) system. It has 3D modelling objects even can start from .DXF or .DWG CAD drawings or BIM models, can import solar irradiance data, can calculate shading effect, wire diagrams, and provide financial analysis report.

ENACT SYSTEMS software was used in this study. ENACT SYSTEMS offers a cloud-based, paid software platform for solar and energy storage projects that includes design, finance, installation management, and asset management. It has 2D-3D design option which can be used either Google Earth or uploaded plan image also its features widening as automated shade analysis, storage calculations, feasibility analysis, user-friendly interface, vast amounts of possibilities to select components such as panels, inverters.

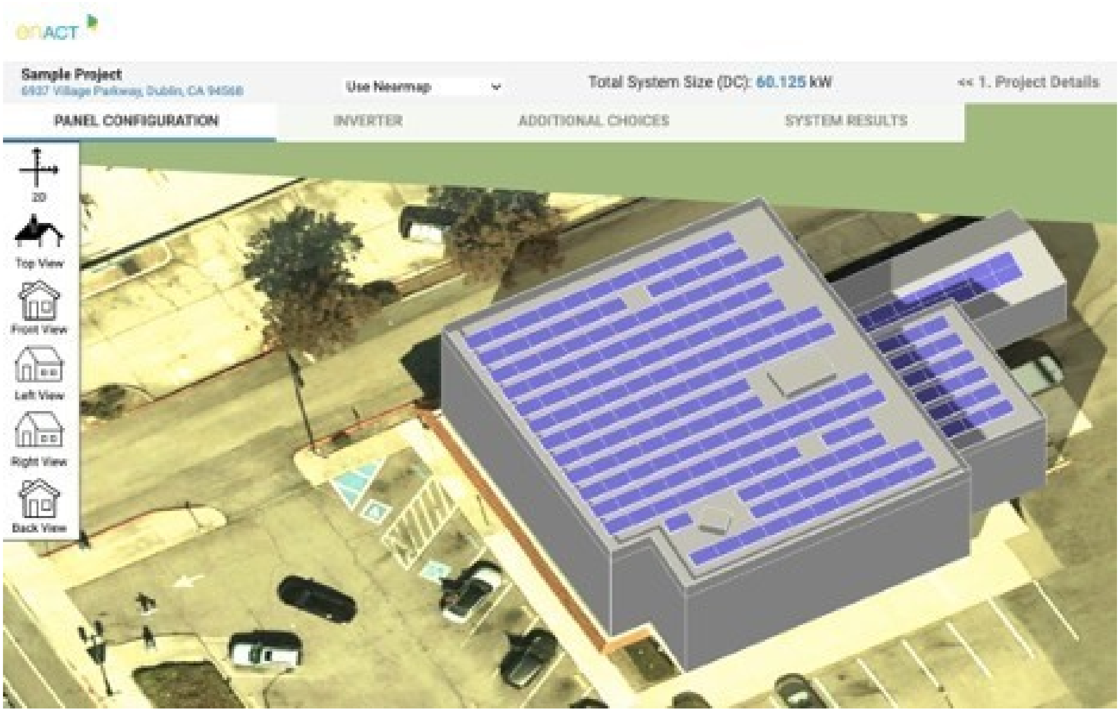

Figure 9: Enact Systems 3D design sample (Source: URL7)

Enact software gives output report after done calculations. This report includes PV design in 2D and 3D, as well as values such as saved money and reduced CO_2 emissions over a 25-year period. Detailed cashflow diagram and production graphs are taking part in report.

2.1 ENACT Software Platform Interface

When logging in to the enact solar system, five windows appear on the interface. These are:

- Dashboard

- Projects
- Tasks
- Manage User
- Settings

Figure 10: Enact systems entrance interface

In the dashboard tab, all ongoing and completed projects are summarized on a pie chart or line chart.

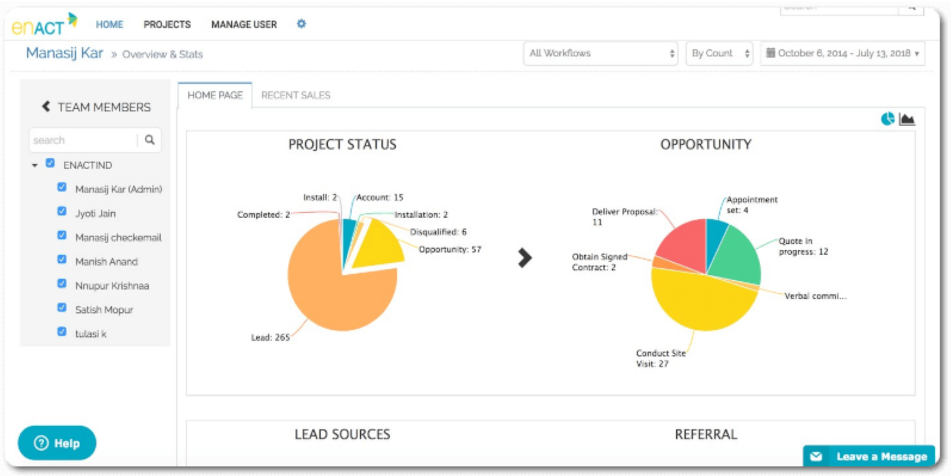

Figure 11: Enact systems dashboard view (Source: URL7)

In the Projects tab, the resumed projects are shown in order. There are twenty-five information columns summarizing the characteristics of the projects which shown in Figure 12.

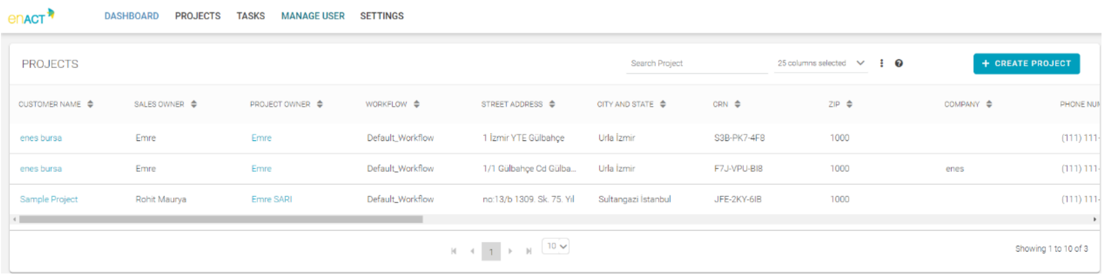

Figure 12: Projects tab view on Enact Systems

The information in the columns that define the features of the projects are such as address details, electricity bill information, electricity consumption, project type. To create a new project, proceed by clicking the "create project" button on the upper right in this tab.

In the Tasks tab, all projects appear in an ordered list, and it is possible to access the content of the project from here. Figure 13 shows the Tasks tab.

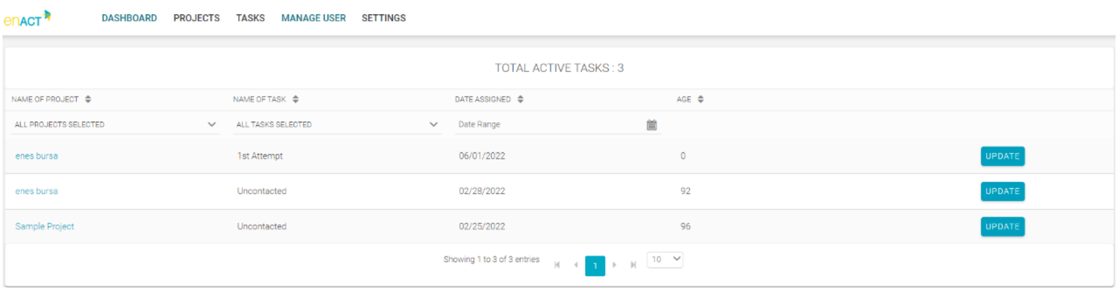

Figure 13: Tasks tab view on Enact Systems

In the Manage User tab, different user and company information is saved for multiple use of the account. The purpose of this tab is to reach the project owner company or persona and their details while preparing a proposal or looking at the project details. This tab can be seen in Figure 14.

In the Settings tab, there are four different options. First one is the Configure Platform. The Configure platform option allows to change the output and input settings as desired. If it is not desired to change the projects settings, the project is continued with the default settings. In Configuration Menu there are four different setup types. In Hardware Setup allows PV module setup, Inverter setup, Battery setup, Racking setup and Monitoring setup manually. Document Setup allows Proposal setup and Contract setup. Finance Setup allows Finance setup, Incentive setup, and Costing setup. General Setup allows the measurement system used in the project to be determined as meters or feet. Second option in Settings tab is Configure Workflow. It can also be used by default when the workflow option is not set. In this tab, the workflow is divided into four main headings. These heading are leading, opportunity, account, install. Under these headings it is possible to make changes as desired.

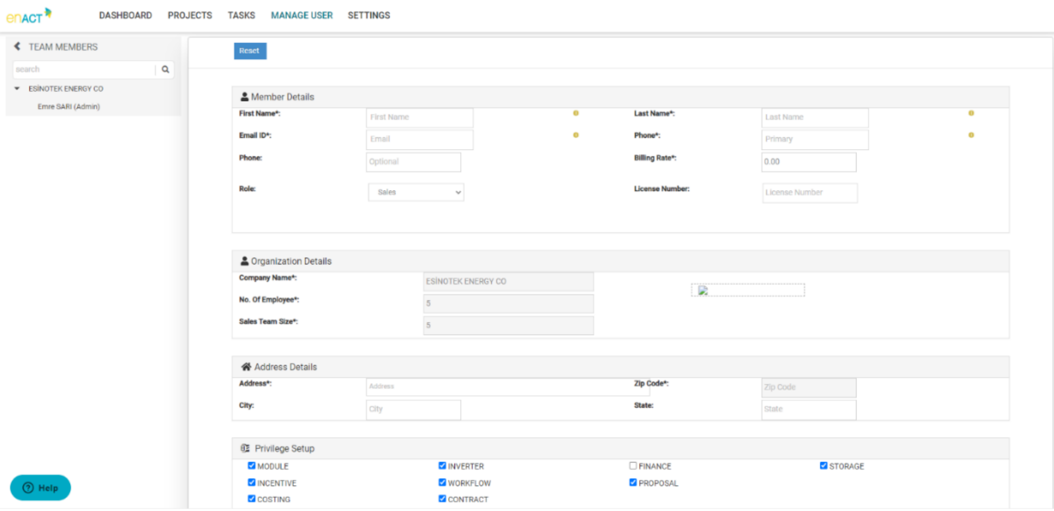

Figure 14: Manage User tab view on Enact Systems

Third option in settings tab is Help button. Clicking the help button brings up the Frequently Asked Questions and Tutorial videos options.

Forth and the last option in Help menu is Log Out option. With this option, the account logged out and access is closed.

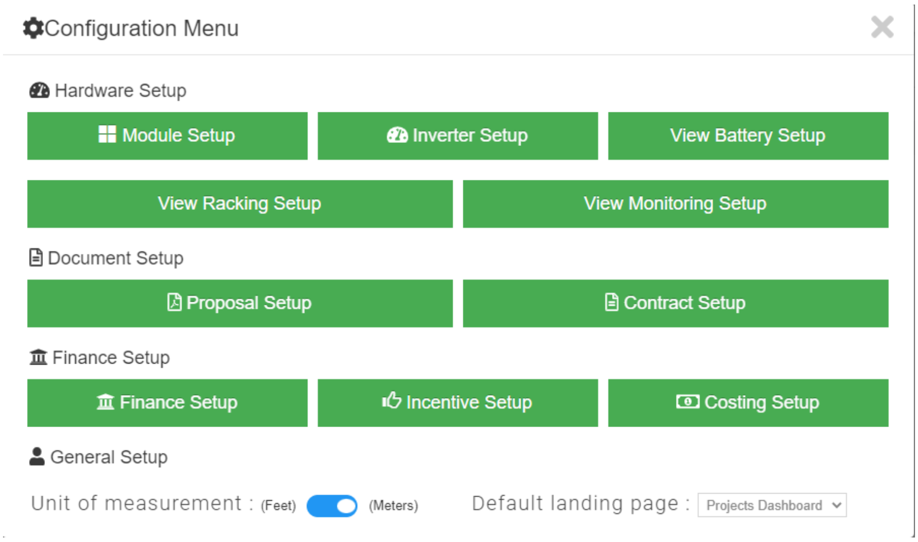

Figure 15: Configuration platform tab view on Enact Systems

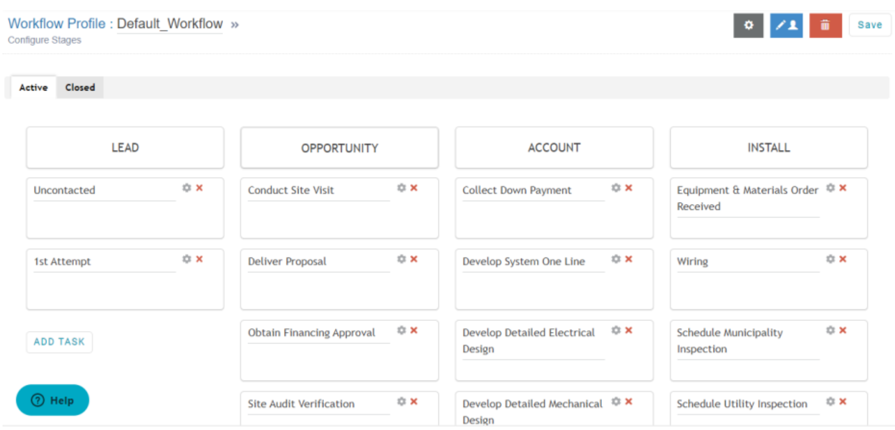

Figure 16: Configuration workflow menu view on Enact Systems

2.2 Create Project on Enact

In the window that comes up after clicking Create Project in the enACT, detailing information such as project details, location details, workflow details are entered. It can be seen in Figure 17.

Personal information such as name, last name, address, email, phone number are entered in the project detail section. In the site details, the specific point information where the project will be located is entered as latitude and longitude. It is also possible to import the latitude and longitude coordinates by selecting the project location via Google Earth by clicking on the Locate Site option. If the workflow detail is entered manually, the created workflow can be selected and progressed, or it can be continued with the default workflow. In the Additional Details section, features such as the type of the project is selected.

After the information about the project is entered, the summary info of the project is shown on the screen. On the same screen, there is a section called Billing Info that can enter monthly electricity bill details or monthly electricity consumption in kWh shown in Figure 18.

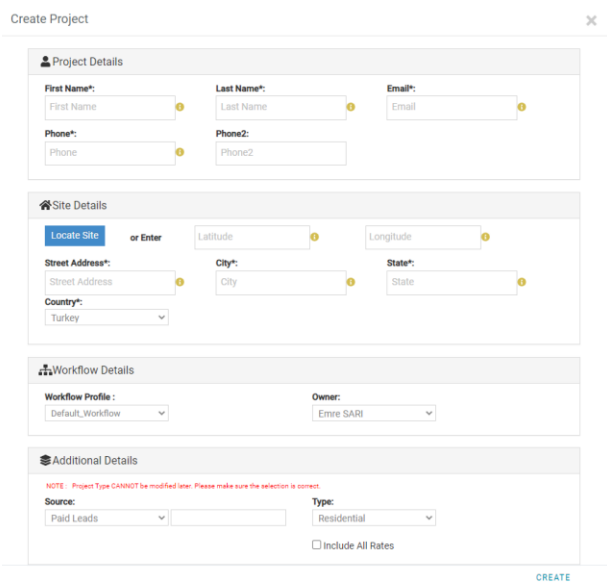

Figure 17: Create Projects details entrance tab view on Enact Systems

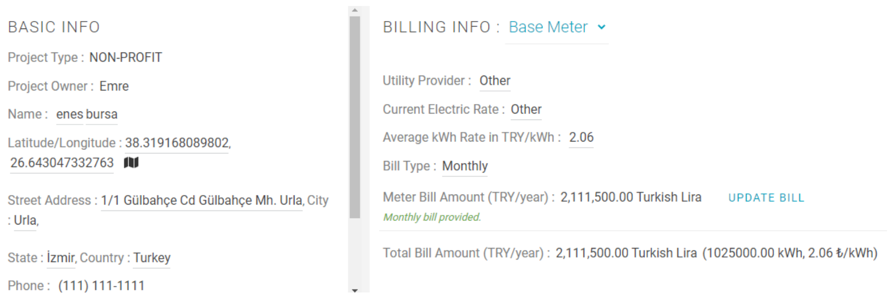

Figure 18: Basic information and Billing information view on Enact Systems

The section where electricity consumption is entered ad kWh is shown in Figure 19. As can be seen in Figure 19, it is also possible to enter the consumption information directly as the monthly bill.

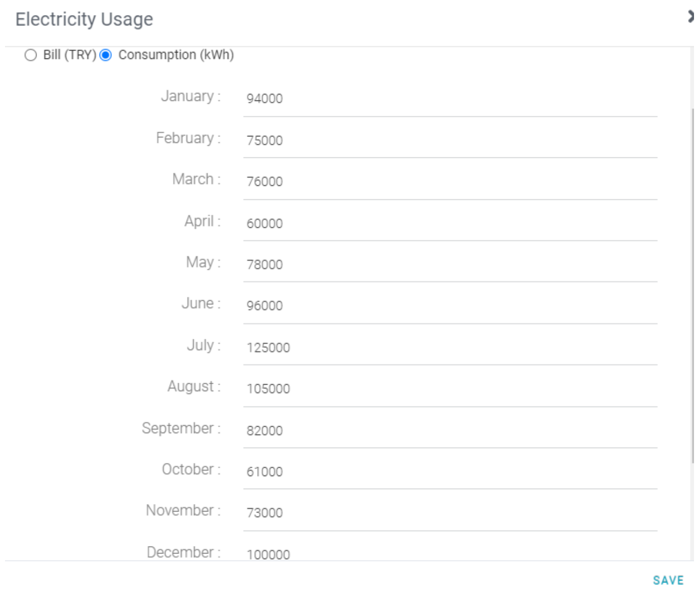

Figure 19: Electricity consumption entrance on Enact Systems

Clicking on the Create Quote button starts the project creation phase. The Google Earth screen opens on where the previously selected location and the tools for drawing the panel or drawing the roof appear on the screen.

There are Draw Roof Outline and Draw PV Array options in the Panel Configuration menu. Before panel placement, settings related to panels and their placements can be made. Array Type menu where the panel array can be fixed or axis tracking open rack and roof mount options can be select. Panel Orientation can be specified as Landscape or Portrait. Panel Tilt and Roof Tilt angles can be determined. Inter-row Spacing and Setback distances can be set manually. Panel manufacturer and the specific panel model produced by the company can be selected. After selecting the manufacturer and model, information such as the length, width, power, panel type, and number of cells of the panel can be entered automatically but can also be entered manually.

In the Panel Configuration menu there are drawing tools. If the PV panels will be placed on the roof of building or the ground, the panels can be started to be placed directly with the Draw PV Array option. If there is no roof and it will be drawn, it can be drawn with the Draw Roof Outline option. With the Draw Keep outs option, objects that cannot be placed panels on it or that can affect panel efficiency with their shadow or presence are drawn. All these drawings are first drawn in 2D, then features such as height and slope information are entered. It also possible to examine how the drawings look in 3D with the 3D option. Since it is possible to switch between 2D and 3D with one click, designing the desired design is relatively quick. With the shadow analysis option, shadow analysis can be made with the position of the sun at different times of the day and losses due to the shadow can be calculated. Enact systems perform shadow analysis as simulation and offers more understandable analysis, and it can also present the analysis as a report. The Capture option allows to take screenshot when desired.

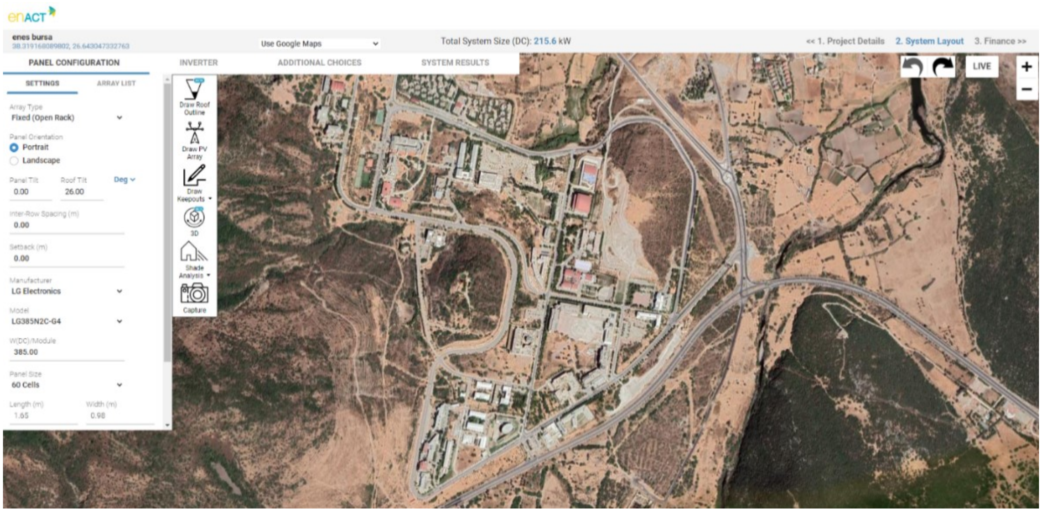

Figure 20: Enact Systems general view

In the Panel Configuration menu Array List is another option. Panel arrays seen as a list in that option. In Array list number of panels, azimuth angle, panel orientation type, racking manufacturer, panel tilt angle, inter-row spacing, setback, annual shading percentage information can be reset or continue with the default values which was entered or calculated before.

In the inverter settings menu, the inverter selection and its related settings are set. The options that can be set here are target dc to ac ratio, the inverter efficiency, and the number of inverters that can be adjusted according to the installed power.

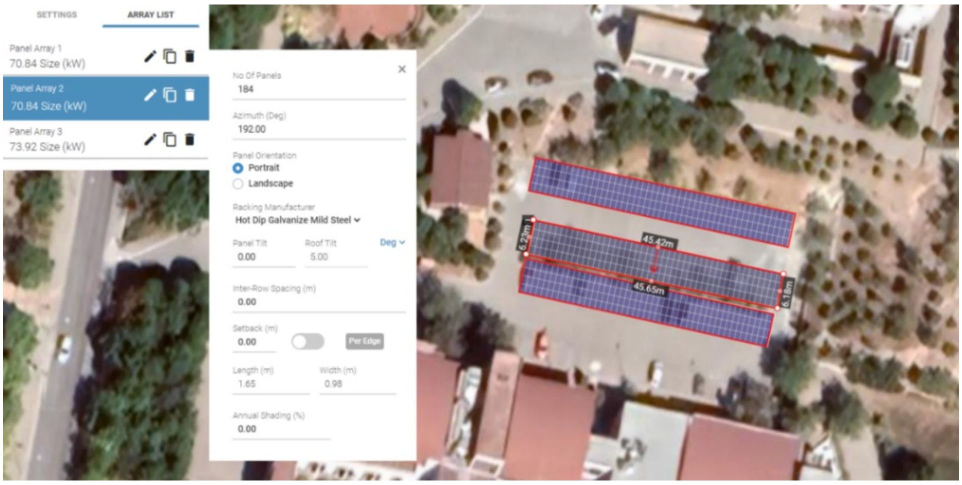

Figure 21: Enact Systems array list menu

After all these data is entered System Results menu appears. When the system results are loaded, the monthly generation-consumption graph for a year is displayed in kWh which shown in Figure 22. In the system results menu, the more general results are displayed on a panel along with the graph, as in Figure 23. These results are including the total number of panels used in the design, the annual electricity consumption in kWh, current annual electricity bill, utility bill savings rate, total PV system power in watts, solar energy generation in kWh, solar production ration in kWh/kW.

Enact Systems also offers a financial analysis option as a final step. The financial analysis menu produces results integrated into the United States system, at this stage, information such as all incentive packages on solar energy and loan rates must be entered separately in order to obtain results in specific Turkey system.

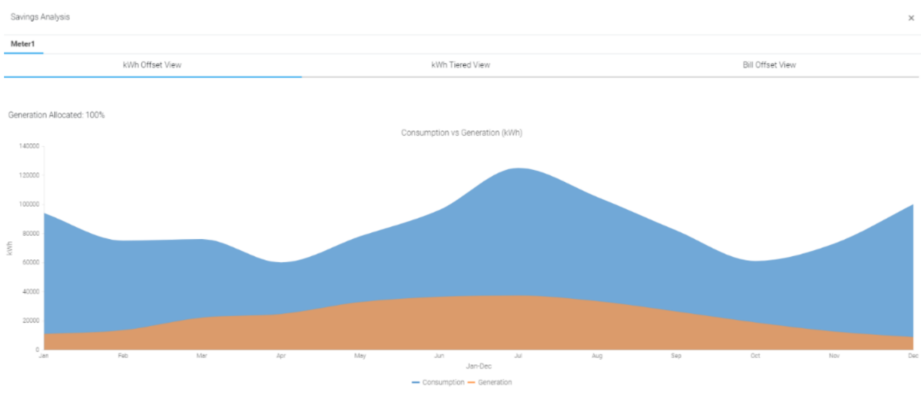

Figure 22: Enact Systems results graph

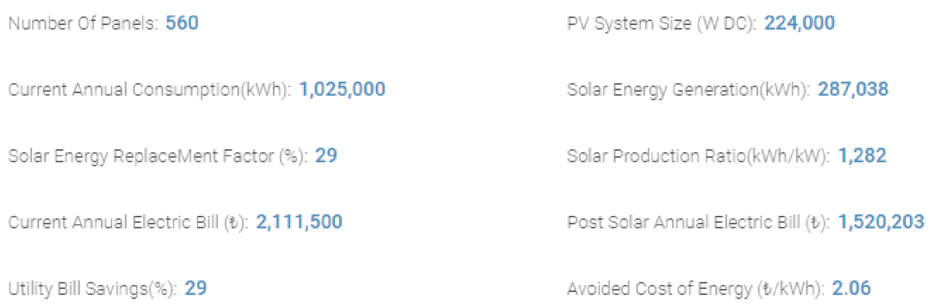

Figure 23: Enact general system results

2.3 Background Calculations Used in Enact Software

Enact systems use the PVWatts software system of its calculations. PVWatts is a popular web-based software specialized on solar PV calculations, developed by National Renewable Energy Laboratory (NREL). To use the system, the location where the PV panels will be installed, system's total power, module type and few more parameters are entered. As a result of these, PVWatts calculates the amount of electricity that the system's hourly and monthly electricity production.

The Enact systems takes meteorological and solar radiation data from the NREL National Solar Radiation Database (NSRDB). NSRDB uses typical meteorological year (TMY) data which contains one year of hourly data that best represents median weather conditions over a multiple year period. After entering on PVWatts system specific latitude and longitude coordinates or directly the street address where the PV system will build, it shows the nearest available grid cell center and the distance between the PV system location and the grid cell center in miles. It can be seen in Figure 24. Blue rectangle on the map indicates the NSRDB grid cell and the red point location is Izmir Institute of Technology campus. Distance between them is about 38 km.

The PVWatts system uses many parameters to calculate the installed PV solar energy power output. These parameters can be listed as follows.

The Module Type is an input parameter. Module type can be selected as standard crystalline silicon, premium crystalline silicon, and thin film. According to these choices, the efficiency coefficients and temperature coefficient of power of the panels change.

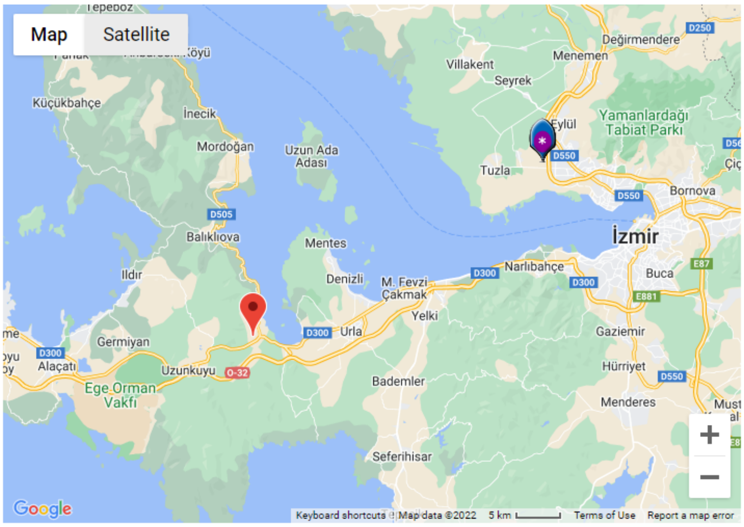

Figure 24: PVWatts Grid Cell point and Iztech campus location (Source: URL8)

Array Type is another input parameter. Array type can be selected as tracking system of fixed system. The fixed system has two options these are fixed open rack and fixed roof mounted. This system calculates the effect of airflow circulating freely around the solar panels, lowering the solar cell temperature.

For the System Losses calculation, ten parameters are calculated together as total loss. The formula is:

Total loss percentage = 100%[1-(1-soiling loss) x (1-shading loss) x (1-snow loss) x (1-mismatch) x (1-wiring loss) x (1-connections loss) x (1-light-induced degradation) x (1-nameplate rating) x (1-age) x (1-availability)]*

System losses categories:

- Soiling: It can be explained as less exposure to solar radiation due to dust, soil or foreign matters accumulating on the photovoltaic module. NREL continues to update and improve soiling loss modelling as more datasets become available.
- Shading: It is defined as less exposure of to the incident light due to nearby objects such as trees, buildings or by self-shading caused by tilt angle and placement of panels. In Figure 25, the factors that effecting the self-shading can be seen on a graph.
- Snow: It can be explained as a reduction of output due to the snow coverage on the panel array.

- Mismatch: Losses due to production imperfection and different current-voltage characteristics caused by imperfections.
- Wiring: It is explained as the losses due to resistance in AC-DC wires, inverter wires and module wires.
- Connections: Defined as resistive losses in electrical connections.
- Light-induced Degradation: It is defined as the loss of efficiency of PV cells due to light-induced degradation within a few months of installation.
- Nameplate Rating: It is explained as the output values differences between nameplate rating and field measurements. There may be differences between the product's characteristics at the place where manufactured and the field.
- Age: It is defined as the efficiency loss of the PV modules and PV cells due to weathering over time.
- Availability: It is defined as the performance loss due to the scheduled or unscheduled system shut down for maintenance, repair, grid outages and other operations.

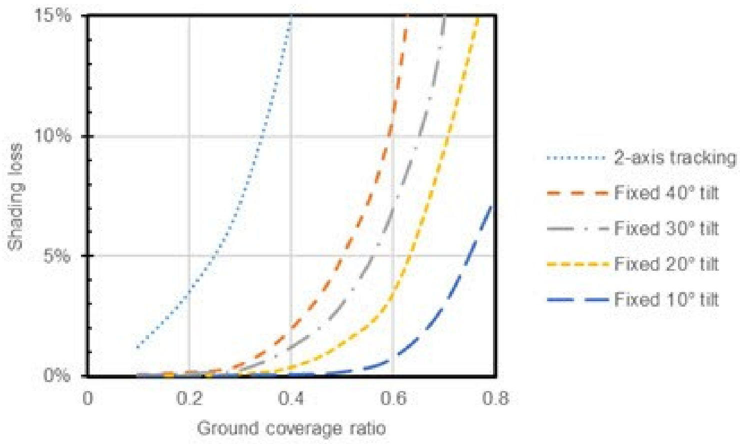

Figure 25: PVWatts self-shading loss analysis graph (Source: URL8)

Tilt angle is another parameter. It refers to the angle between horizontal plane and the PV modules in the array. Usually equating the tilt angle to the latitude at where to install PV power plant gives the maximum annual output. Lower tilt angle maximizes production in summer and higher tilt angle maximizes production in winter times. The high angle system increases the racking and equipment cost to be used and increases the possibility of damage due to wind load.

The azimuth angle is another input parameter. Azimuth angle is the angle clockwise direction between where the array facing and geographical north. In northern hemisphere 180° azimuth angle (south facing array), in southern hemisphere 0° azimuth angle (north facing array) maximized the electricity production. These values given as a general opinion, the optimum azimuth angle may be different according to geographical location and local weather dynamics. In northern hemisphere, an increase in azimuth angle favors production in the afternoon, and a decrease in the azimuth angle favors production in the morning.

DC to AC size ratio is the ratio of the DC nominal size produced by the panel array to the AC nominal size of the inverter.

Inverter efficiency is the ratio of the nominal AC power output to the nominal DC input power.

Ground Coverage Ratio (GCR) is defined as the ratio of the surface area of modules to the area of the roof or floor where panels placed on. Lower GCR ratio means wider spacing between rows of modules vice versa. PVWatts uses this value to calculate the loss due to self-shadowing.

CHAPTER 3

IZTECH LIBRARY CAR PARK AREA SOLAR PANEL DESIGN

Izmir Institute of Technology campus is located at the coordinates of 38.3199 N, 26.6434 E within the borders of the Urla district of Izmir. [28] The campus has an area of 35000000 m^2 (thirty-five million square meters). Education and research activities are carried out in a closed area of 132000 m^2 (one hundred thirty-two thousand square meters). [29]

Izmir Institute of Technology Department of Library and Documentation building started its activities in 2007 on an area of 6100 m^2 (six thousand one hundred square meters) and 1000 people seating capacity. [30] The library building consists of two floors. On the first floor there is the user service, periodicals hall and cafeteria, on the second floor there is library a-p, library q-z and mind games hall. [30]

There are no specific exam weeks at IZTECH, so student density in the library remains high throughout the academic year. This is the one of the reasons affecting the energy consumption of the library.

According to the IZTECH Directorate of Construction and Technical Works data the annual electricity consumption of the library building varies between 450.000 kilowatt-hours and 650.000 kilowatt-hours. [31] It can be seen in Figure 26.

In Figure 27, the consumption between 2015 and 2019 is shown monthly. The highest electricity consumption is in the summer months. Consumption generally follows a trend, although there is volatility in some months between years.

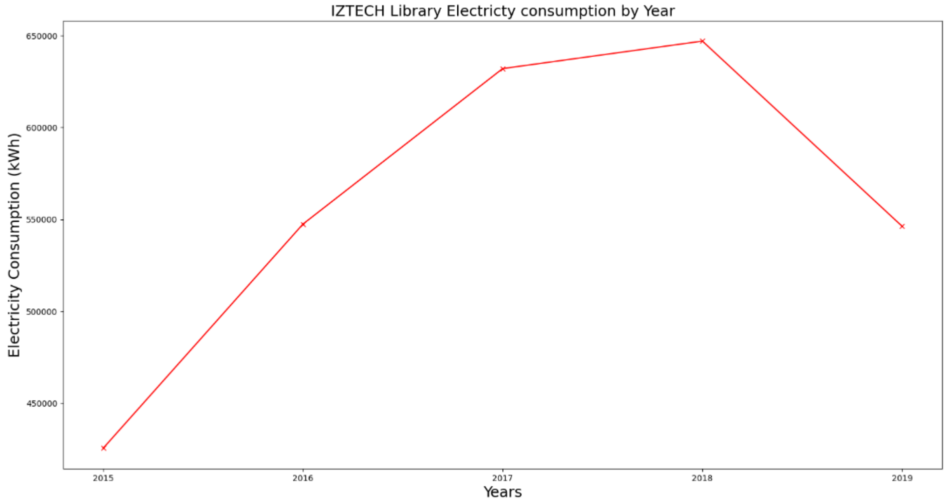

Figure 26: IZTECH Library electricity consumption by year (Data Source: URL9)

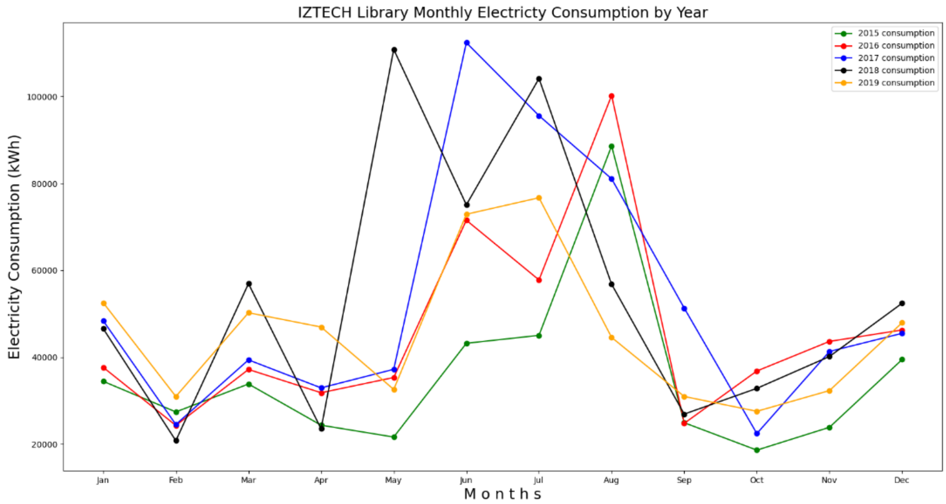

Figure 27: Library monthly electricity consumption by year (Data Source: URL9)

The averages of the monthly consumption data were entered into the project as the amount of library electricity consumption. While calculating the average, extreme values in some months were not included in the average. As seen in Figure 27, some extreme values are several times more or less than the same months consumption of other years. Since five' years data is used in the calculation, extreme values have been removed so that it does not affect the result too much. In Figure 28, the monthly average consumption data entered in the Enact Software System is seen as plotted on the graph.

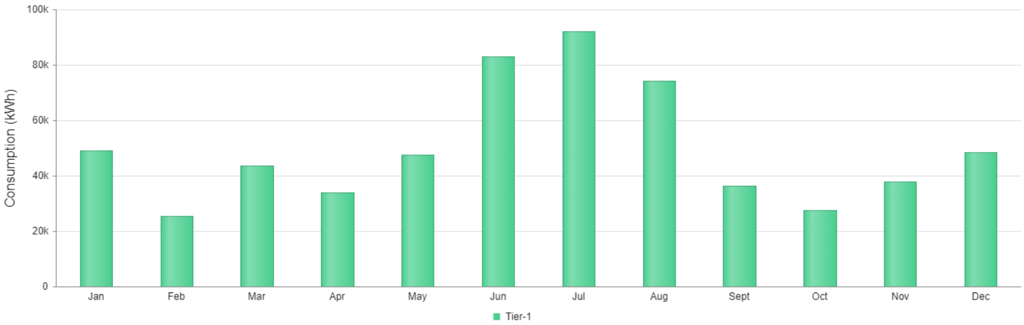

Figure 28: Enact Systems monthly electricity consumption graph

3.1 Library Car Park

Izmir Institute of Technology library has approximately 1700 m^2 open parking area. The entire park area is roughly (50m x 35m) fifty meters long and thirty-five meters wide. This area is completely open and has four different parking spaces. Satellite image of the library car parking area is seen in Figure 29. In this study three parking areas were included in the project. The southernmost which closest to the library parking area was not included in this study. Since this area is close to the library, it cannot benefit from sunlight during the early morning and close to sunset because of library's shade. Since the sun is lower in the sky during the winter months, this area does not receive sunlight for a longer period. [32] The total settlement area of the three roofs on which the panel will be placed is approximately 835 square meters (about twice the area of a basketball court).

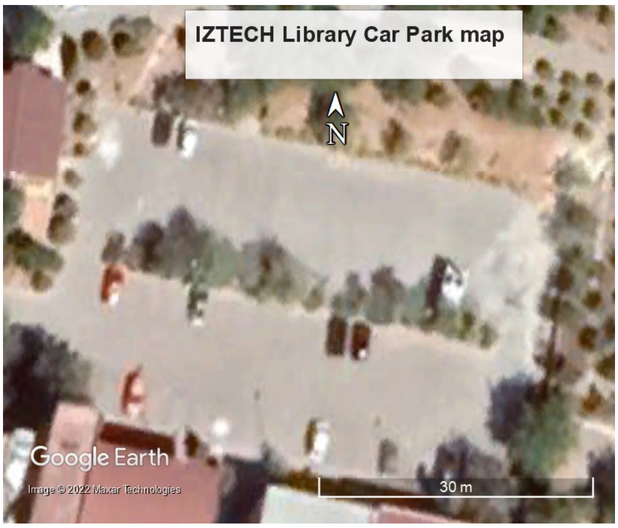

Figure 29: Library car park area satellite image [47]

3.2 Library Car Park Roof Parameters

In this project, the orientation and slope of the roofs to be built on the parking areas were calculated. For this, the parameter called Solar Production Ratio calculated by the software in the Enact Systems system output panel is used.

The solar production ratio is obtained by dividing the annual production of the system (kWh) by photovoltaic system size (W DC). It is known that due to the location of the library car park, it will be more efficient to place the panels in the south-facing direction. By using this it can be confirmed that the output of the solar production ratio can be used as a tool to calculate efficiency. To test that, a design was made in the Enact software that keeps all parameters constant except the roof orientations being north and south.

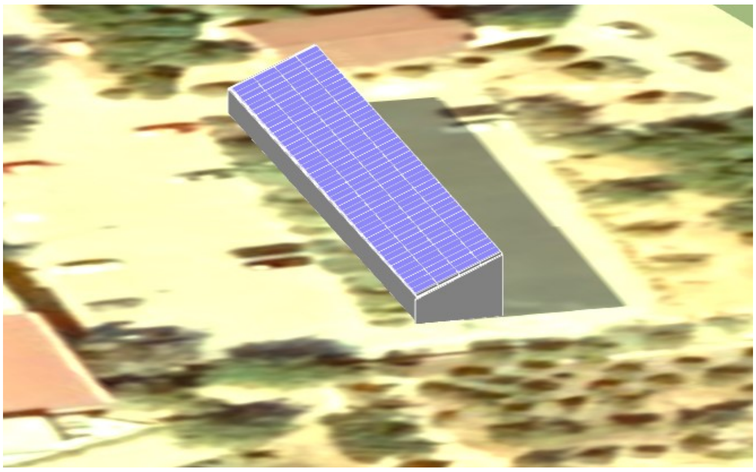

Figure 30: South oriented panel array 3D view

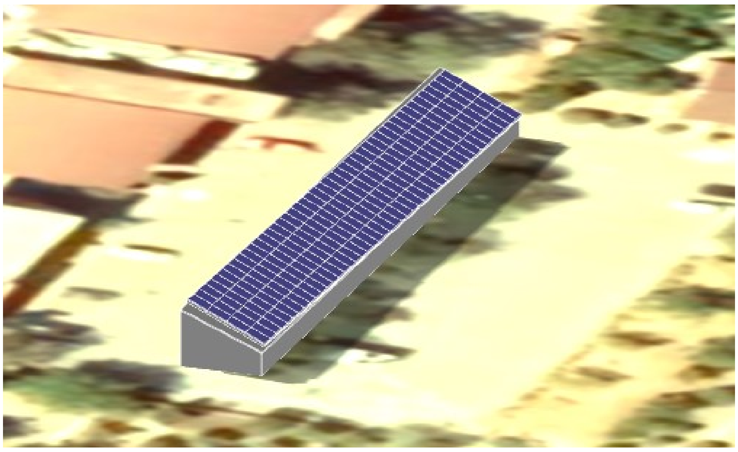

Figure 31: North oriented panel array 3D view

The three-dimensional view of the south and north oriented panel arrays can be seen in Figure 30 and Figure 31.

Figure 32 shows the north oriented solar panels array's output values. Solar production ratio of the north oriented array is 1007. Figure 33 shows the south oriented solar panels array's output values, and its solar production ratio is 1458.

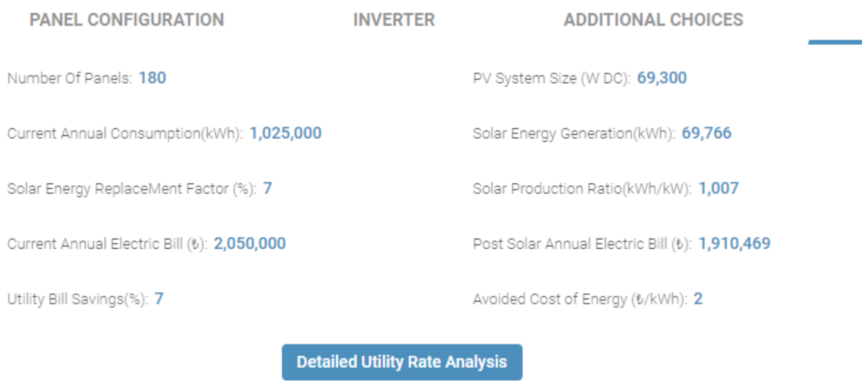

Figure 32: North oriented solar panel array output

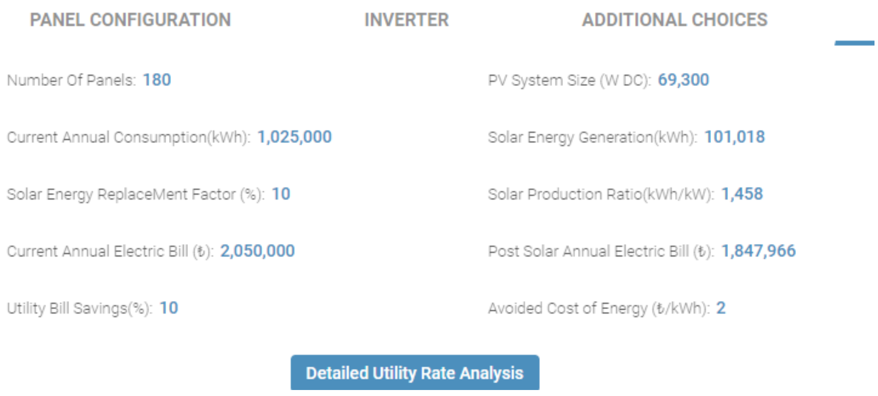

Figure 33: South oriented solar panel array output

As expected, the solar production ratio of the south-facing panels is greater than the north-facing panels. Based on this, Enact systems calculated the SPR as expected, showing the SPR can be used for efficiency measurement. As the next step in the project, different angles are simulated to find the most efficient slope. The most efficient tilt angle was determined by looking at the SPR value of the simulations.

SPR values of different angles were calculated with two degrees spacing. Table 3 shows the outputs of this calculation. As seen in the Table 3 the most efficient tilt angle is between 27 degrees and 35 degrees with horizontal. The angles between 27° and 35° were calculated by giving a half-degree gap to obtain clearer results.

Table 3: SPR value of different tilt angles with two degrees spacing

Tilt Angle	Solar Production Ratio
15°	1425
17°	1435
19°	1444
21°	1451
23°	1458
25°	1462
27°	1465
29°	1467
31°	1467
33°	1467
35°	1464

Table 4: SPR values for different tilt angles with half degree spacing

Tilt Angle	Solar Production Ratio
28°	1466
28.5°	1467
29°	1467
29.5°	1467
30°	1467
30.5°	1467
31	1467
31.5°	1467
32°	1467
32.5°	1467
33°	1467
33.5°	1466

Table 4 shows the SPR values calculated with half degree spacing. The Enact systems found the SPR values of inclination angles between 28.5° and 33° with horizontal to be the same. When compared with the literature, it is seen that the outputs of the system are compatible with the literature. [33,34] Since the model had to choose a single angle and continue, this model was continued with an angle of 28.5°. The reason for this is that in the northern hemisphere, since sunlight comes at steeper in summer, the optimum placement angle of the solar panels decreases in summer. [32–34] Although the efficiency is the same, the choice to increase the production in the summer months is more suitable for this project. Considering the electricity consumption of the IZTECH library, this approach will gain even more meaning. Since the consumption in the summer months is higher than the consumption in the winter months, it is more appropriate to maximize the summer production. The next step of the study is to examine the other features of the panel design on the south oriented 28.5° sloping roof.

According to the parking regulations published in the Official Gazette of Turkey dated February 22, 2018, the entrance to the parking lot can be at least 2 meters high. The width of the parking area in the project has been determined as 6 meters. When the shortest end of the roof with a slope of 28.5° is calculated to be 2 meters, the highest end is 5.26 meters. This is inconsistent for parking lot design, both in terms of usability and aesthetics. The height of 5.3 meters is insufficient to protect parked vehicles. In addition, having to spend extra resources to overcome the stability problems caused by wind load can be considered as an important problem. Additively, the southernmost array of panels with a 28.5° design overshadows the array of panels immediately adjacent to the north, reducing overall efficiency. The overshadowing effect was simulated and calculated by the shadow analysis method of Enact Systems. As seen in Figure 34, about half of the adjacent panel array is under shadow.

Figure 35 and Figure 36 are outputs of shadow analysis of Enact systems and dark areas in that figures represent shaded areas. Shaded areas receive almost 60% less irradiation as shown in the Figures 35 and 36. Due to the fact that design will be used as a car park and all other problems which mentioned above, 28.5° as the optimum angle is not suitable for this project. In order to overcome problems of this project and to design a suitable car park lot, it is imperative to compromise on efficiency. Since the optimum value is known, how much production loss could be calculated after the design.

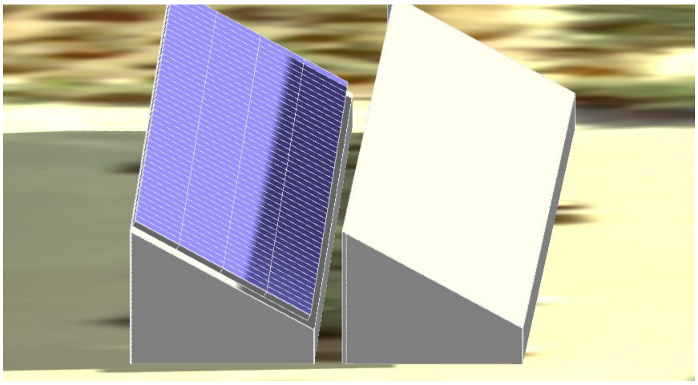

Figure 34: 28.5 degrees design overshadowing its adjacent

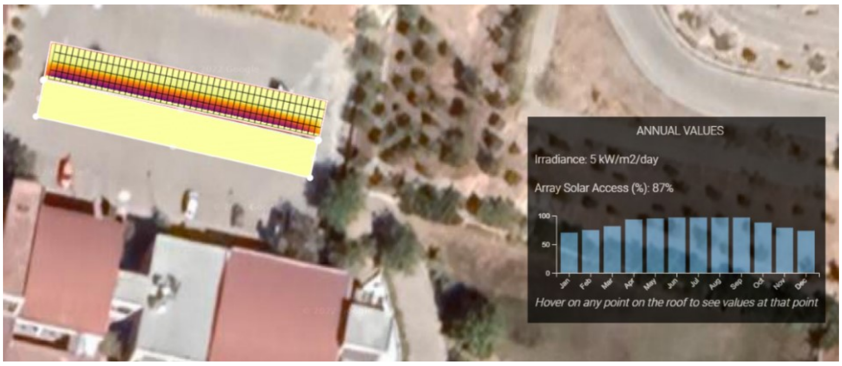

Figure 35: Irradiation of the non-shaded area

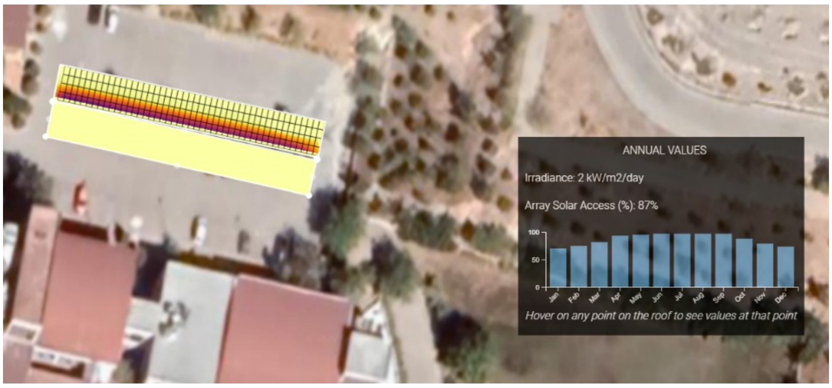

Figure 36: Irradiation of the shaded area

The roof of the car park was considered as a flat floor, and the panel layout was made with an inclination angle of 28.5° and analyzed. Since the panels are inclined, 2 rows of panels can be placed on the floor of the single car park roof, as the distance is left between them to avoid overshadowing. When the roof is inclined and panels are placed parallel to the roof, 4 roofs of panels can be placed. Despite the 10% loss of efficiency in this project, 2 more rows of panels were deemed more appropriate, and the project continued with 4 panel array design option. Figure 37 shows a sloping panel design on a flat plate. As seen here, 2 rows of panels can be placed per roof.

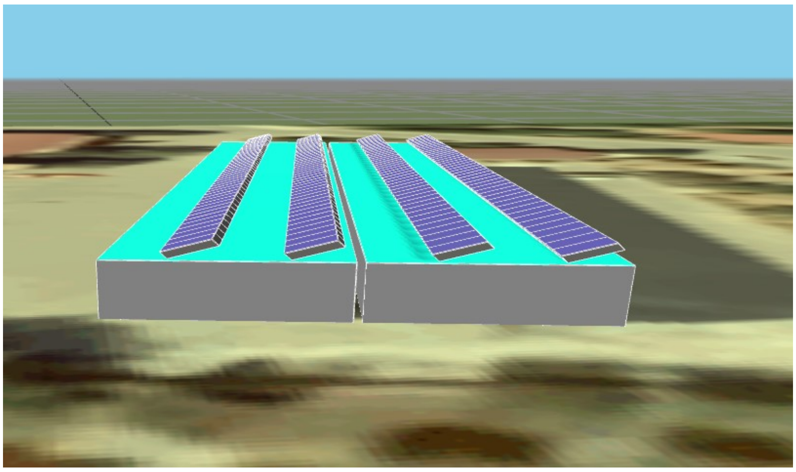

Figure 37: Tilted panels on flat plate placement

The two adjacent areas of the parking lot were designed symmetrically, and the project continued with that design. The designs were simulated as A-like and V-like shaped and their efficiency was calculated. Since the designs are symmetrical, one array faces south and the other faces north. It can be predicted that the production in the north-faced array for angles with high inclination will decrease considerably. For this reason, calculations were made for small angles, provided that are at least 5°. The reason for taking the minimum value of 5° is to reduce the efficiency loss by accumulating pollution on the panels. In the literature, it is stated that for the wind to clean the dust on the panel, it should be built with a slope of at least 5°. [35] Figure 38 and Figure 38 show how A-like and V-like designs look like.

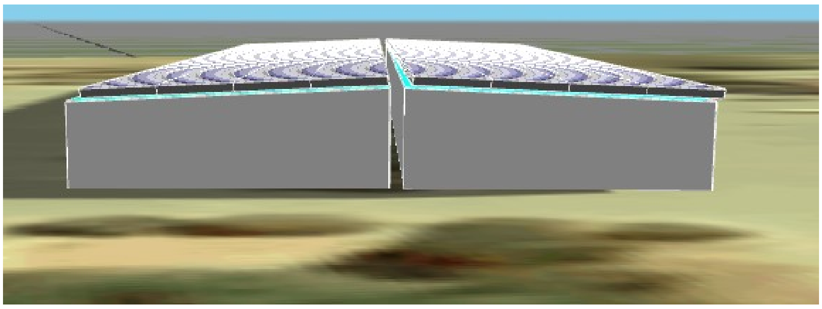

Figure 38: A-like shape car park roofs

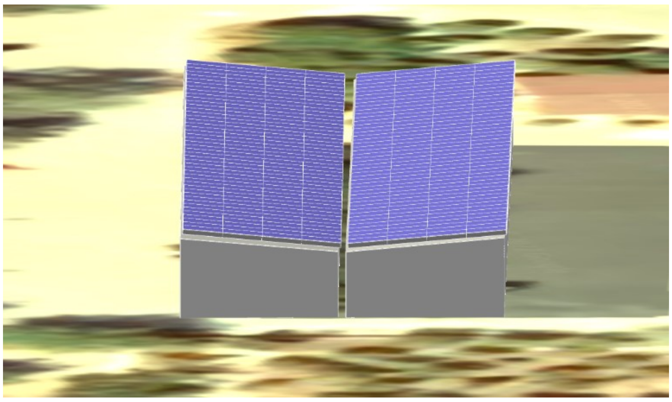

Figure 39: V-like shape car park roofs

Table 5: SPR values of A-like and V-like design on different angles

	Solar Production Ratio	
	V Like Shape	A Like Shape
5°	1303	1252
6°	1301	1241
7°	1300	1229
9°	1295	
11°	1290	

Table 5 shows the SPR values of A-like and V-like designs at different horizontal angles. While the optimum tilt angle was 28.5° in previous design, the reason for not going up to such big angles in this design is as seen in Table 5, as the angle increases, the SPR value decreases. As can be seen from Table 5, the V-like shape is more efficient than the A-like shape. Since the 5° V-like design gives the most efficient result for adjacent parking areas, that design was used in this study. The roof design of northernmost parking area is south oriented and designed with an inclination of 18.5°. The reason why it was determined as 18.5° can be said try to determine larger angles as possible. The reason for not determining a larger angle is to prevent from the larger angles problems which are mentioned above. With a 18.5° roof tilt, when the car park entrance height is 2 meters, the highest side become 4 meters.

3.3 Final Design

Figures between 40 and 45 show 3D and 2D view of the final design of the work from different directions.

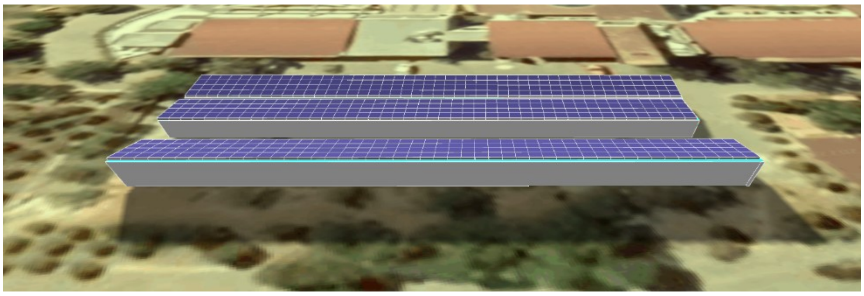

Figure 40: Final design 3D view from North

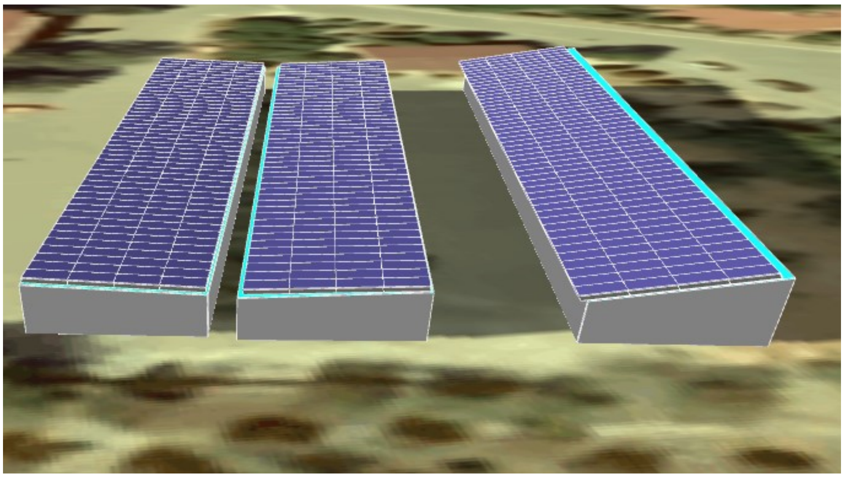

Figure 41:Final design 3D view from East

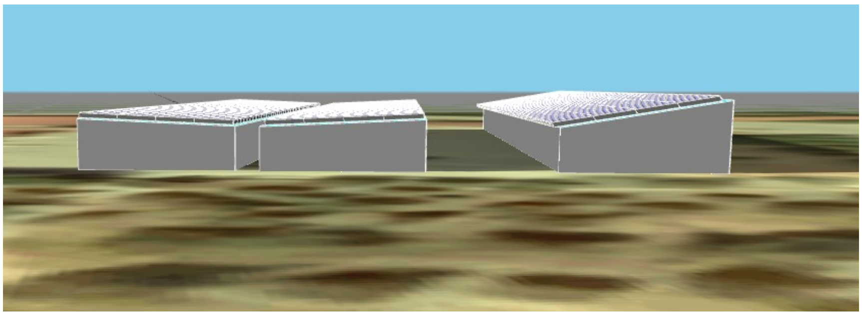

Figure 42: Final design 3D view from East (2)

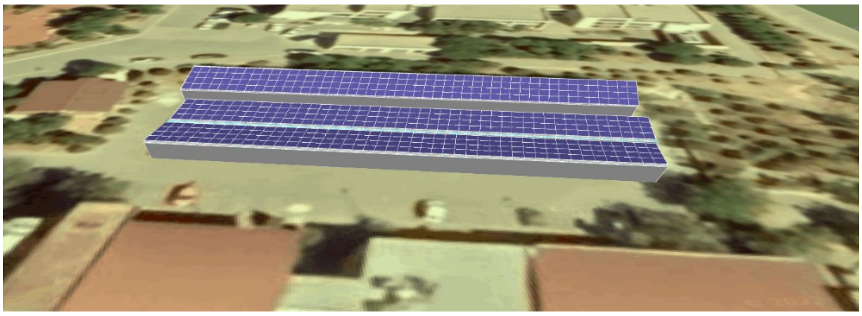

Figure 43: Final design 3D view from South

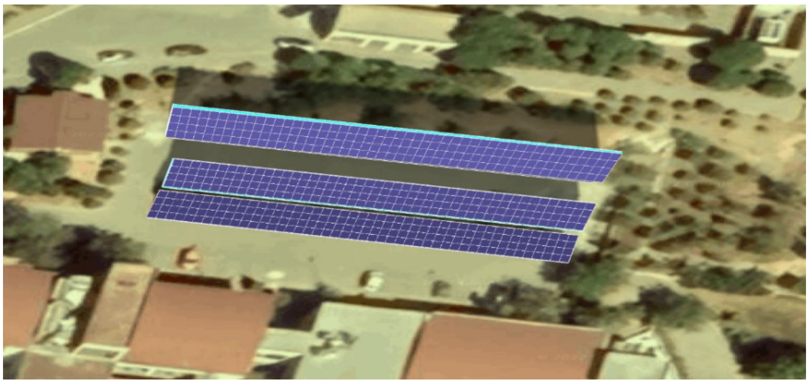

Figure 44: Final design 3D top view

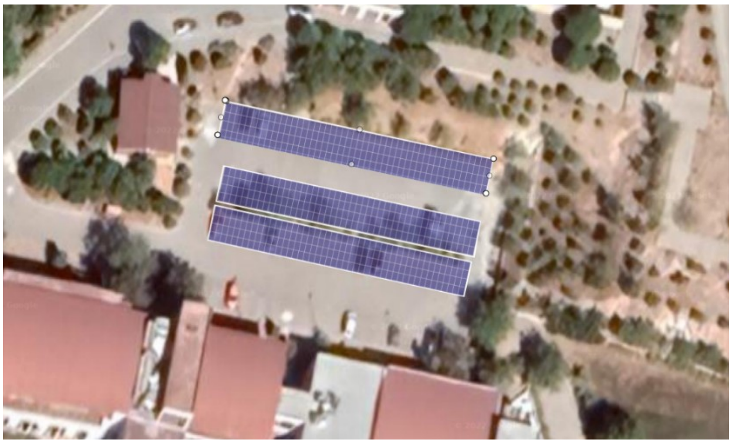

Figure 45: Final design 2D top view

CHAPTER 4

RESULTS AND DISCUSSION

A total of 560 panels were used in this simulation with a power of 400 W, 192 in the northernmost array and 184 in the other arrays. This system could generate about 51% of the IZTECH Library's annual consumption, according to this study. In Figure 46, monthly consumption-generation data throughout the year can be seen.

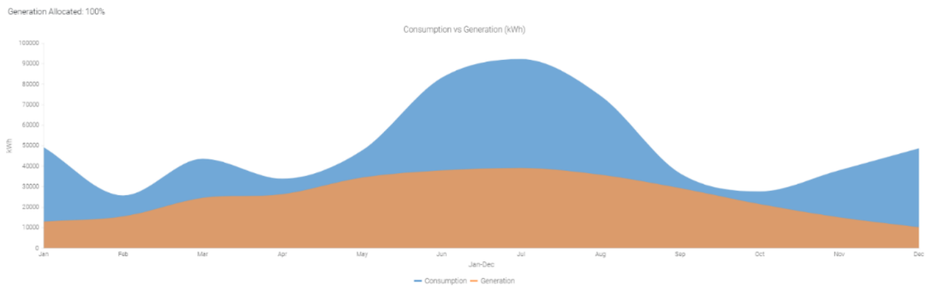

Figure 46: Consumption by library versus generation by system graph

Although production is at its maximum point in summer, the difference between consumption and generation is numerically seen the most in summer. The reason for this is the consumption in a year is become maximum at summer times. In some months, production meets most of the consumption. For example, in September consumption is about 36400 kWh and the generation 29225.5 kWh which means is the system has 80% of coverage ratio of consumption.

The installed power of the system is 224 kW DC. The annual solar energy generation is 301702 kWh. The final solar production ratio of the system is 1347 which is 8% far from the optimum value. Some other of the outputs of the system are seen in the panel in Figure 47.

In the proposal prepared by the Enact software, it is stated that this system reduces 208 tons of greenhouse gas emissions to nature and gives the same effect as planting 5333 trees.

Number Of Panels: **560**	PV System Size (W DC): **224,000**
Current Annual Consumption(kWh): **599,567**	Solar Energy Generation(kWh): **301,720**
Solar Energy ReplaceMent Factor (%): **51**	Solar Production Ratio(kWh/kW): **1,347**
Current Annual Electric Bill (₺): **1,235,109**	Post Solar Annual Electric Bill (₺): **613,566**
Utility Bill Savings(%): **51**	Avoided Cost of Energy (₺/kWh): **2.06**

Figure 47: System output statistics

4.1 Economic Analysis

Although it is a tool of the Enact software systems for financial analysis, additional resources are also used. [36] The expected cost is shown in Table 6 in US dollars.

Table 6: System installation price

	Average Price (1 unit in $)	Quantity	Total Price ($)
Module	110	560	61600
Inverter (50 kW)	2750	5	13750
AC, DC Cable			10000
Cable Tray, Grounding			3000
Scada			1000
Labor			15000
TEDAS follow-up			5000
Transportation, insurance, accommodation			10000

According to the cost calculation in Table 6, the cost of installing the solar system has been calculated as approximately 120000$ (one hundred twenty thousand

US dollars). As of June 4, 2022, the last date of updating the cost of this project, the $/₺ rate is around 16.5. With this exchange rate, the TL equivalent of 120000$ is 1 million 980 thousand TL (1980000₺). According to the cost calculation made by Enact software, the system analyzed in this study pays off its cost in a period of 4 years. When the cost of building in the par park roof added to the expenses, the amortization period will change.

In the communique titled "Communique on the approximate unit costs of the building for the year 2022/2 to be used in the calculation of the architectural and engineering service cost" in the official gazette of Turkey, which was last published on 21 June 2022, the cost calculation for the parking lot was determined as 3200 ₺/m^2. In this study, the parking area to be covered was specified as 835 square meters. The total parking lot construction cost was calculated as 2672000₺ (two million six hundred seventy-two thousand Turkish Lira). When combine both parking lot construction and solar panel equipment cost, the total cost is 4650000₺. For these expenses, the Enact software calculates the amortization period as 8 years. Detailed financial analysis can be seen in Appendix A.

4.2 Suggestions and Future Work

In this study, it has been shown that the solar panels to be built in the library parking lot area on the IZTECH campus are economically viable. Universities need to take more responsibility for the use of the renewable energy sources and lead the energy transformation. In this context, states should allocate more resources to universities to promote the use of renewable energy resources. The projects should apply in real life that have been shown to be economically feasible with the studies.

To give a specific example, the chemical engineering parking lot, civil engineering parking lot, life center parking lot, the parking lot above the technopark and the science faculty parking lot can be subject of future studies. Satellite views of these parking areas are shown in the figures below. (Figures 48-51)

Figure 48: Chemical engineering parking lot area

Figure 49: Civil engineering parking lot area

Figure 50: Science Faculty parking lot area

Figure 51: Technopark parking lot area

Figure 52: Life center parking lot area

CONCLUSION

In this study, a photovoltaic system was designed and simulated on the open car park areas of the library building in the campus of Izmir Institute of Technology. Enact systems software package is used in this simulation and calculations. Enact software uses the PVWatts solar energy calculation tool developed by National Renewable Energy Laboratory which is specially designed to make solar energy calculations.

Library parking area is fully open. Since 3 of 4 rows of parking areas are suitable for panel placement, it was deemed appropriate to build roof over these areas. The total roof area to be built is calculated as 835 square meters and this area also means the total area where the panels will be placed. A total of 560 panels were placed in this area. The annual production of the designed system is calculated as approximately 302 000 kWh. When examined on a monthly production basis, the simulated system produces to meet 25% to 80% of the monthly consumptions. In the whole year, the system generates 51% of the annual consumption throughout the year.

Costs such as roof construction, panels, inverters, cables, transportation, and labors in the system design are calculated. The designed system pays off the cost in 8 years period with the savings arising from electricity generation which is calculated by the Enact software.

In order to increase the use of renewable sources, it is essential to increase such studies, especially in universities. Because these studies carried out in universities are doubly important as they are both encouraging and cause an increase in the number of competent people in this field.

REFERENCES

[1] BP. Full report –BP Statistical Review of World Energy 2021. <*www.bp.com/statisticalreview*>, accessed 05/05/2022.

[2] Zheng, X. *et al.* A review of greenhouse gas emission profiles, dynamics, and climate change mitigation efforts across the key climate change players. *Journal of Cleaner Production* 234, 1113–1133 (2019).

[3] BP. BP Statistical Review of World Energy 2020. <*www.bp.com/statisticalreview*>, accessed 03/05/2022

[4] UN- United Nations. ADOPTION OF THE PARIS AGREEMENT 2015- Paris Agreement text English.

[5] Energy Agency, I. Renewables 2021 - Analysis and forecast to 2026. <*www.iea.org/t&c/*> (2021). accessed 06/05/2022.

[6] UN- United Nations. UN Climate Change Conference UK 2021- COP26-Negotiations-Explained.

[7] Thirugnanasambandam, M., Iniyan, S. & Goic, R. A review of solar thermal technologies. *Renewable and Sustainable Energy Reviews* 14, 312–322 (2010).

[8] Solar module prices not expected to stabilize until 2024: analysts | IHS Markit. <*https://cleanenergynews.ihsmarkit.com/research-analysis/solar-module-prices-not-expected-to-stabilize-until-mid2024-an.html*>, accessed 10/05/2022

[9] Kannan, N. & Vakeesan, D. Solar energy for future world: - A review. *Renewable and Sustainable Energy Reviews* 62, 1092–1105 (2016).

[10] Radyasyon Mevsimler - Meteoroloji Genel Müdürlüğü. <*https://mgm.gov.tr/kurumici/radyasyon_iller.aspx*>, accessed 12/05/2022

[11] Kucukali, S. & Baris, K. *Renewable energy policy in Turkey*. (2011).

[12] Elektrik Piyasası Kanunu ile Bazı Kanunlarda Değişiklik Yapılmasına Dair Kanun (EPKBKDYDK), Resmi Gazete 31322 (2/12/2020), Kanun No. 7257, md. 23

[13] Yenilenebilir Enerji Kaynaklarının Elektrik Enerjisi Üretimi Amaçlı Kullanımına İlişkin Kanun (YEKEEÜAKİK), Resmi Gazete 25819 (15/05/2005), Kanun No. 5346.

[14] Kurulu Güç Raporları. Türkiye Elektrik İletim A.Ş., <*https://www.teias.gov.tr/tr-TR/kurulu-guc-raporlari*>, accessed 13/05/2022

[15] European Construction Industry Federation (FIEC)- Turkey Statistical Report. <*https://fiec-statistical-report.eu/turkey*>, accessed 13/05/2022

[16] Ecofys, Istanbul Aydın University, IZODER- Turkish Building Sector Energy Efficiency Technology Atlas Executive Summary and Roadmap (June 2018), <*https://www.giz.de/de/downloads/giz2019-en-turkish-building-sector.pdf*>

[17] Energy Agency, I. Turkey 2021 - Energy Policy Review. <*www.iea.org/t&c/*>, acceseed 13/05/2022

[18] Acar, A., Sarı, A. C. & Taranto, Y. *Rooftop solar energy potential in buildings-financing models and policies for the deployment of rooftop solar energy systems in Turkey*. (2020).

[19] Celik, A. N. Present status of photovoltaic energy in Turkey and life cycle techno-economic analysis of a grid-connected photovoltaic-house. *Renewable and Sustainable Energy Reviews* 10, 370–387 (2006).

[20] Akpolat *et al.* Performance Analysis of a Grid-Connected Rooftop Solar Photovoltaic System. *Electronics (Basel)* 8, 905 (2019).

[21] Kılıç, U. & Kekezoğlu, B. A review of solar photovoltaic incentives and Policy: Selected countries and Turkey. *Ain Shams Engineering Journal* **13**, 101669 (2022).

[22] Duman, A. C. & Güler, Ö. Economic analysis of grid-connected residential rooftop PV systems in Turkey. *Renewable Energy* 148, 697–711 (2020).

[23] Kutlu, E. Ceren (2020). Technical Potential of Rooftop Solar Photovoltaic for Ankara: A Preliminary Study, MSc Thesis, Middle East Technical University, Ankara.

[24] Ceylan, M. (2018). Kampüs Binalarında Şebekeden Bağımsız Bir Çatı Üstü Fotovoltaik Sistem Tasarımı ve Benzetimi, MSc Thesis, Istanbul Technical University, Istanbul.

[25] Keskinel, S. (2015). Enerji Verimliliği Kapsamında Binalarda Fotovoltaik Güç Sistemlerinin Uygulamalı Analizi, MSc Thesis, Istanbul Technical University, Istanbul.

[26] Ali, S. M. H. (2015). Optimal Photovoltaic Size Estimation for a Campus Area Considering Uncertainties in Load, Power Generation and Electricity Rates, MSc Thesis, Middle East Technical University Northern Cyprus Campus, Northern Cyprus Turkish Republic.

[27] Fuzen. List of Solar PV Design Software Tools. <*https://www.fuzen.io/solar-epc/list-of-solar-pv-design-software-tools/#other*>, accessed 01/06/2022.

[28] İzmir Institute of Technology, Wikipedia, Wikimedia Foundation, 26 February 2022, <*https://en.wikipedia.org/wiki/İzmir_Institute_of_Technology*>, accessed 01/06/2022.

[29] İzmir Institute of Technology. (n.d.). General Information, Retrieved June 1, 2022, from <*https://en.iyte.edu.tr/about/general-information/*>, accessed 01/06/2022.

[30] IZTECH Library. (n.d.) General Information, Retrieved June 1, 2022, from <*https://library.iyte.edu.tr/en/about-us/general-information/*>, accessed 01/06/2022

[31] İzmir Yüksek Teknoloji Enstitüsü Yapı İşleri ve Teknik Daire Başkanlığı. 2020 Yılı Faaliyet Raporu (Ocak 2020). <*https://yapi.iyte.edu.tr/wp-content/uploads/sites/109/2021/02/2020-Y%C4%B1l%C4%B1-Yap%C4%B1-%C4%B0%C5%9Fleri-ve-Teknik-Daire-Ba%C5%9Fkanl%C4%B1%C4%9F%C4%B1-Birim-Faaliyet-Raporu.pdf*>, accessed 02/06/2022

[32] Yadav, A. K. & Chandel, S. S. Tilt angle optimization to maximize incident solar radiation: A review. *Renewable and Sustainable Energy Reviews* **23**, 503–513 (2013).

[33] Bawazir R. O., Çetin N. S, Chakchak J. and Ulgen K. "Invest Investigating the Optimum Tilt Angle for Solar Receiver in Izmir" in ISEM2016: 3rd International Symposium on Environment and Morality, November 2016, Alanya, Turkey. Available: <*https://www.researchgate.net/publication/333042042_Investigating_the_Optimum_Tilt_Angle_for_Solar_Receiver_in_Izmir*>, accessed 03/06/2022

[34] Bakirci, K. General models for optimum tilt angles of solar panels: Turkey case study. *Renewable and Sustainable Energy Reviews* 16, 6149–6159 (2012).

[35] Conceição, R., González-Aguilar, J., Merrouni, A. A. & Romero, M. Soiling effect in solar energy conversion systems: A review. *Renewable and Sustainable Energy Reviews* 162, 112434 (2022).

[36] My Enerji solar. (n.d.). *100 kW Güneş Enerjisi Kurulum Maliyeti 2021,* Retrieved June 5, 2022, from <*https://www.myenerjisolar.com/100-kw-gunes-enerjisi-kurulum-maliyeti-2021/#:~:text=Toplamda%20100%20KW%20Güneş%20Enerjisi,USD%2FMWp%20arasında%20değişeceği%20hesaplanmalıdır.>,* accessed 05/06/2022.

[37] URL1, <*https://globalsolaratlas.info/map?c=39.749434,31.530762,6&s=38.308797,26.648712&m=site* >, accessed 20/04/2022

[39] URL2, < *https://mgm.gov.tr/kurumici/turkiye-guneslenme-suresi.aspx* >, accessed 01/05/2022

[40] URL3, < *https://helioscsp.com/first-concentrated-solar-power-plant-in-chile-and-latin-america-has-80-progress/* >, accessed 03/05/2022

[41] URL4, < *https://en.wikipedia.org/wiki/Solar_thermal_energy* >, accessed 03/05/2022

[42] URL5, < *https://www.enerjiatlasi.com/gunes-enerjisi-haritasi/turkiye* >, accessed 04/05/2022

[43] URL6, < *https://www.epdk.gov.tr/Detay/Icerik/3-0-23-3/elektrikaylik-sektor-raporlar* >, accessed 08/05/2022

[44] URL7, < *https://enact-systems.com/* >, accessed 06/05/2022

[45] URL8, < *https://pvwatts.nrel.gov/pvwatts.php* >, accessed 15/05/2022

[46] URL9, < *https://yapi.iyte.edu.tr* >, accessed 19/05/2022

[47] Google Earth Pro V 7.3.2.5776. (May 10, 2021). Urla, Turkey. 38°19’12.73” N, 26°38’24.96” E, Eye alt 93 m. Maxar Technologies, accessed 20/05/2022

APPENDIX A

ESTIMATED CASH FLOW OF PROJECT

YR	Pre-Solar Electric Bill	Post-Solar Electric Bill	Down Payment & Maintenance	Net Savings	Cu Net Savings
0	TRY 0	TRY 0	-TRY 4,600,000	-TRY 4,600,000	-TRY 4,600,000
1	TRY 1,235,108	TRY 613,566	TRY 44,800	TRY 490,231	-TRY 4,109,769
2	TRY 1,296,863	TRY 647,507	TRY 44,800	TRY 513,873	-TRY 3,595,897
3	TRY 1,361,707	TRY 683,292	TRY 44,800	TRY 538,572	-TRY 3,057,324
4	TRY 1,429,792	TRY 721,018	TRY 44,800	TRY 564,378	-TRY 2,492,947
5	TRY 1,501,282	TRY 760,790	TRY 44,800	TRY 591,338	-TRY 1,901,609
6	TRY 1,576,346	TRY 802,717	TRY 0	TRY 657,584	-TRY 1,244,025
7	TRY 1,655,163	TRY 846,914	TRY 0	TRY 687,011	-TRY 557,013
8	TRY 1,737,921	TRY 893,503	TRY 0	TRY 717,755	TRY 160,742
9	TRY 1,824,817	TRY 942,612	TRY 0	TRY 749,874	TRY 910,616
10	TRY 1,916,058	TRY 994,374	TRY 0	TRY 783,431	TRY 1,694,047
11	TRY 2,011,861	TRY 1,048,931	TRY 0	TRY 818,490	TRY 2,512,537
12	TRY 2,112,454	TRY 1,106,433	TRY 0	TRY 855,117	TRY 3,367,655
13	TRY 2,218,077	TRY 1,167,037	TRY 0	TRY 893,384	TRY 4,261,039
14	TRY 2,328,980	TRY 1,230,906	TRY 0	TRY 933,363	TRY 5,194,402
15	TRY 2,445,429	TRY 1,298,216	TRY 0	TRY 975,131	TRY 6,169,532
16	TRY 2,567,701	TRY 1,369,150	TRY 0	TRY 1,018,768	TRY 7,188,300
17	TRY 2,696,086	TRY 1,443,900	TRY 0	TRY 1,064,358	TRY 8,252,658
18	TRY 2,830,890	TRY 1,522,669	TRY 0	TRY 1,111,988	TRY 9,364,646
19	TRY 2,972,435	TRY 1,605,670	TRY 0	TRY 1,161,750	TRY 10,526,396
20	TRY 3,121,056	TRY 1,693,129	TRY 0	TRY 1,213,738	TRY 11,740,134
21	TRY 3,277,109	TRY 1,785,282	TRY 0	TRY 1,268,053	TRY 13,008,186
22	TRY 3,440,965	TRY 1,882,379	TRY 0	TRY 1,324,798	TRY 14,332,985
23	TRY 3,613,013	TRY 1,984,680	TRY 0	TRY 1,384,083	TRY 15,717,067
24	TRY 3,793,664	TRY 2,092,463	TRY 0	TRY 1,446,021	TRY 17,163,088
25	TRY 3,983,347	TRY 2,206,017	TRY 0	TRY 1,510,730	TRY 18,673,819