Power generation by using Photovoltaic systems for Yanbu and Rabigh regions in Saudi Arabia: a cost-effective study

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Abstract: Saudi Arabia's power producing capacity will need to be expanded to meet anticipated increases in energy consumption. The expansion of solar energy consumption in Saudi Arabia has a promising future, owing to the availability of strong solar radiation, a huge rain-free territory, and lengthy sunshine. The Kingdom intends to enhance solar energy generation in order to fulfill a significant portion of the nation's future energy requirements. To accomplish its solar energy aims, the monarchy is now undertaking a variety of installations and research projects. As a result, the most current improvements to the country's solar business are critical for advancing Research and Development (R&D). The area of Yanbu and Rabigh was previously studied by the student Qasim Alabdali in 2021. In this research, the student Abdulaziz Shendi will continue the previous research by studying the two areas in addition to drawing using the SketchUp program and a feasibility study of total costs for the project. Current situation of the Saudi Arabian solar sector and its prospective possibilities.

Additionally, the study initiative intends to conduct a comprehensive research study of the Yanbu and Rabigh areas of the Kingdom. For the Yanbu and Rabigh area, a feasibility study will be done in order to determine if solar energy can be produced there and whether there are acceptable locations and amounts of energy produced. As well as securing the top high-efficiency solar panel manufacturers and incorporating their products into the PVsyst program for use in our studies. First, select the appropriate sort of solar cells for Yanbu and Rabigh areas. Then, calculate the project's total cost in Saudi riyals for the On-Grid system. Besides, using SketchUp program, create a 2D or 3D model of an integrated On-Grid system. Finally, select the study region on the map and use PVsyst program to compute the area.

Keywords: Energy, Solar, Power, Electricity, Photovoltaic, Saudi Arabia.

توليد الطاقة باستخدام الأنظمة الكهروضوئية لمنطقتي ينبع ورابغ في المملكة العربية السعودية: دراسة فعالة من حيث التكلفة

الملخص: ستحتاج المملكة العربية السعودية إلى توسيع قدرة إنتاج الطاقة لمواجهة الزيادات المتوقعة في استهلاك الطاقة. إن التوسع في استهلاك الطاقة الشمسية في المملكة العربية السعودية له مستقبل واعد ، نظرًا لتوفر إشعاع شمسي قوي ، ومنطقة شاسعة خالية من الأمطار ، وضوء الشمس الطويل. تعتزم المملكة تعزيز توليد الطاقة الشمسية من أجل تلبية جزء كبير من متطلبات الطاقة المستقبلية للأمة. لتحقيق أهداف الطاقة الشمسية ، يقوم النظام الملكي الآن بمجموعة متنوعة من المنشآت والمشاريع البحثية. نتيجة لذلك ، تعد أحدث التحسينات في أعمال الطاقة الشمسية في البلاد بالغة الأهمية لتعزيز البحث والتطوير .(R & D) سبق للطالب قاسم العبدلي أن درس منطقة ينبع ورابغ عام 2021. وفي هذا البحث سيواصل الطالب عبدالعزيز شندي البحث السابق بدراسة المجالين بالإضافة إلى الرسم باستخدام برنامج SketchUp ودراسة جدوى التكاليف الإجمالية. للمشروع. الوضع الحالي لقطاع الطاقة الشمسية في المملكة العربية السعودية وإمكانياته المستقبلية.

تهدف المبادرة الدراسية إلى إجراء دراسة بحثية شاملة لمنطقتي ينبع ورابغ بالمملكة. بالنسبة لمنطقة ينبع ورابغ ، سيتم إجراء دراسة جدوى لتحديد ما إذا كان يمكن إنتاج الطاقة الشمسية هناك وما إذا كانت هناك مواقع وكميات مقبولة من الطاقة المنتجة. بالإضافة إلى تأمين أفضل مصنعي الألواح الشمسية عالية الكفاءة ودمج منتجاتهم في برنامج PVsyst لاستخدامها في دراساتنا. أولاً ، حدد نوع الخلايا الشمسية المناسب لمنطقتي ينبع ورابغ. ثم احسب التكلفة الإجمالية للمشروع بالريال السعودي لنظام .On-Grid بالإضافة إلى ذلك ، باستخدام برنامج SketchUp ، قم بإنشاء نموذج ثنائي الأبعاد أو ثلاثي الأبعاد لنظام مدمج على الشبكة. أخيرًا ، حدد منطقة الدراسة على الخريطة واستخدم برنامج PVsyst لحساب المنطقة.

1. Introduction

The Kingdom of Saudi Arabia (KSA) recognizes the necessity of a diverse energy mix, as well as the spread of renewable energy technology, for its long-term socioeconomic success. As a result, the country's National Renewable Energy Program (NREP) and National Transformation Program (NTP), administered by the Ministry of Energy, Industry, and Mineral Resources, have devised a roadmap for the promotion and deployment of RETs in order to meet KSA's future energy demand. On April 25, 2016, KSA made public for the first time the contents of Vision 2030, with an initial objective of 50 percent renewable power [1]. On June 7, 2016, the Ministry of Energy, Industry, and Mineral Resources revealed that the Kingdom of Saudi Arabia changed Vision 2030 to reduce the renewable energy deployment objective to 10% of power production from renewables in its energy mix, down from 50% before. The updated objectives for 2020 and 2023 were 3.45 GW and 9.5 GW, respectively [2]. In order to meet the increased objective of 3.45 GW in 2020, the KSA Renewable Energy Project Development Office (REPDO) submitted a request for proposal (RFP) in 2018 for a 300 MW grid-connected solar power plant in Sakaka [3] and a 400 MW wind power plant in Dumat Al-Jandal [4]. The Saudi Renewable Energy Project Development Office (REPDO) amended the Vision 2030 goals for the second time in January 2019. The updated plans include a significant increase in RE targets, from 9.5 GW to 27.3 GW in 2023, with an overall target of 58.7 GW in 2030. As indicated in Figure 1, of this 58.7 GW, 40 GW will be solar PV, 16 GW will be wind, and 2.7 GW will be other RE sources by 2030 [5], as shown in Figure 1.

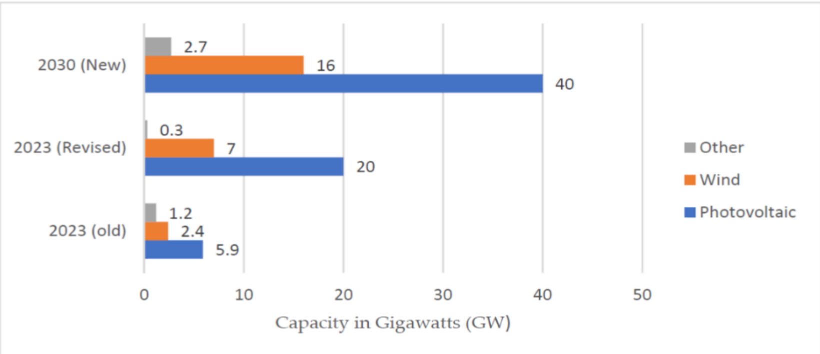

Figure 1. Revised renewable targets of KSA's Vision 2030.

1.2 Electricity

Saudi Arabia produced the most electricity in the Middle East, with an estimated 362 terawatt hours in 2019, almost the same as in 2018 [6]. After expanding at a 6% annual pace between 2000 and 2015, power generation growth has slowed dramatically as population growth has slowed, GDP growth has slowed, energy efficiency and demand-side control measures have been introduced, and electricity costs have risen between 2016 and 2018 [7].

According to statistics from the BP Statistical Review of World Energy 2021, power production fell by 1% in 2020 because of the contraction caused by the COVID-19 pandemic [8]. Residential power usage increased as a result of COVID-19-related lockdowns and limitations, whereas business and government energy sales declined [9].

In 2020, Saudi Arabia powered virtually all of its electricity production with natural gas (61%) and crude oil (39%), however the Saudi government intends to diversify fuels used for electricity generation in order to boost accessible crude oil for export and minimize carbon emissions (Figure 2).

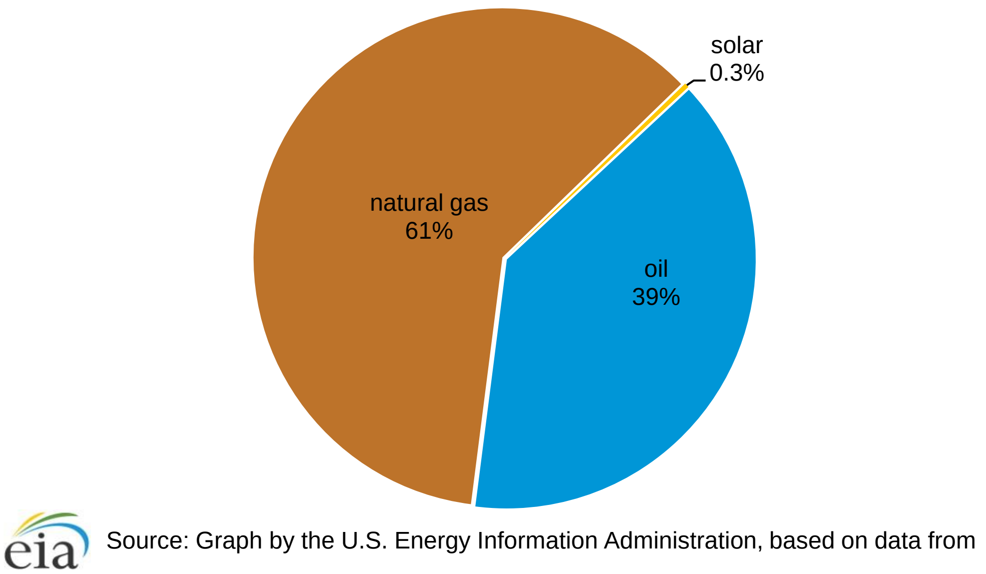

Figure 2. Saudi Arabia's electric power generation by fuel, 2020

1.3 Research Problem

Unpolluted air is a fundamental need for human health, yet air pollution continues to be a global hazard to public health. The traditional electricity-generation business is a major source of hazardous gases that pollute the environment. Low-quality fuels and typical Saudi Arabian generating techniques (such as crude oil with high sulfur content in power plants with little emission controls) produce a range of pollutants that contribute to public health concerns [10].

Conventional power plants release greenhouse gases such as CO_2, NO_x, and SO_2) all of which have been linked to global warming. The Kingdom of Saudi Arabia was identified as a major CO_2 emitter, accounting for about 1.8 percent of world emissions in 2017 [11]. As shown in Figure 3, the country's yearly CO_2 emissions were estimated to reach 559.6 million tons in 2019, a significant rise from 394.68 million tons in 2007 [11].

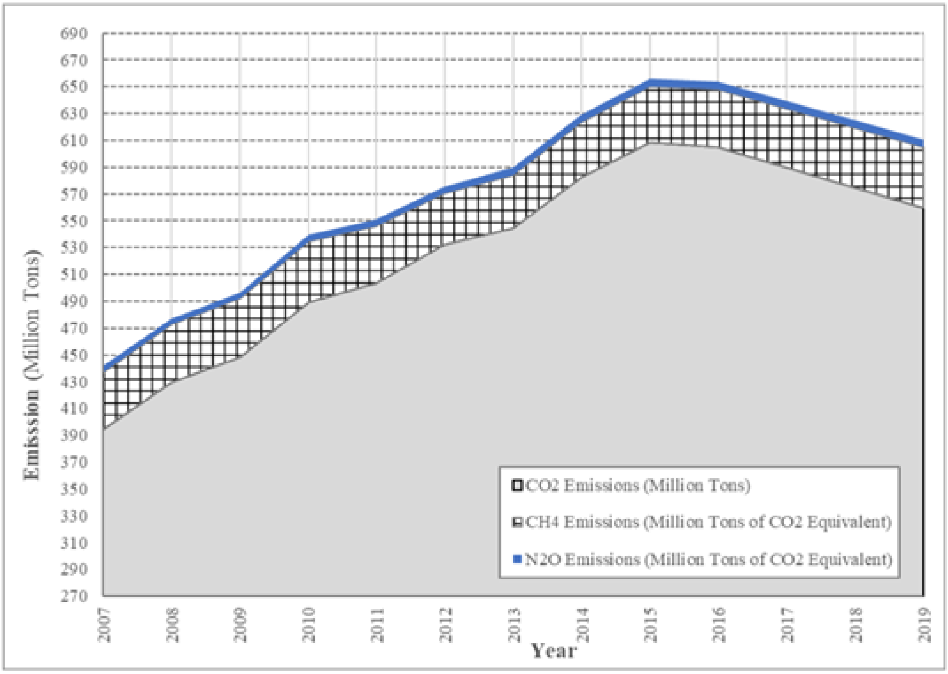

Figure 3. GHG emissions from the energy sector of Saudi Arabia [11].

CO_2 emissions have climbed by about 11% in the previous 10 years. A similar pattern has been seen for CH_4 and NO_x emissions. From 41.88 million tons of CO_2 equivalents (CO_2e) in 2007 to 44.97 million tons CO_2e in 2019, CH_4 emissions have grown. Overall emissions of CO_2 from the electrical field are the greatest contribution to total GHG emissions in the nation, which have climbed by 22% between 2012 and 2017 becouse of consistent expansion in practically all sectors. In 2017, the primary fields of CO_2 emissions were industry (38%), power, heating, and others (38%), transportation of road (23%), and home, agriculture, and services (1%). According to prior data, power generating is one of Saudi Arabia's major CO_2 and CH_4 emitting industries. As a result, in accordance with Saudi Vision 2030, the Kingdom has been attempting to cut GHG emissions by gradually eliminating subsidies for fossil fuels. It has previously said that it intends to reduce its annual carbon dioxide emissions by up to 130 metric tons by 2030 [12].

The demand for electricity in Saudi Arabia rises at a 5.8 percent annual rate [13] due to a variety of factors such as the rapid rise of economies, population growth, cheap electricity costs, and neglect of energy preservation [14]. In 2008, the nation used 35 GW and could not supply all demand for peak-time applications, causing a lack of energy in certain areas; this volume is anticipated to increase to 70 GW 11 by the year 2023[15]. The population growth and development prosperity in Saudi Arabia are driving up the country's power needs. Continuously increasing loads need enough power generation.

This undoubtedly leads to the running out of fossil fuels, raising environmental worries. Nonetheless, it is recognized as the principal source of environmental pollution and the adverse health effects of conventional fossil fuels caused by polluting gases such as nitric oxide, nitrogen dioxide, nitrous oxide, and carbon oxides.

Consequently, there is a great patriotic need for alternate sources of energy that are ecologically friendly and can readily provide the nation's energy needs in the post-oil era. In Saudi Arabia, an alternative plan to boost existing conventional Saudi generations and safeguards human health and the environment must be developed. This necessitates the development of new techniques for transacting with increasing numbers.

In the 1970s, modest dispersed operations around the Kingdom proved the effectiveness and operational efficiency of the usage of PV systems in collecting power, demonstrating the suitability for domestic conditions. Solar energy is an infinitely renewable source of power production. It was demonstrated to have several features and enormous economic avails, and also to be promising for prospective usage. Saudi Arabia's energy consumption is exacerbated by yearly population expansion, guaranteeing that the sector of residential, which utilizes over half of the nation's yearly energy production, is the dominant user of local energy [16].

Because solar energy is a significant renewable energy source, many organizations and governments have invested in solar energy as a viable alternative to burning fossil fuels.

1.4 Aim and Objective

This research investigates the existing situation in Saudi Arabia as well as the future potential of the solar sector. In addition, the study effort intends to conduct an integrated research study on several places around the Kingdom. A feasibility study will be done to determine the optimum locations for producing solar energy in Saudi Arabia, as well as the sites and amount of energy production. On the map, choose the study region and use the PVsyst application to calculate the area. Then, create a 2D or 3D model of an integrated On-Grid system in SketchUp. In addition to this, research the sunshine tracking system and its installation for solar panels, as well as the possibilities of enhancing energy output with this technology. Furthermore, determine, using diagrams, how to link the solar energy system to the electrical grid. Also, determine and compute the CO_2 emissions saved from projected Saudi Arabian locations by

using a PV system.

1.5 Reducing Emissions in Saudi Arabia

Saudi Arabia would need to reduce its emissions to below 389 Mt CO_2e by 2030 and to below 263 MtCO_2e by 2050 to be within its emissions allowances under a fair-share range compatible with global 1.5°C.

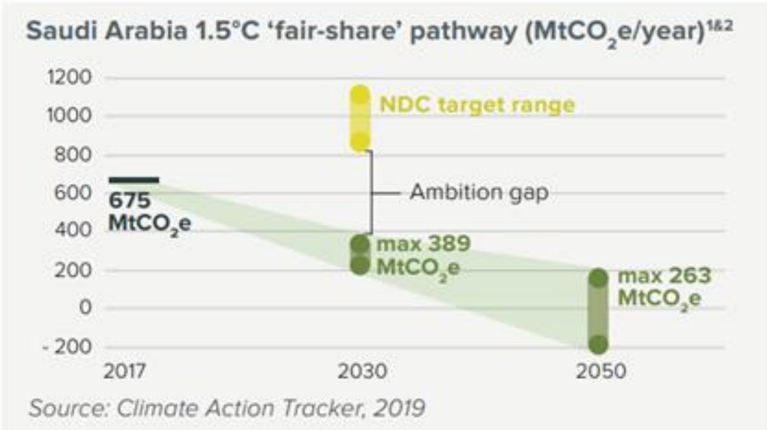

Figure 4. Reducing Emissions in Saudi Arabia 2017 – 2050 [17]

Saudi Arabia does not utilize coal to generate energy; yet, the electrical industry remains heavily reliant on fossil fuels (65 percent natural gas, 35 percent oil). Renewable energy is becoming more important, although it is still insignificant. To be consistent with a 1.5°C trajectory, the percentage of renewables must expand dramatically and quickly [17].

Study photovoltaic energy production in Saudi Arabia

2.1 Simulation and Analysis

2.1.1 A feasibility assessment for the installation of PV systems on the Rabigh region

This section will cover the installation of PV systems for two locations near Saudi Electricity Company's power plants, making it simple to connect PV systems directly to the grid and with short distribution line distances. That sites located in Rabigh and Yanbu. All computations and simulations were carried out using the PVsyst 7.2.12 software, the GLOBAL SOLAR ATLAS, the NOAA SOLAR Calculator, Latlong.net, and Google Earth. Also the reason of this study is calculate how much the CO_2 emissions will decrease. Comparison between Rabigh and Yanbu, which one is better for the solar cell system.

Each site's power generating capacity is anticipated to be 200 MWp. The first site in this study is Rabigh, the Coordinates are (Latitude 22.68°N, Longitude, 39.06°E). The steps as follow:

1: Find Latitude by using Pvsyst program or https://www.latlong.net/

2: Find PV power output by using Pvsyst program or https://gml.noaa.gov/grad/solcalc/

Figure 5. Location of Rabigh project on the map by using Google Earth

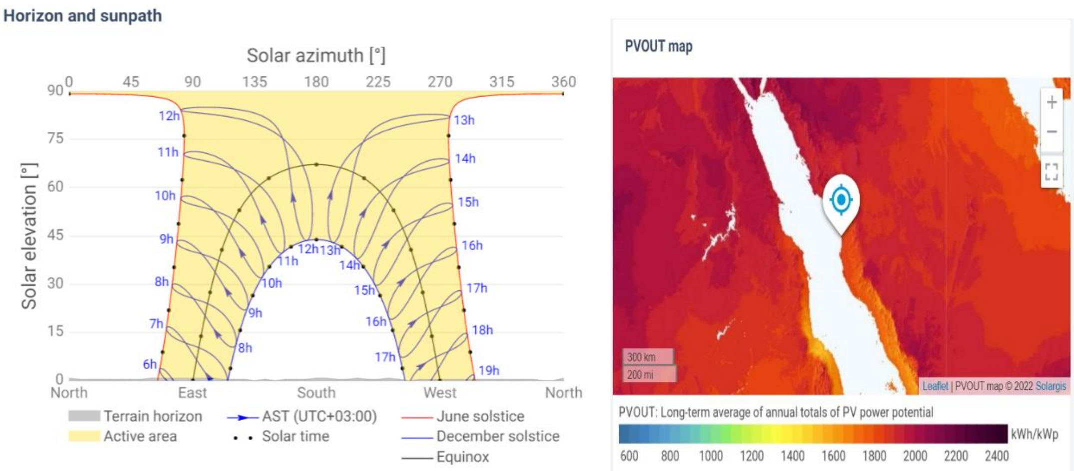

Figure 6. Solar path at Rabigh from January to December & PVOUT by using globalsolaratlas.
Figure 6 (left) relationship between solar elevation , solar azimuth according to sun path to obatin the best solar azimuth for the plant.

Figure 6 (Right) the right map to display the specific producation of the pv plant in Rabigh region measured in KWh/KWp /year

SITE INFO

Map data — Per year

Specific photovoltaic power output	PVOUT specific	**1860.2**	kWh/kWp
Direct normal irradiation	DNI	**2056.5**	kWh/m²
Global horizontal irradiation	GHI	**2251.4**	kWh/m²
Diffuse horizontal irradiation	DIF	**832.4**	kWh/m²
Global tilted irradiation at optimum angle	GTI opta	**2411.0**	kWh/m²
Optimum tilt of PV modules	OPTA	**24 / 180**	°
Air temperature	TEMP	**28.5**	°C
Terrain elevation	ELE	**2**	m

Figure 7. PV power output by using globalsolaratlas

Figure 7 shows general information an summry about the side project like that:

Plant capacity, DNI (direct normal irradiation), DIF (Diffuse horizontal irradiation), GHI (Global horizontal irradiation 2251.4= 832.4 + 2056.6 cos()), tilt angle (24), Azumith angle (180) and nominal temperature (28.5).

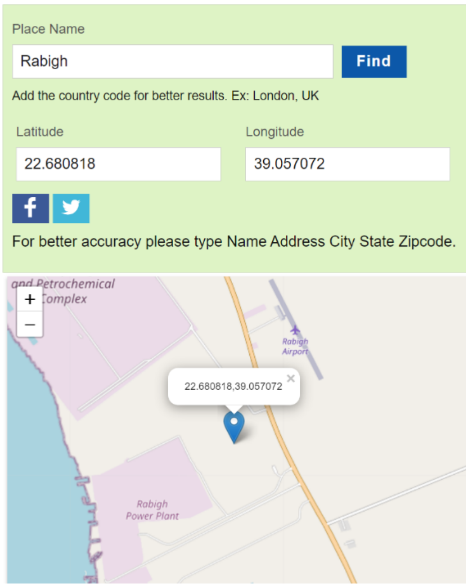

Figure 8. Latitude of Rabigh by using latlong website

Figure 8 shows the latitude which equals 22.680818 degree and longitude which equals 39.057072 for the plant location

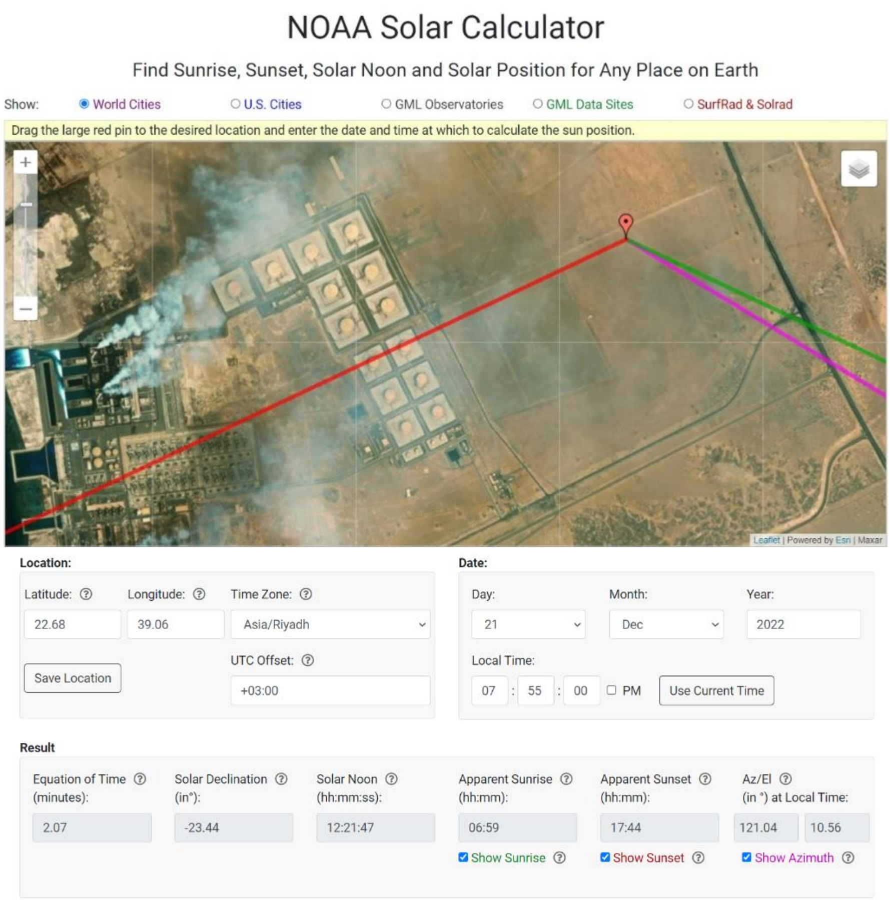

Figure 9. Find Sunrise, Sunset, Azimuth of Rabigh by using NOAA Solar Calculator.

Figure 9 shows the maximum shading time in year and although obtain sunrise, Sunset and solar noon acording to location details (longatude, latitude and time zone)

3: Select type solar panel

4: Calucalte how to installation solar panels and shadow angle

5: calculate Panel tilt: For all year performance panel tilt should be equal Latitude.

- In summer panel Tilt = Latitude – 15

- In winter Panel Tilt = Latitude + 15

2.1.2 Impact of Shading in Rabigh region

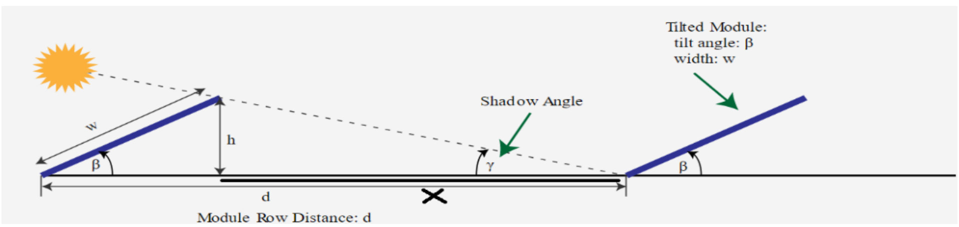

Figure 10. Shadow angle of solar module [18]

To calculate shadow angle should be to know W , h and B

type of solar module type we selected in this research is Jinko solar(JKM540M-72HL4-TV)

Equation of h= sin (latitude angle) x solar panel width (m)

$$\text{Equation of } X = \frac{h}{\tan(\text{shadow angle})}$$

The width of the solar panel in this research is 2.274m and Latitude is 25 , to calculate

h= sin(25)x 2.274= 0.96

Where h is height the solar panel on the surface

To find shadow angle from NOAA website, on December 21 at local time (7:55 AM) we have Y angle= 10.56

$$\text{Now } \tan 10.56 = \frac{h}{X}$$

$$X = \frac{h}{\tan(10.56)}, \text{ where } h = 0.96$$

X= 5.15 m This distance is between the end of the first solar panel and the beginning of the second solar panel, Thus there is no shadow between the solar panels if we leave a distance of 5.15 meters.

So will leave a distance of about 12 meters because to put two solar panels on top of each other. And therefore, there is no shadow between rows of solar modules.

Figure shows below the optimal Azimuth angle and tilt for the Rabigh area; the optimal tilt angle for PV panels is 25 degrees with an azimuth of zero degrees.

The sun path statistics are gathered from the Meteonorm software, which offers an unrivaled mix of accurate data and powerful mathematical materials. This data may be used to get accurate history and information for any period of year.

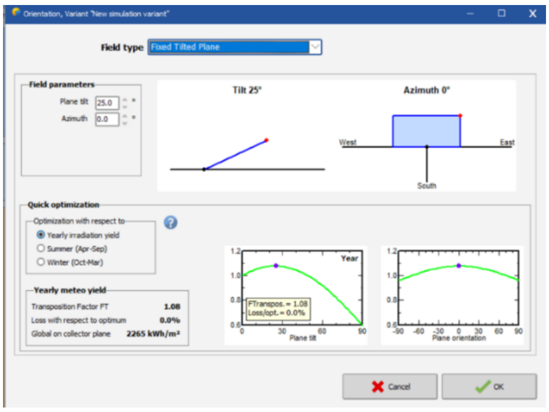

Figure 11. Tilt and Azimuth angle for Rabigh site by using PVSYST

Figure 11 shows the optimum tilt angle and azimuth according to the plant location with optimization with respect to yearly irradiation yield and the loses of the plant with respect to the optimum. In this system, roughly (366,984) PV modules with unit nominal power (540wp) will be used to produce 200MWp, and the modules connection design will be (13592 strings)*(27 series)

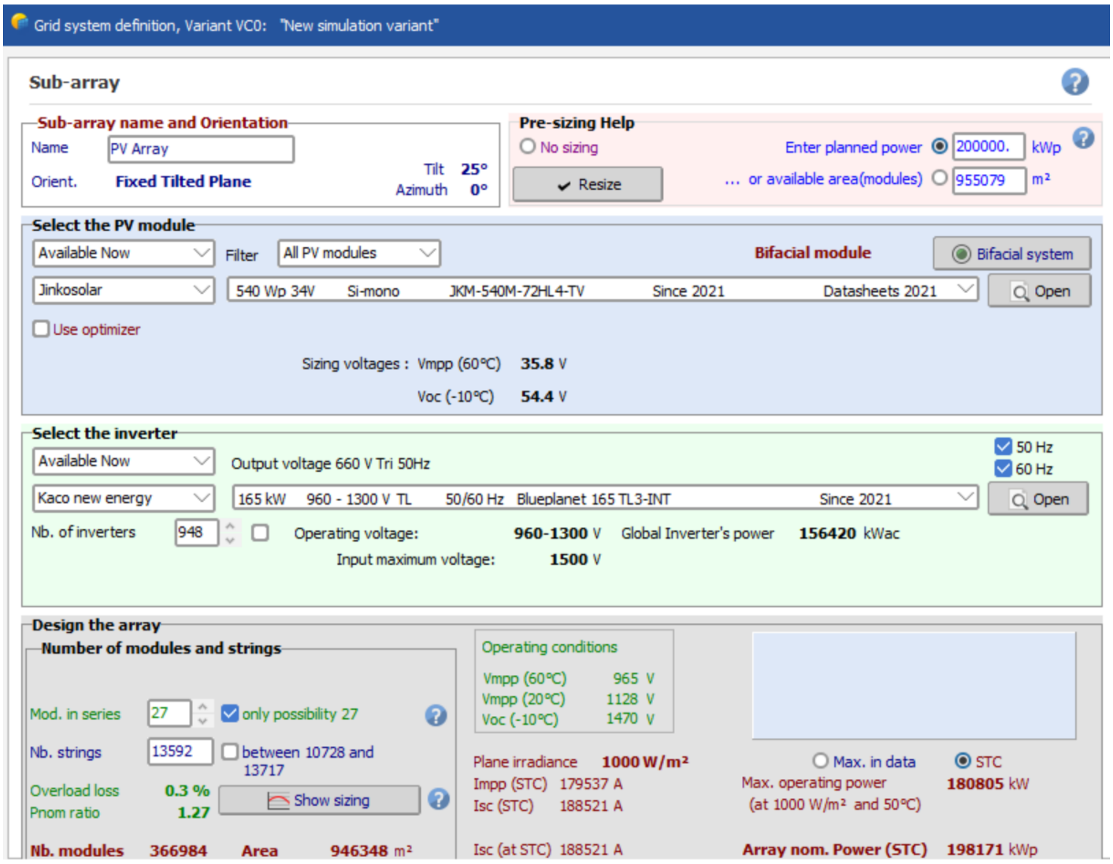

Figure 12. shows the distribution number of modules and PV strings.

Figure 12 shows the orientation of the plant, the plant capacity and area, the used PV module, the used inverter, its number, operating voltage and the design of the array which contain 13592 strings each string have 27 modules, with over sizing ratio 127%

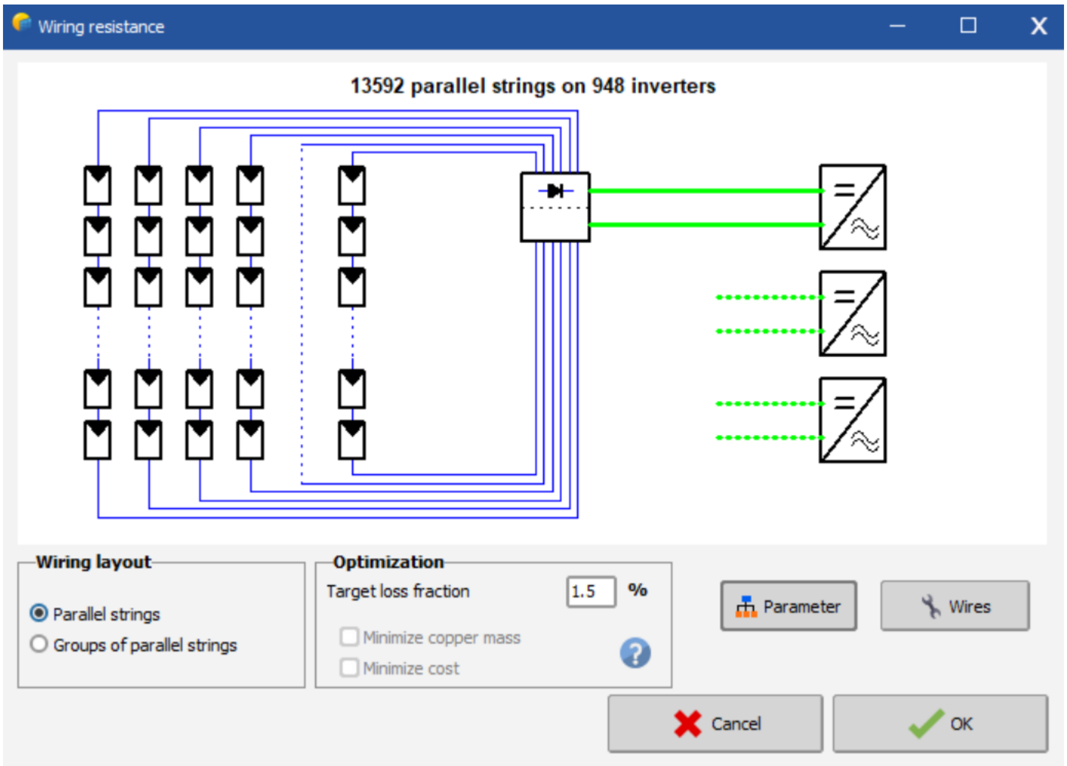

Figure 13. Connecting solar panels strings with inverter

Figure 13 shows single line diagram of the plant (strings to inverters)

Loss fraction is the ratio between Ohmic losses and output AC power

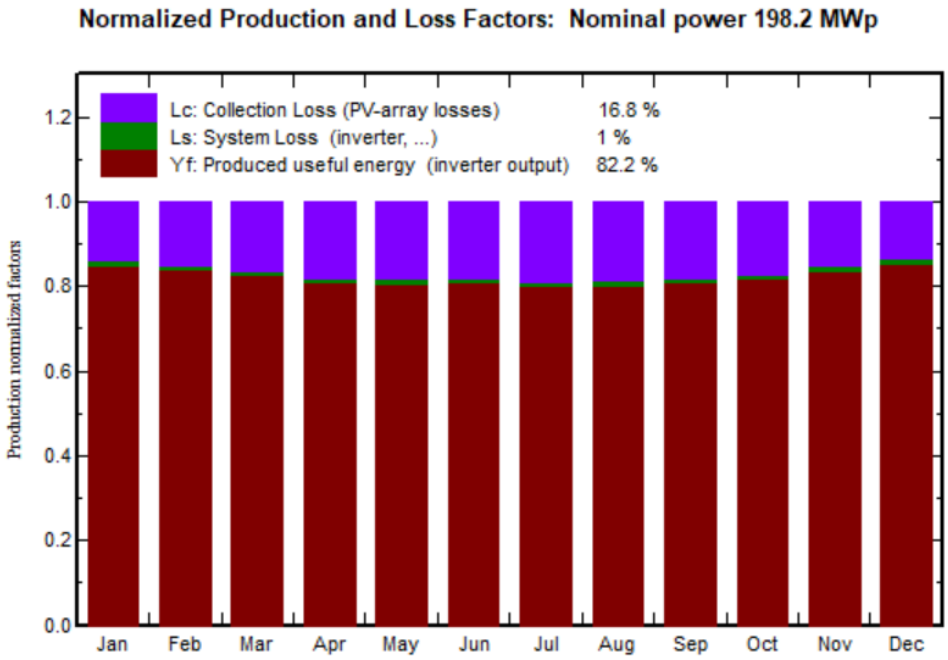

Figure 14. Normalized production and loss factors of Rabigh Site

Diagram 14 displays produced energy from the plant (82.2% * 198.2 MWp= 162.9 MWp) , systems losses (1% * 198.2 MWp = 1.92 MWp) and collection losses (16.8% * 198.2 MWp= 33.279MWp). Note that: the plant supposed to generate 198.2 MWp, but due to collection and system losses we get only 162.9 MWp.

New simulation variant

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New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray GWh	E_Grid GWh	PR ratio
January	142.7	39.4	22.17	190.5	188.2	32.47	32.06	0.849
February	147.3	49.6	23.47	179.8	177.2	30.32	29.94	0.840
March	187.2	69.6	26.20	206.3	202.7	34.20	33.79	0.827
April	210.8	69.8	28.91	211.2	207.2	34.23	33.81	0.808
May	213.7	91.4	32.22	197.8	193.3	32.00	31.63	0.807
June	203.8	97.1	33.18	182.8	178.5	29.71	29.37	0.811
July	209.2	97.3	34.65	190.4	186.2	30.61	30.26	0.802
August	188.8	100.0	34.25	182.6	178.9	29.40	29.06	0.803
September	172.6	80.5	31.91	181.1	177.8	29.42	29.07	0.810
October	163.1	68.7	30.14	189.2	186.3	31.02	30.65	0.818
November	138.7	47.1	26.88	179.1	176.6	30.04	29.68	0.836
December	126.3	45.8	24.03	170.3	167.9	29.18	28.83	0.854
Year	2104.1	856.2	29.03	2261.1	2220.8	372.59	368.13	0.822

Table 1. The total power generation of Rabigh site

Table 1 shows monthly for total power generation of Rabigh site where (DiffHor is Horizontal diffuse irradiation, GlobHor is Global horizontal irradiation, GlobInc Global is incident in coll. Plane, T_Amb is Ambient Temperature, GlobEff Effective Global, corr for IAM and shadings, EArray is Effective energy at the output of the array, E_Grid is Energy injected into grid, PR is Performance Ratio. Finally, the plant will injected in to grid 368.13 GWh energy).

PR is the performance ratio that measure the quality of the PV plant that is independent of location and also describes as the quality factor on the plant, ranging from 80 to 100 percent. PR= Actual reading of plant output in KWh/ nominl plant output in KWh

New simulation variant

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New simulation variant

Monthly Hourly sums for E_Grid [MWh]

	0H	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H	21H	22H	23H
January	0	0	0	0	0	0	0	73	1721	3133	4062	4505	4646	4551	4071	3191	1858	251	0	0	0	0	0	0
February	0	0	0	0	0	0	0	277	1554	2737	3625	4114	4254	4171	3746	2942	1856	668	0	0	0	0	0	0
March	0	0	0	0	0	0	0	706	2012	3208	4058	4489	4609	4503	4062	3236	2096	812	2	0	0	0	0	0
April	0	0	0	0	0	0	105	1008	2270	3362	4096	4414	4437	4300	3903	3116	1993	776	30	0	0	0	0	0
May	0	0	0	0	0	0	265	1075	2177	3148	3842	4144	4118	3940	3521	2802	1769	747	83	0	0	0	0	0
June	0	0	0	0	0	0	286	961	1927	2810	3494	3822	3857	3671	3238	2582	1721	782	218	0	0	0	0	0
July	0	0	0	0	0	0	241	903	1933	2897	3567	3883	3991	3775	3421	2767	1821	842	219	0	0	0	0	0
August	0	0	0	0	0	0	105	817	1787	2813	3547	3791	3869	3754	3332	2664	1723	772	86	0	0	0	0	0
September	0	0	0	0	0	0	48	932	2087	3055	3763	3950	3967	3655	3206	2442	1465	501	1	0	0	0	0	0
October	0	0	0	0	0	0	8	985	2223	3286	3985	4333	4266	4058	3481	2528	1321	176	0	0	0	0	0	0
November	0	0	0	0	0	0	0	855	2064	3144	3882	4213	4288	4072	3473	2458	1225	11	0	0	0	0	0	0
December	0	0	0	0	0	0	0	390	1776	2971	3795	4170	4242	4028	3536	2539	1363	23	0	0	0	0	0	0
Year	-3	-3	-3	-3	-3	-3	1057	8983	23531	36565	45716	49828	50545	48479	42990	33266	20210	6362	638	-3	-3	-3	-3	-3

Table 2. Monthly Hourly sums for E-Grid [MWh]

Table 2 shows the hourly-monthly energy generated for 24 hours note that we will find the plant is generating energy from April to September from 6:00AM to 6:00 PM, So the plant will generate energy for 12 hours for 6 months per year. With absence the sun, the inverters consume energy as self-consumption.

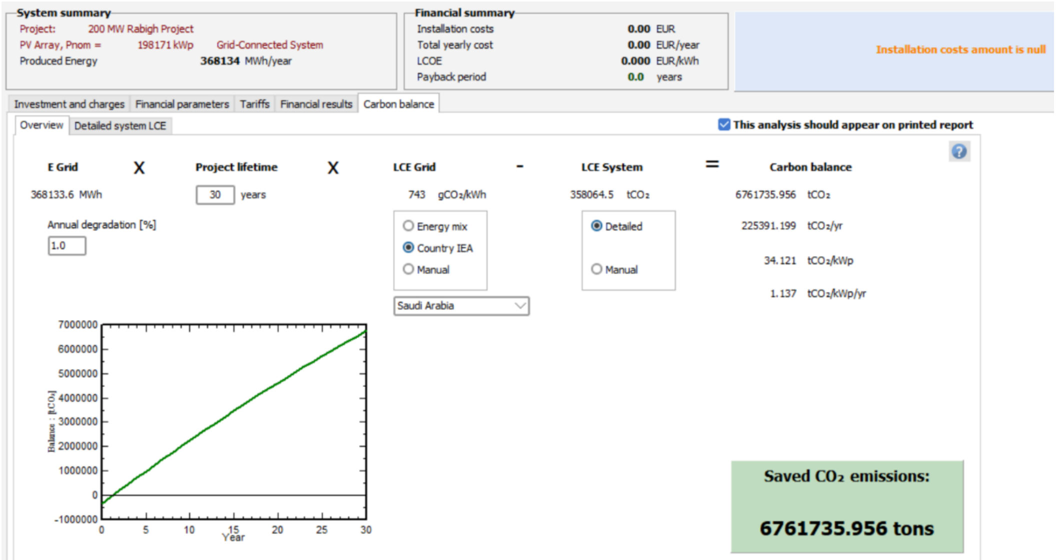

Figure 15. CO2 emissions saved at Rabigh site

Figure 15 shows the quantity of CO_2 emissions saved by building the plant in Rabigh region for 30 years, the plant will saved 6761735.956 tons of CO_2 emissions.

2.3 A feasibility assessment for the installation of PV systems on the Yanbu region

This section will cover the installation of PV systems for two locations near Saudi Electricity Company's power plants, making it simple to connect PV systems directly to the grid and with short distribution line distances. That sites located in Rabigh and Yanbu. All computations and simulations were carried out using the PVsyst 7.2.12 software, the GLOBAL SOLAR ATLAS. Also, the reason of this study is calculating how much the CO_2 emissions will decrease. Comparison between Rabigh and Yanbu, which one is better for the solar cell system. Each site's power generating capacity is anticipated to be 200 MWp. • The second site in this study is Yanbu, the Coordinates are (Latitude 23.91°N, Longitude, 38.33°E). The steps as follow: First: Find Latitude by using Pvsyst program or https://www.latlong.net/. Second: Find PV power output by using Pvsyst program or https://gml.noaa.gov/grad/solcalc/

Figure 16. Location of Yanbu project on the map by using Google Earth

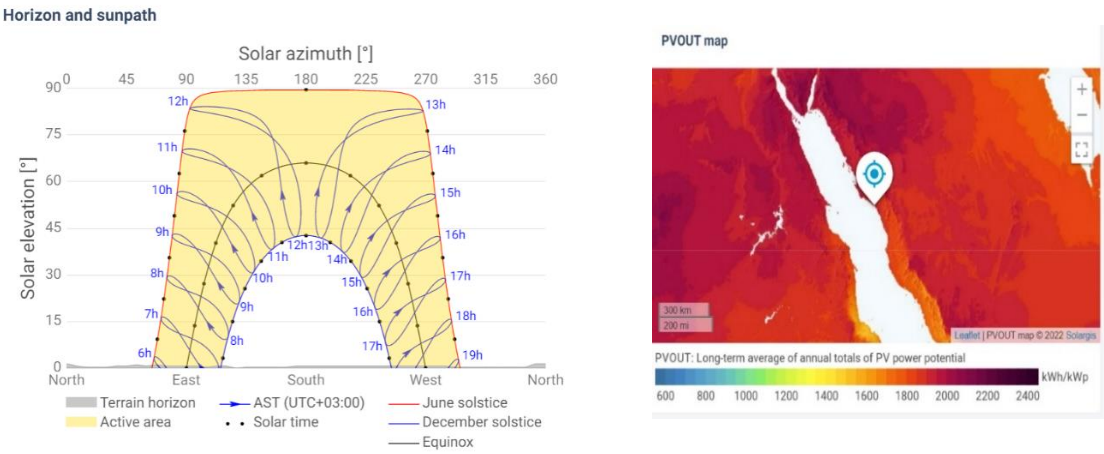

Figure 17. Solar path at Yanbu from January to December & PVOUT by using globalsolaratlas.

Figure 17 (left) shows the relationship between solar elevation , solar azimuth according to sun path to obatin the best solar azimuth for the plant.

Figure 17 (Right) shows the right map to display the specific producation of the pv plant in Rabigh region measured in KWh/KWp /year

Map data — Per year

Specific photovoltaic power output	PVOUT specific	1890.0	kWh/kWp
Direct normal irradiation	DNI	2137.7	kWh/m²
Global horizontal irradiation	GHI	2253.8	kWh/m²
Diffuse horizontal irradiation	DIF	802.5	kWh/m²
Global tilted irradiation at optimum angle	GTI opta	2429.4	kWh/m²
Optimum tilt of PV modules	OPTA	24 / 180	°
Air temperature	TEMP	27.6	°C
Terrain elevation	ELE	2	m

Figure 18. Find PV power output of Yanbu by using globalsolaratlas.

Figure 18 shows general information an summry about the side project like that:
Plant capacity, DNI (direct normal irradiation = 2137.7 kWh/m²), DIF (Diffuse horizontal irradiation is 802.5 kWh/m²), GHI (Global horizontal irradiation is 2253.8 kWh/m²), tilt angle (24°), Azumith angle (180°) and nominal temperature (27.6 °C).

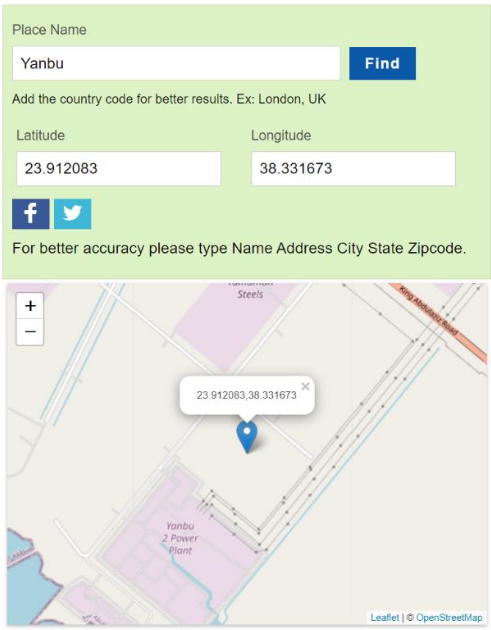

Figure 19. Latitude of Yanbu by using latlong website

Figure 19 shows the latitude which equals 23.912083 degree and longitude which equals 38.331673 for the plant location

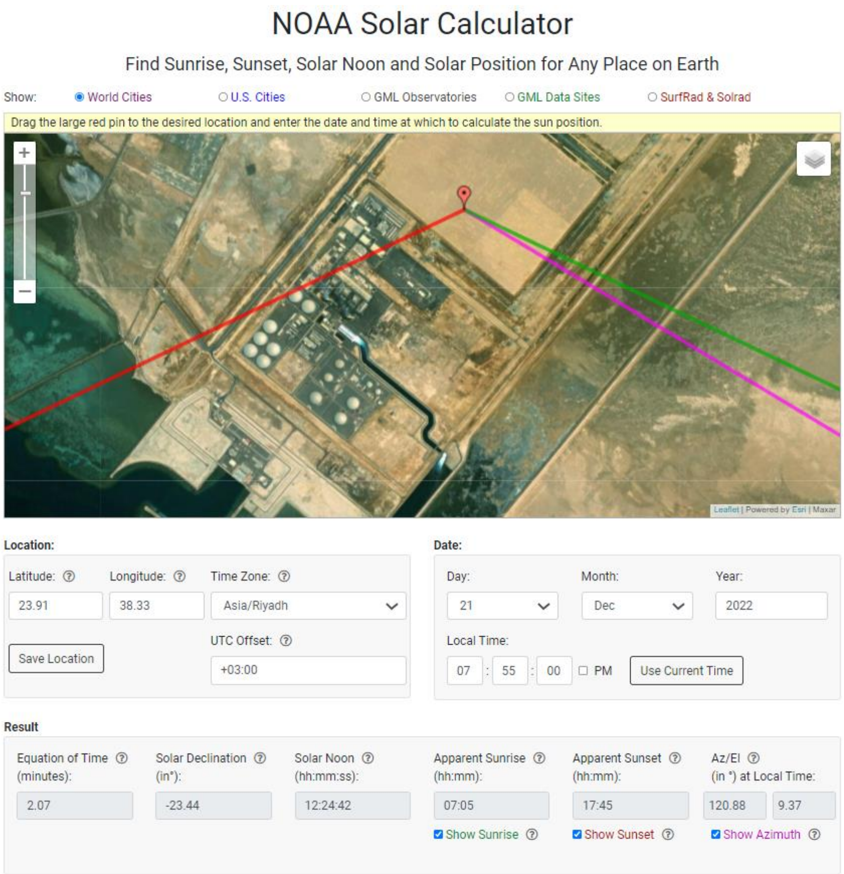

Figure 20. Sunrise, Sunset, Azimuth of Yanbu by using NOAA Solar Calculator.

Figure 20 shows the maximum shading time in year and although obtain sunrise, Sunset and solar noon acording to location details (longatude, latitude and time zone)

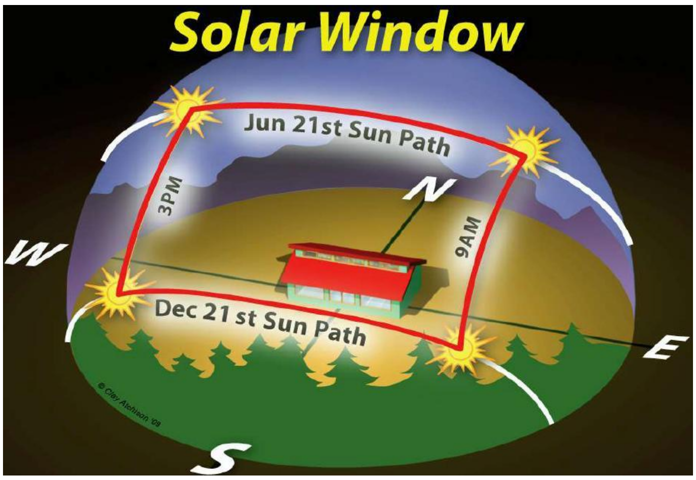

Figure 21. The sun on June 21 and December 21 [19] [20]

Figure 21 shows the path of the sun in summer and winter according to peak sun hour (9AM to 3PM). On June 21 of every year, the sun is as high as possible and there are no shadows during that day, while on December 21 of every year the sun is the lowest possible and the shadows are as high as possible and based on this day we calculate how we can install the panels and leave a distance between them to avoid shadows.

2.3.1 Impact of Shading in Yanbu region

As shown below to calculate shadow angle should be to know W , h and B

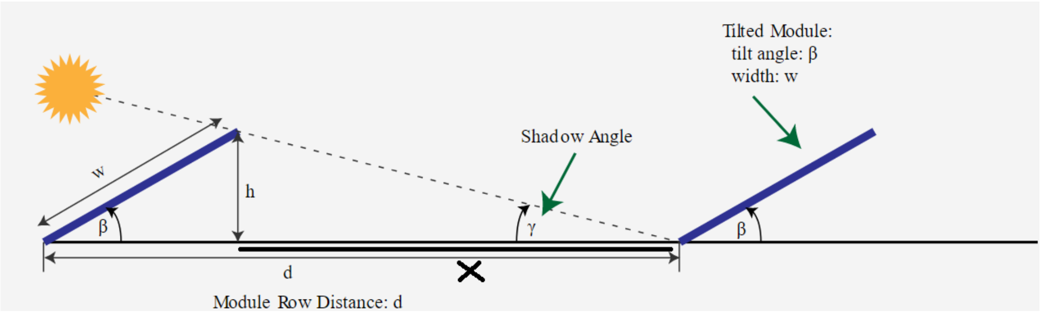

Figure 22. Shadow angle of solar module [17]

Type of solar module type we selected in this research is Jinko solar(JKM540M-72HL4-TV)
Equation of h= sin (latitude angle) x solar panel width (m)
Equation of X= $\frac{h}{\tan(\text{shadow angle})}$

The width of the solar panel in this research is 2.274m and Latitude is 25 , to calculate

Where h is height the solar panel on the surface.

h= sin(25)x 2.274= 0.96

To find shadow angle from NOAA website, on December 21 at local time (7:55 AM) we have Y angle= 9.37

Now tan9.37=h÷x

X= $\frac{h}{\tan(9.37)}$, where h = 0.96

X= 5.82 m This distance is between the end of the first solar panel and the beginning of the second solar panel, Thus there is no shadow between the solar panels if we leave a distance of 5.82 meters.

So will leave a distance of about 12 meters because to put two solar panels on top of each other. And therefore, there is no shadow between rows of solar modules.

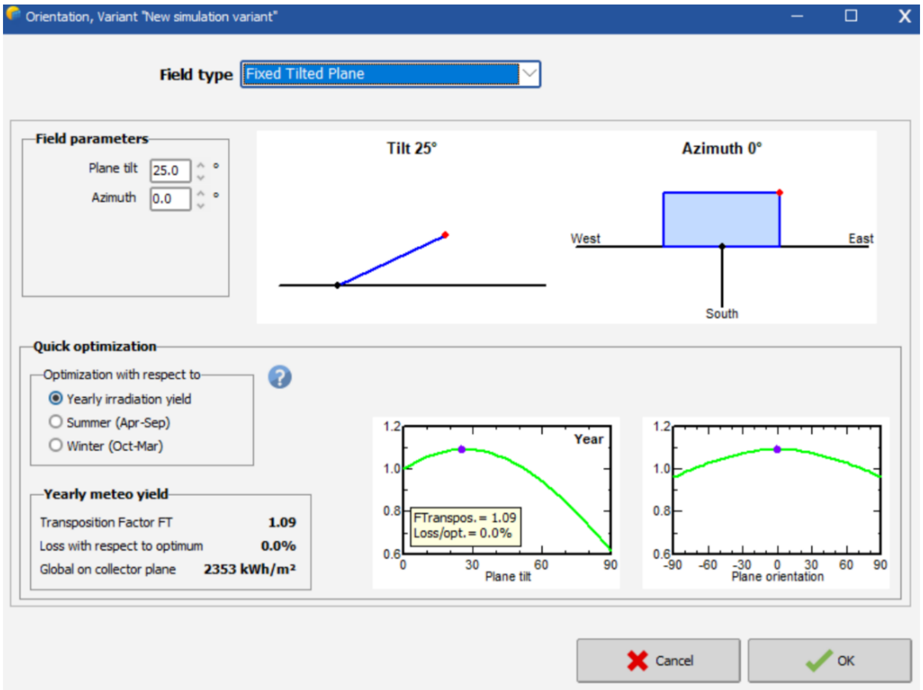

Figure 23. Tilt and Azimuth angle for Yanbu site

Figure 23 displays the optimal Azimuth angle and tilt for the Yanbu area; the optimal tilt angle for PV panels is 25 degrees with an azimuth of zero degrees. The sun path statistics are gathered from the Meteonorm software, which offers an unrivaled mix of accurate data and powerful mathematical materials. This data may be used to get accurate history and information for any period of year. In this system, roughly (366,984) PV modules with unit nominal power (540wp) will be used to produce 200MWp, and the modules connection design will be (13592 strings)*(27 series).

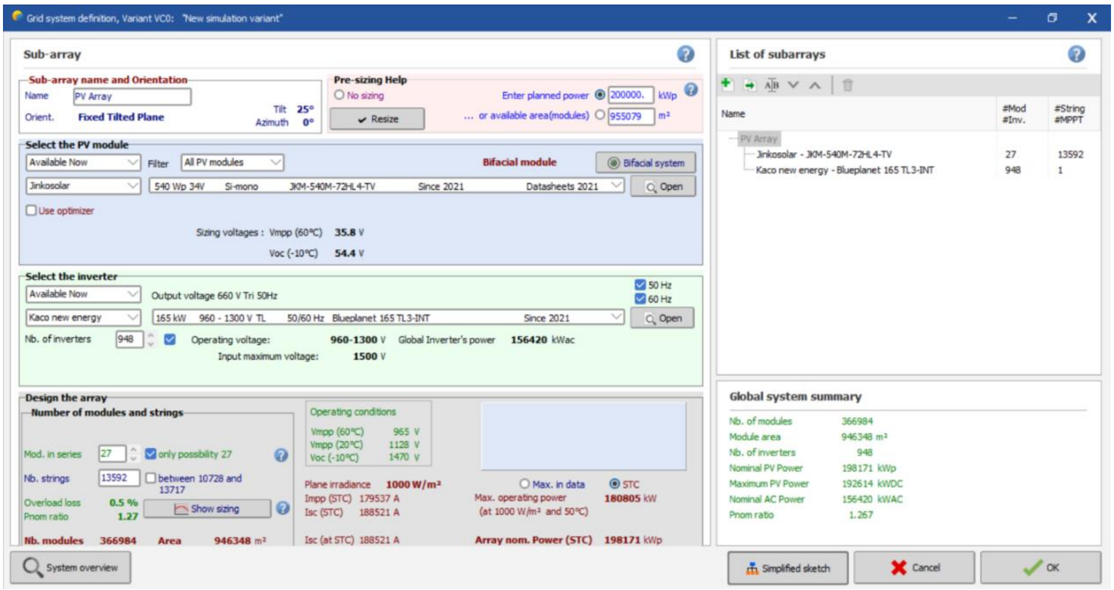

Figure 24. shows the distribution number of modules and PV strings.

Figure 24 shows the orientation of the plant, the plant capacity and area, the used PV module, the used inverter, its number, operating voltage and the design of the array which contain 13592 strings each string have 27 modules, with over sizing ratio 127%

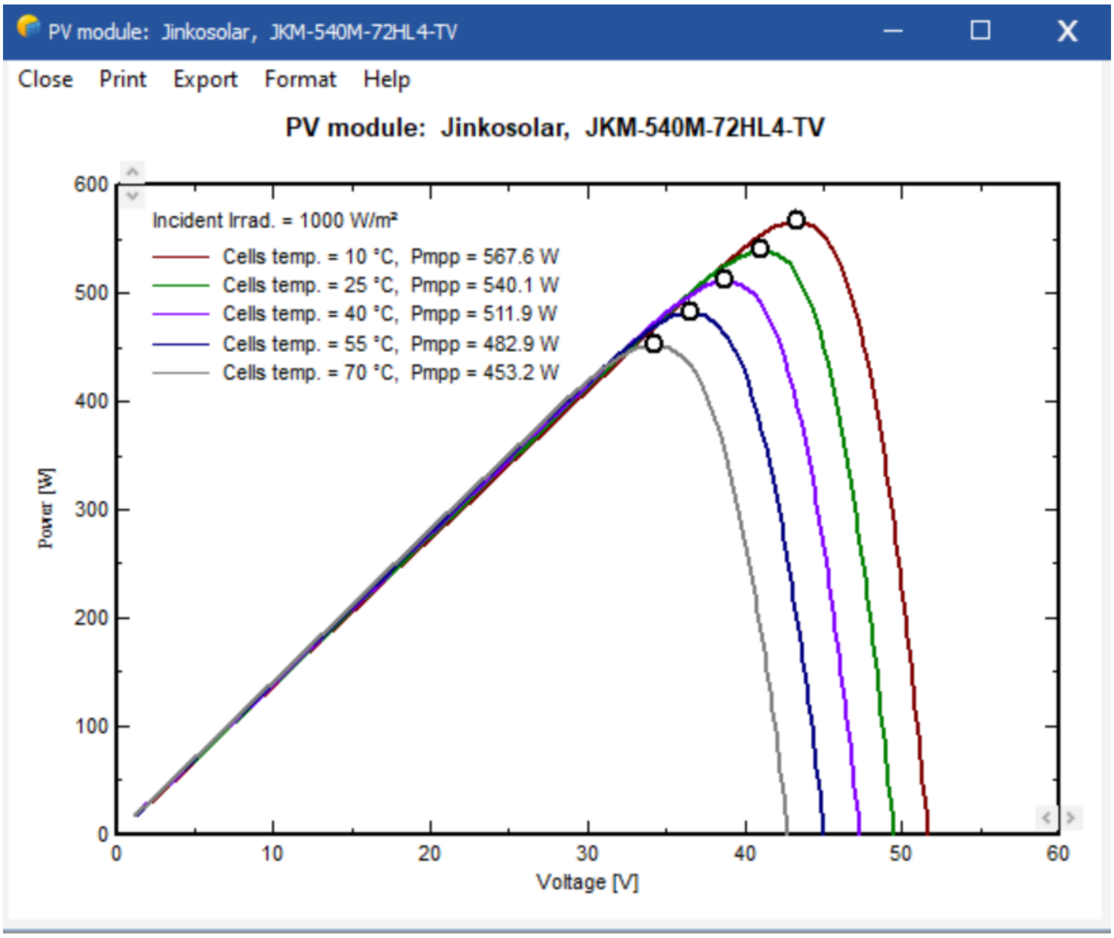

Figure 25. The relationship between voltage and power

figure 25 shows the relationship between the power of the module and its voltage
Note that if the cell temperture increces, the voltage and power of the module decreas.
For example: at temperature 25 degree, the module generate 540 W but at 55 degree the module generate 482.9 W. all of that at the constant radaition equal to 1000 W/m²

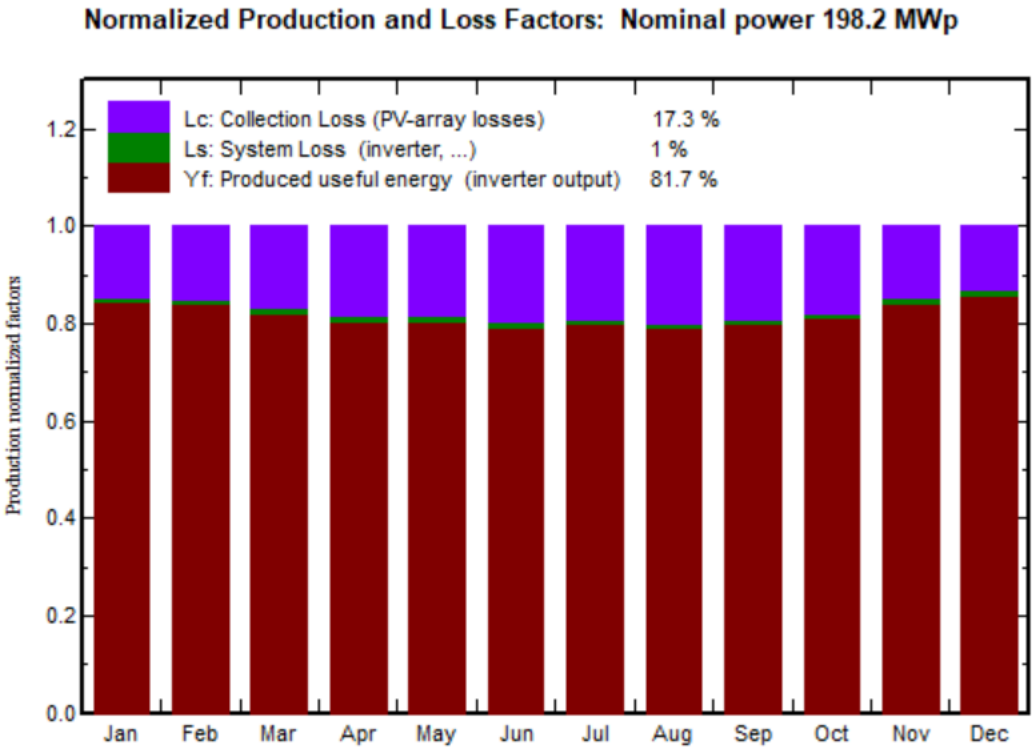

Figure 26. Normalized production and loss factors of Yanbu Site.

Diagram 26 displays produced energy from the plant (81.7% * 198.2 MWp= 162 MWp) , systems losses (1% * 198.2 MWp = 1.92 MWp) and collection losses (17.3% * 198.2 MWp= 34.2 MWp). Note that: the plant supposed to generate 198.2 MWp, but due to collection and system losses we get only 162 MWp.

New simulation variant

Close Print Export Help

New simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	148.4	26.30	19.37	204.1	201.7	34562724	34119325	0.844
February	149.7	43.31	21.42	185.6	183.1	31270097	30878370	0.839
March	194.4	58.83	25.07	217.3	213.7	35811292	35369705	0.821
April	214.1	64.30	28.15	216.2	212.3	34953671	34522029	0.806
May	208.7	89.84	32.35	194.2	189.9	31349526	30982305	0.805
June	221.7	84.90	33.98	198.6	194.2	31586080	31218499	0.793
July	212.7	94.29	34.64	194.3	189.9	31150600	30792315	0.800
August	197.8	93.90	34.97	193.1	189.4	30644495	30285677	0.791
September	179.5	75.96	32.41	190.8	187.4	30632962	30270335	0.800
October	167.4	60.06	29.90	198.3	195.3	32318665	31930784	0.812
November	137.8	42.77	25.19	181.9	179.2	30693955	30323770	0.841
December	126.8	39.18	21.39	174.9	172.6	30124769	29754399	0.858
Year	2158.9	773.64	28.27	2349.3	2308.6	385098836	380447515	0.817

Table 3. The total power generation of Yanbu site

Table 3 shows monthly for total power generation of Yanbu site where (GlobHor is Global horizontal irradiation, DiffHor is Horizontal diffuse irradiation, T_Amb is Ambient Temperature, GlobInc Global is incident in coll. plane, GlobEff Effective Global, corr for IAM and shadings, EArray is Effective energy at the output of the array, E_Grid is Energy injected into grid, PR is Performance Ratio).

Finally, the plant will be injected in to grid 380447515 kWh or 380.45 GWh energy. PR is the performance ratio that measure the quality of the PV plant that is independent of location and also describes as the quality factor on the plant, ranging from 80 to 100 percent. PR= Actual reading of plant output in KWh/ nominl plant output in KWh.

New simulation variant

Close Print Export Help

New simulation variant

Monthly Hourly sums for E_Grid [MWh]

	0H	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H	21H	22H	23H
January	0	0	0	0	0	0	0	46	1922	3336	4314	4752	4804	4749	4362	3457	2075	306	0	0	0	0	0	0
February	0	0	0	0	0	0	0	167	1536	2819	3742	4235	4323	4269	3925	3125	1999	742	0	0	0	0	0	0
March	0	0	0	0	0	0	0	689	2062	3341	4263	4681	4739	4653	4281	3466	2275	920	3	0	0	0	0	0
April	0	0	0	0	0	0	90	981	2270	3393	4160	4476	4503	4375	4004	3242	2118	865	47	0	0	0	0	0
May	0	0	0	0	0	0	243	1029	2132	3101	3745	3969	4002	3859	3466	2757	1776	783	123	0	0	0	0	0
June	0	0	0	0	0	0	287	998	2057	3020	3679	3975	3992	3848	3504	2852	1896	868	245	0	0	0	0	0
July	0	0	0	0	0	0	223	882	1911	2896	3543	3905	3963	3870	3520	2905	1994	939	245	0	0	0	0	0
August	0	0	0	0	0	0	95	826	1842	2832	3574	3950	4056	3897	3546	2855	1843	845	128	0	0	0	0	0
September	0	0	0	0	0	0	41	915	2088	3095	3827	4032	4022	3839	3444	2705	1675	588	2	0	0	0	0	0
October	0	0	0	0	0	0	3	988	2297	3407	4148	4426	4433	4199	3629	2712	1476	216	0	0	0	0	0	0
November	0	0	0	0	0	0	0	843	2148	3274	3958	4284	4310	4097	3503	2578	1324	9	0	0	0	0	0	0
December	0	0	0	0	0	0	0	214	1814	3085	3953	4337	4441	4200	3629	2649	1425	11	0	0	0	0	0	0
Year	-3	-3	-3	-3	-3	-3	979	8579	24080	37599	46906	51021	51588	49854	44812	35305	21878	7091	791	-3	-3	-3	-3	-3

Table 4. Monthly Hourly sums for E-Grid [MWh].

Table 4 shows the hourly-monthly energy generated for 24 hours note that we will find the plant is generating energy from April to September from 6:00AM to 6:00 PM, So the plant will generate energy for 12 hours for 6 months per year.

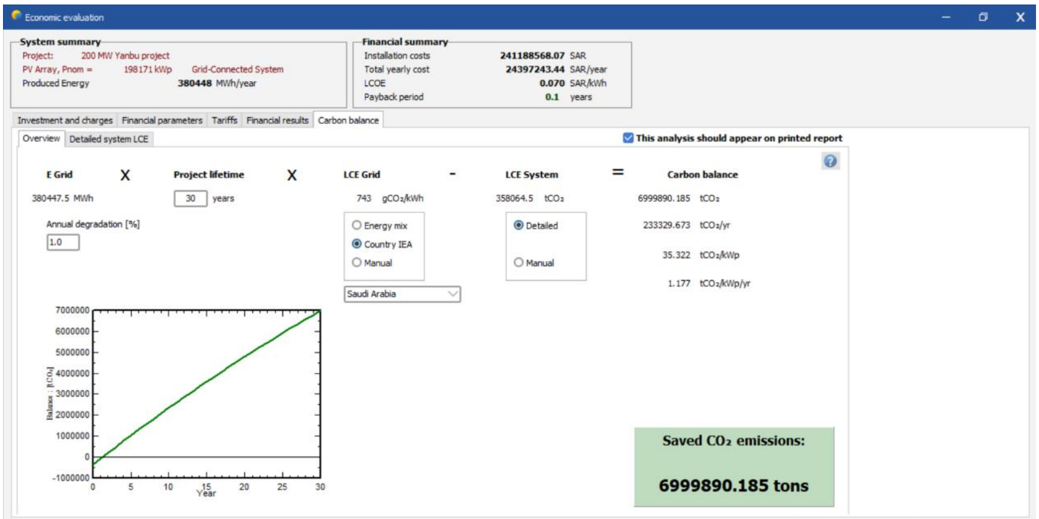

Figure 27. CO2 emissions saved at Yanbu site.

Figure 27 shows the quantity of CO2 emissions saved by building the plant in Yanbu region for 30 years, the plant will saved 6999890.185 tons of CO2 emissions.

2.4 Drawing By using SketchUp

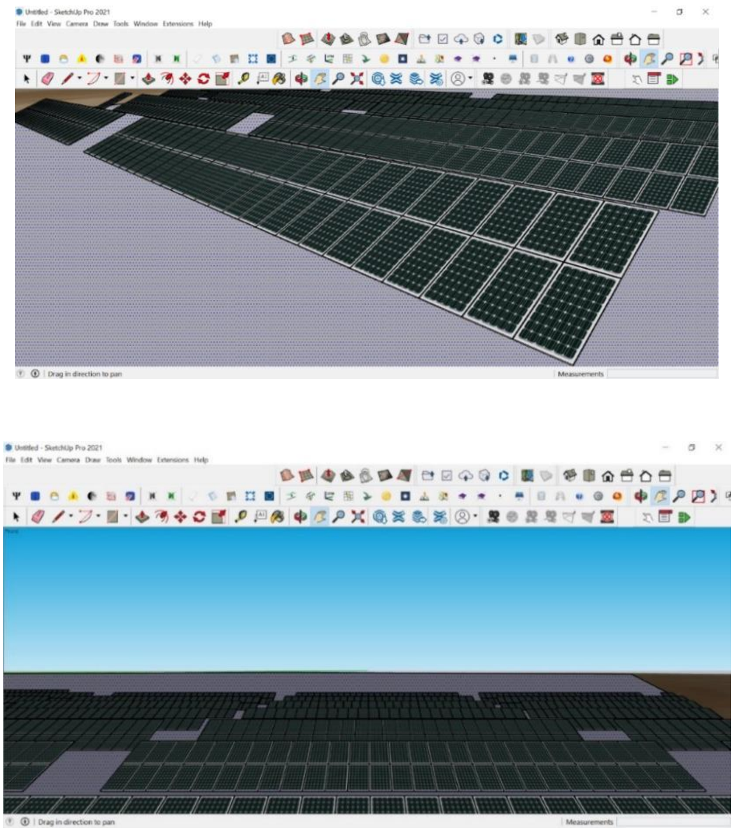

Figure 28. Sketch solar panels by using Sketchup program

Figure 28 shows the distribution of the solar panel in ground. the PV plant is consisting of tables each table consider as two string each table consisting of two portrait module.

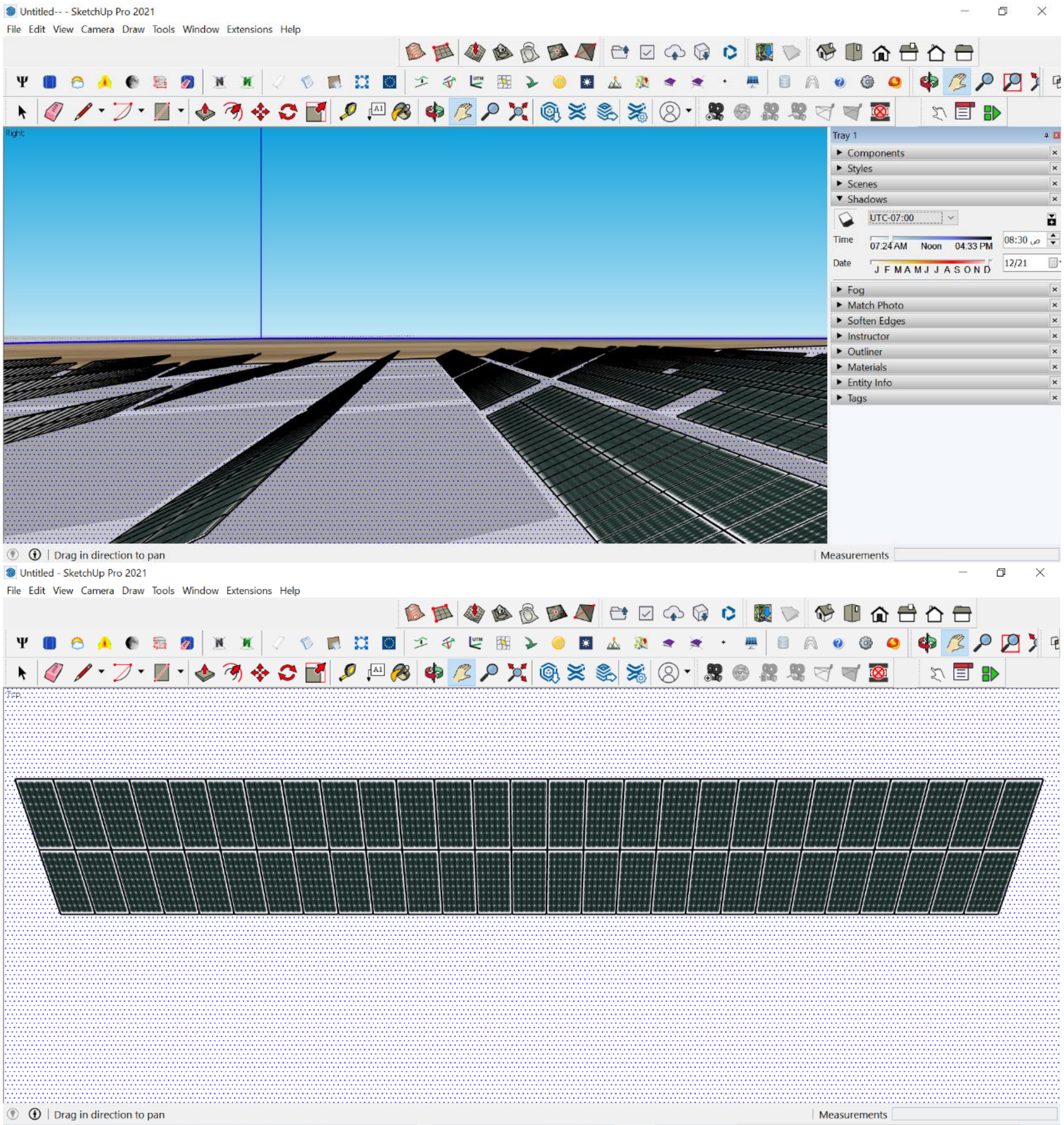

Figure 29. Impact of Shading in SketchUp program

Figure 29 shows the shading analysis of the plant at December 21, 8:30 AM

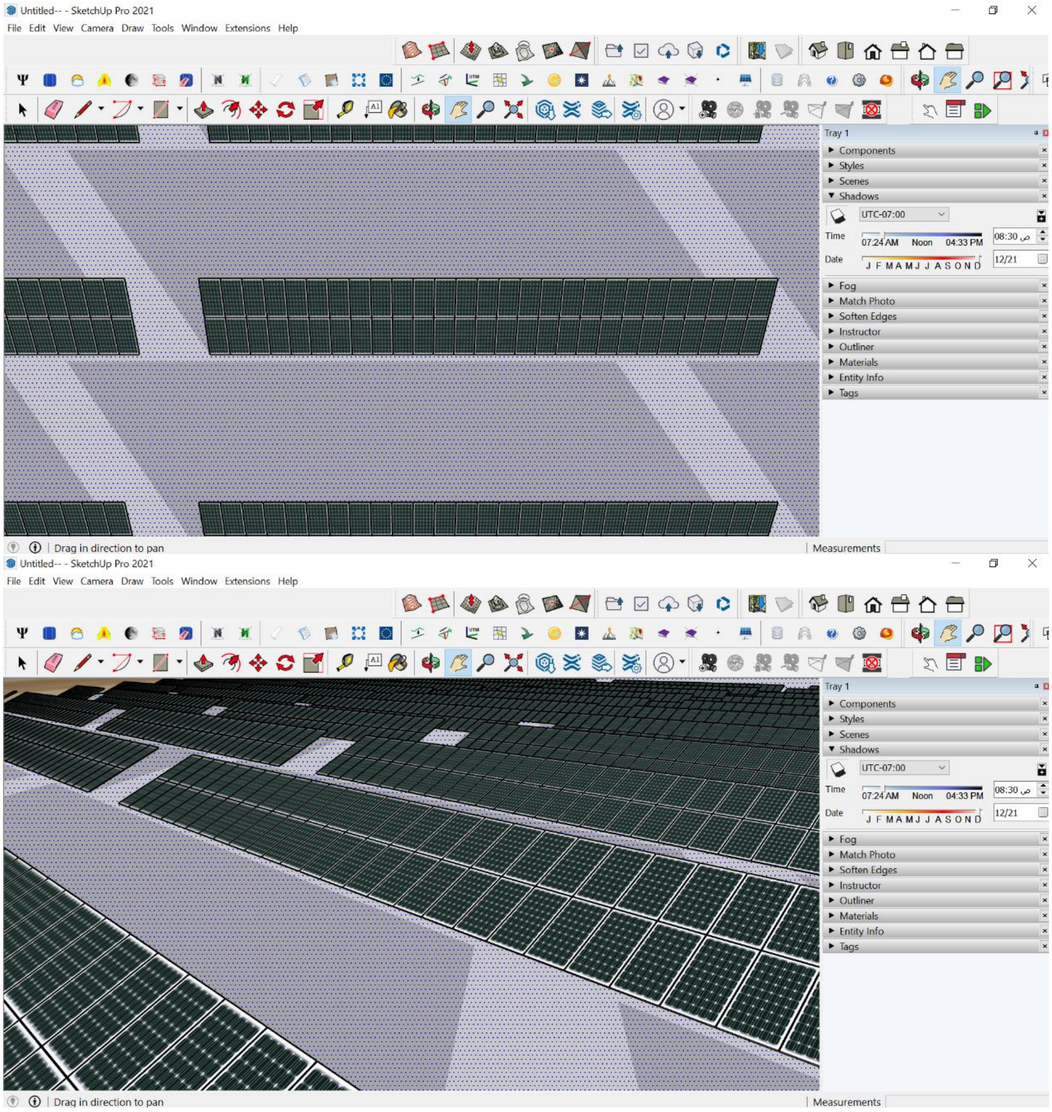

Figure 30. Impact of Shading on December 21 at 8:30AM

Figure 30 shows a distance of 12 meters has been left between the solar panels to avoid the effect of shadow

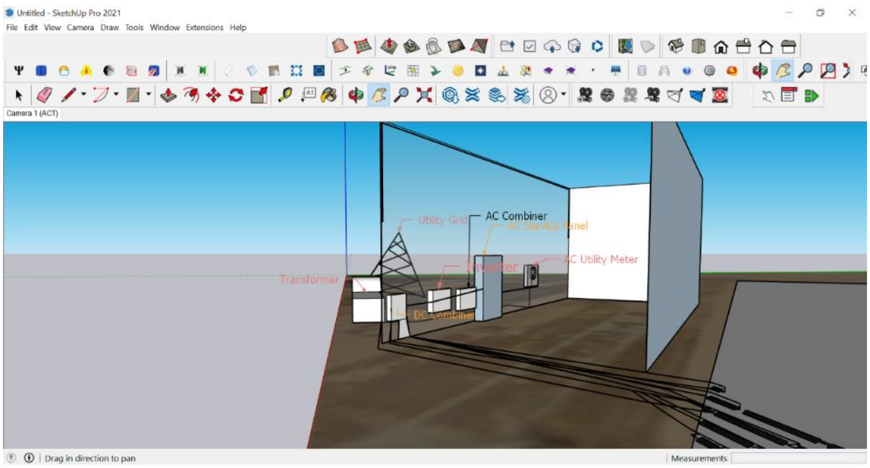

Figure 31. Sketch solar panels connected to the on-grid by using SketchUp program.

Figure 31 shows the room that contain inverters combiner boxes main distributed board and the connection between the transformer and the grid.

2.5 Project's total cost in Saudi Riyals

200 MW Ongrid system Bill of material

Total price SAR	Unit Price SAR	QTY	Description	Vendor	ref.
SAR 193,217,076.00	SAR 526.50	366,984	540 Watt solar panel	Jinko solar	1
SAR 23,700,000.00	SAR 25,000.00	948	165KW ongrid inverter with Combiner DC	Kako New energy	2
SAR 15,000,000.00	SAR 15,000,000.00	1	Fixation frame	Chint	3
SAR 2,114,229.00	SAR 3.00	704,743	DC Cable 6mm	El sewedy	4
SAR 17,839.50	SAR 1.31	13,592	MC4 Connector	Sun tech	5
SAR 127,425.00	SAR 9.38	13,592	Cable Connector 6mm	ABB	6
SAR 924,489.60	SAR 12.19	75,840	60mm Ac cable	El Swedey	7
SAR 1,023.84	SAR 0.18	5,688	Cable Lug	ABB	8
SAR 3,555,000.00	SAR 15,000.00	237	AC Combiners	ABB	9
SAR 200,000.00	SAR 50,000.00	4	AC Cabinets	ABB	10
SAR 238,857,082.34	Total before Installation				11
SAR 23,885,708.184	10% of total cost		Installation		12
SAR 262,742,790.02	Total				13

Table 5. The cost of the on-grid connected solar panel system project [21].

Table 5 shows the detail Bill of quantities of the plant including prices with SAR and All technical data: There are 366,984 Jinko solar panels, the capacity of one panel is 540 watts, and the price of one panel is 526.5 Saudi riyals, and the total panels = 193,217,076.00 SAR. We have 948 Kako New energy inverters, each with a power of 165 kilowatts, and the price of one inverter is 25,000 SAR. The total cost of inverters = 23,700,000.00 SAR. In addition to the aluminum frame of the Chint type, on which solar panels are installed, and its price is 15,000,000 SAR, and we also need DC Cable 6mm of the El sewedy type, and in this project we need 704,743 and the cable is 3.00 Saudi riyals per meter, and the total of the cable is 2,114,229.00 SAR and we have an MC4 Connector of the Sun type tech, and we need 13,592 MC4 Connector to connect the solar panels with each other. The price of one MC4 Connector is 1.31 Saudi riyals. The total MC4 Connector is 17,839.50. Also need to 13,592 Cable Connector 6mm of type ABB the price of Cable Connector 6mm is 9.38 SAR, and the total cost of Cables Connector 6mm is 127,425.00 SAR. And we need a 60mm Ac cable of the El Swedey type to connect the inverters to the AC panel box, and in this project, we need 75,840 (60mm) Ac cable, and the cable price is 12.19 Saudi riyals, with a total cost of 924,489,60 SAR.

We also need ABB Cable Lug to connect the solar panels side by side. We need 5,688. The Cable Lug price is 0.18 SAR.

The total cost Cable Lug is 1,023.84 SAR. Also need to ABB AC Combiners to connect every 4 inverters to the AC Combiner. The price of the AC Combiner is 15,000.00 SAR and the total cost of AC combiners are 3,555,000 SAR, and we have AC Cabinets so that AC Cabinets are connected to the transformer and to the grid, and we need AC Cabinets to connect 237 inverters AC Cabinet, and the price of the AC cabinet is 50,000.00 SAR, and the total cost of AC Cabinets are 200,000.00 SAR, and the installation and manpower fees are 10% of the project cost, which is 23,885,708.184 SAR. The total project cost = 262,742,790.02 SAR

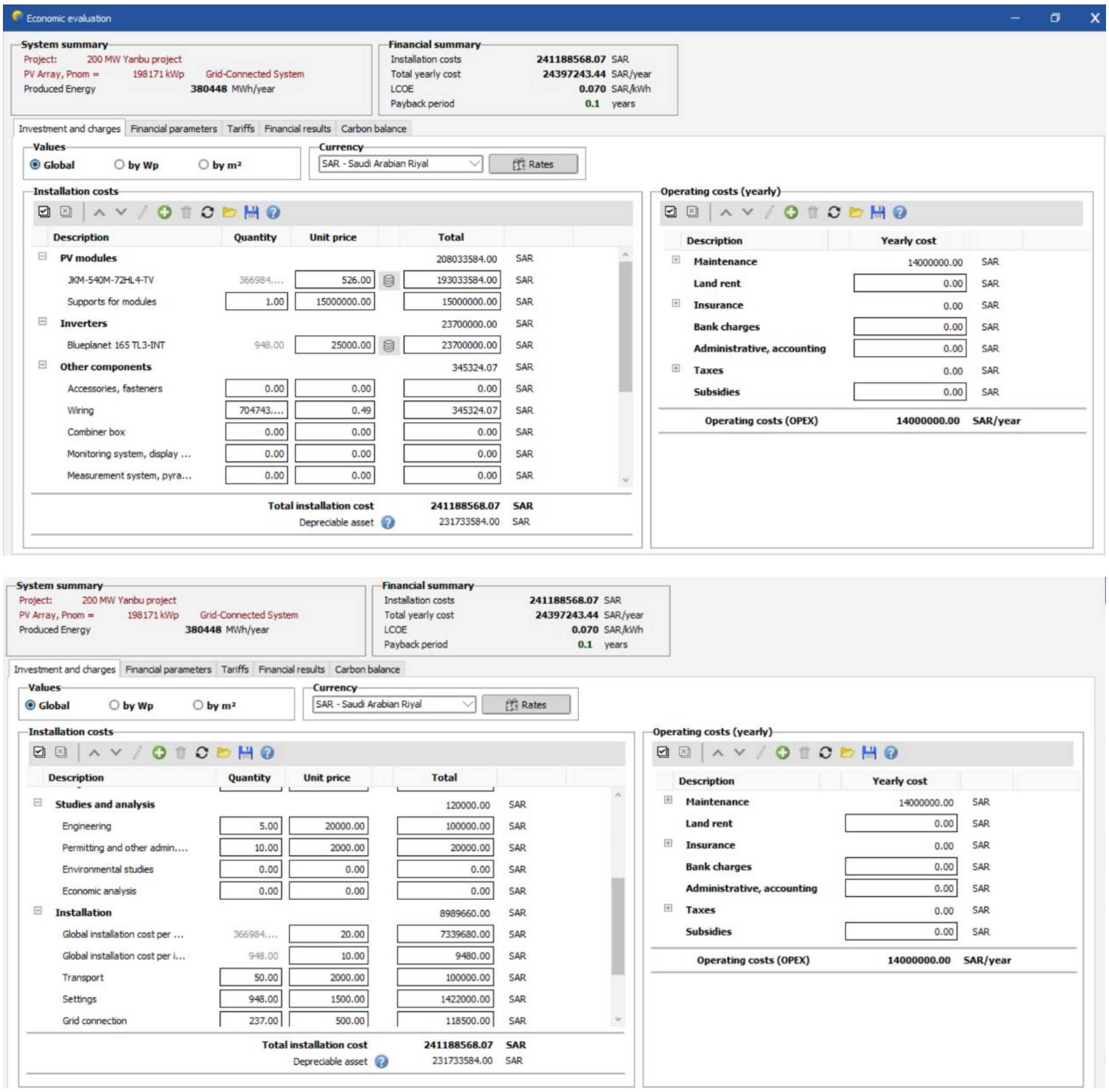

Figure 32. Investment & charges of economic evaluation solar project

Figure 32 shows a detialed in econmic analysis for the plants including CAPEX and OPEX. CAPEX consisting of hard cost (PV modules, Inverters, mounting structure, MDBs,

Transformer, Cabales, combiner box, and installation), and soft cost(Engineering, Permitting fees).
OPEX including all operitional cost like that(Team Salaries, Rapairs, and Cleaning).

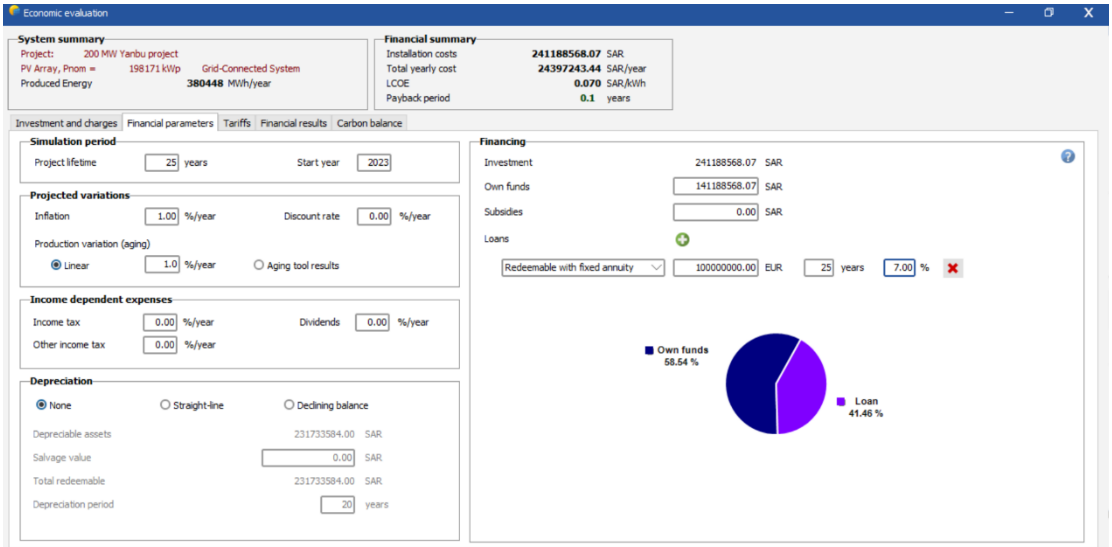

Figure 33. financial Parameters for solar project

Figure 33 shows the financial parameters: Simulation period which started at 2023 and last for 25 years, So the simulation period will end at 2048. Projected variations which include the inflation(which considered to be 1% per year), and the production variations due to aging(which considered to be 1% per year due to annual degradation of PV modules).financing and investment which include: the total investment for the project is dividing into own funds with 58.54% which equals 141,188,568.07 SAR and a loan with 41.46% which equals 100,000,000.00 SAR for a payment plan for 25 years with fixed interest 7%.

As shown below, there is the financial analysis of the solar energy project, as the project starts in 2023 until 2048, and the project cost starts from 261 million. In 2023, revenues were recorded at about one billion and 738 million and 670 thousand Saudis, and then in 2024, the revenues were recorded at one billion and 898 million and 744 thousand. And the cumulative profit for the year 2024 (one billion and 738 million and 670 thousand + one billion and 898 million and 744 thousand) is the total = 3 billion and 637 million and 414 thousand.

Where the cumulative profit from 2023 to 2048 (46 billion and 714 million and 757 thousand Saudi riyals)

Financial analysis

Detailed economic results (kSAR)

	Electricity sale	Loan principal	Loan interest	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
2023	1902440	1581	7000	14000	0	1881440	0	1879859	1738670	780.1%
2024	1921464	1692	6889	14140	0	1900435	0	1898743	3637414	1568.0%
2025	1940489	1810	6771	14281	0	1919436	0	1917626	5555040	2363.8%
2026	1959513	1937	6644	14424	0	1938445	0	1936508	7491548	3167.5%
2027	1978538	2072	6509	14568	0	1957460	0	1955388	9446936	3979.1%
2028	1997562	2218	6364	14714	0	1976484	0	1974267	11421203	4798.6%
2029	2016586	2373	6208	14861	0	1995517	0	1993144	13414347	5626.0%
2030	2035611	2539	6042	15010	0	2014559	0	2012020	15426366	6461.2%
2031	2054635	2717	5865	15160	0	2033611	0	2030894	17457261	7304.4%
2032	2073660	2907	5674	15312	0	2052674	0	2049767	19507027	8155.5%
2033	2092684	3110	5471	15465	0	2071748	0	2068638	21575666	9014.4%
2034	2111708	3328	5253	15619	0	2090836	0	2087508	23663174	9881.3%
2035	2130733	3561	5020	15776	0	2109937	0	2106376	25769550	10756.1%
2036	2149757	3810	4771	15933	0	2129053	0	2125243	27894793	11638.9%
2037	2168782	4077	4504	16093	0	2148185	0	2144108	30038900	12529.5%
2038	2187806	4362	4219	16254	0	2167334	0	2162971	32201872	13428.1%
2039	2206830	4668	3914	16416	0	2186501	0	2181833	34383705	14334.7%
2040	2225855	4994	3587	16580	0	2205688	0	2200693	36584398	15249.2%
2041	2244879	5344	3237	16746	0	2224896	0	2219552	38803950	16171.7%
2042	2263904	5718	2863	16914	0	2244127	0	2238409	41042359	17102.1%
2043	1141464	6118	2463	17083	0	1121918	0	1115800	42158160	17567.3%
2044	1150976	6546	2035	17253	0	1131688	0	1125142	43283301	18036.5%
2045	1160488	7005	1576	17426	0	1141486	0	1134481	44417783	18509.8%
2046	1170001	7495	1086	17600	0	1151314	0	1143819	45561602	18987.1%
2047	1179513	8020	561	17776	0	1161175	0	1153155	46714757	19468.6%
Total	**47465877**	**100000**	**114526**	**395405**	**0**	**46955946**	**0**	**46855946**	**46714757**	**19468.6%**

Table 6. Financial analysis (kSAR) of solar project

Table 6 shows a detail financial and economic analysis for the period 25 years regirding to : Electricity sale, loan principal, loan interest, run costs, taxable income, after-tax profit, cumulative profit in kSAR for the first year of the investment (2023) Electricity sale will be 1902440 kSAR, Loan principal 1581 kSAR, loan interest 7000kSAR, run costs 2450 kSAR, taxable income 1892990 kSAR, after-tax profit 1879859 kSAR, cumulative profit 1738670 kSAR, and cumulative profit 46714757 kSAR.

As shown below, there is the yearly cashflow & Financial results of the project from 2023 to 2048

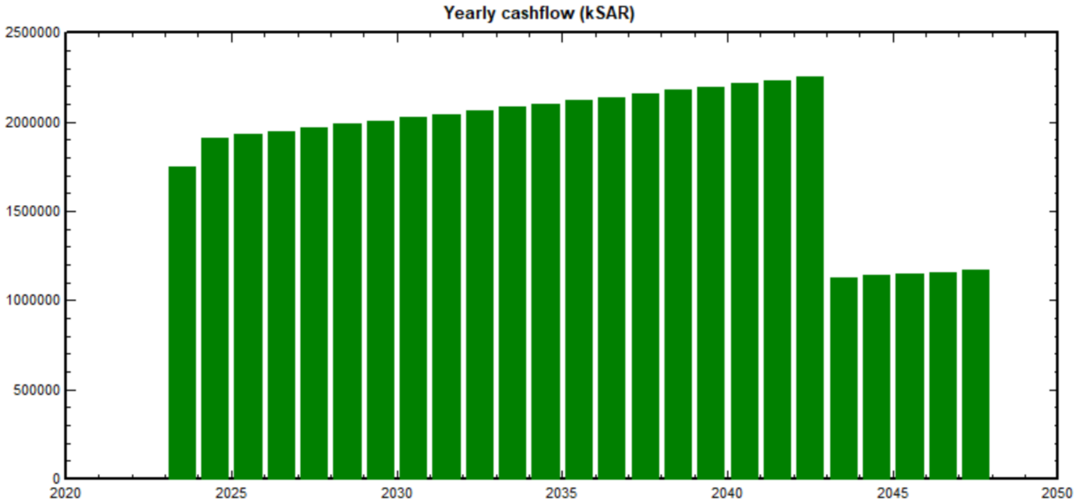

Figure 34. Yearly cashflow of the project (kSAR), 2023 to 2048

Figure 34 shows the yearly net cashflow earn due to plan production for example: 2025 the net cash flow is equals 1917626 kSAR

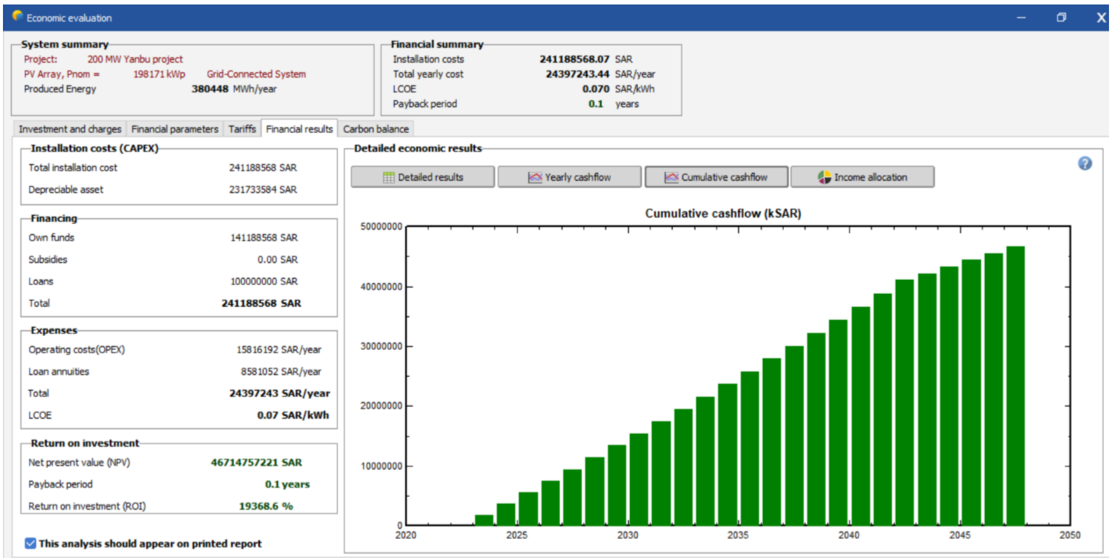

Figure 35. Financial results of the project from 2023 to 2048

Figure 35 shows the cumulative cashflow of the project starts with 1738670 kSAR and ends with 46714757 kSAR

Conclusion

3.1 Conclusion

Saudi Arabia has significant natural solar energy potential as well as an economic opportunity to expand renewable energy to fulfill local energy demand. Solar energy technology, in particular, has advanced at a dizzying pace in recent years, and so represents the most potential alternative to conventional energy systems. While experimental initiatives to expand solar energy production were initiated in the 1980s, Saudi Arabia has chosen a much more aggressive approach to solar energy production. This research project presents the results of an analytical study that was conducted on the use of PV systems in two locations within Saudi Arabia.A feasibility study for a project to establish a solar power plant with a capacity of 200 megawatts in the regions of Yanbu and Rabigh The study includes the design of a photovoltaic system using PVsyst and SketchUp programs and a feasibility work on quantities for all components required and total costs for the construction of the station.

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List of Abbreviations

Abbreviation	Meaning
R&D	Research and Development
RETs	renewable energy technologies
PV	photovoltaic
NREP	National Renewable Energy Program
NTP	National Transformation Program
REPDO	Renewable Energy Project Development Office
RFP	request for proposal
CO_2	Carbon Dioxide
SO_2	sulphur dioxide
NO_2	Nitrogen dioxide
CH_4	*Methane* is a chemical compound
GHG	Greenhouse gas
OPEC's	Organization of the Petroleum Exporting Countries
GDP	Is the total monetary or market value of all the finished goods and services produced within a country's borders in a specific time period
EIA	*Energy Information Administration* - *EIA* - Official Energy Statistics from the U.S. Government.
JODI	The Joint Organisations Data Initiative (JODI) is a concrete outcome of the producer-consumer dialogue and aims to improve gas and oil data transparency.
Tcf	The term trillion cubic feet refers to a volume measurement of natural gas used by the U.S. oil and gas industry. The measurement is usually abbreviated as Tcf.
Bcf	Billion cubic feet (Bcf)
$MtCO_2$/Year	Metric tons of carbon dioxide equivalent per year
DNI	Direct normal irradiance
GHI	Global horizontal irradiance
DHI	Diffuse horizontal irradiance
Solar PV IPP	An independent power producer (IPP) is an entity that is not a public utility but owns facilities to generate electric power for sale to utilities and end users.
KACST	King Abdulaziz City for Science and Technology
KAPSARC	King Abdullah Petroleum Studies and Research Center
NOAA	The National Oceanic and Atmospheric Administration (NOAA) is an American scientific and regulatory agency within the United States Department of Commerce works to understand and predict changes in climate, weather, oceans, and coasts.