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Simulation Study of Grid Connected Photovoltaic System Using PVsyst Software: Analytical Study for Yanbu and Rabigh Regions in Saudi Arabia

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Abstract This paper presents an analytical study of PV power generation of two regions in Saudi Arabia. Saudi Arabia need to expand its power generation capacity to meet expected rises in electricity demand. Saudi Arabia has good future to use the solar energy more extensively because of the availability of high solar radiation, large rainless area, and long sunlight. Saudi Arabia aims to increase the solar power production to meet a significant portion of potential energy demand in the country. In order to achieve its solar power goals, various installations and research works are being undertaken nowadays in Saudi Arabia. Therefore, the most recent updates of the solar industry in the country are important to further R&D research. In this work the Saudi Arabia the potential prospect of the solar industry is presented. This paper discusses the scope of connect of photovoltaic (PV) system with grid. Moreover, it presents the solution for reducing carbon dioxide (CO_2) emissions during the production of electricity in Saudi Arabia. The simulation program (***PVsyst 7.1***) was used to simulate the installation of the PV cells on the two regions of Saudi Arabia, Yanbu and Rabigh.

Keywords: *format, microsoft word template, style, insert, template*

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1. Introduction

Electric power generation is critical hotspot for the future, for Saudi Arabia, yet for the world. Saudi Arabia has bountiful potential for using sunlight-based energy, which is inexhaustible, clean, and uninhibitedly accessible. Figure 1 shows the normal yearly sunlight radiation falling on Saudi Arabia is around 2200 kWh/m^2 [1]. The consolidated impacts of the exhaustion of petroleum products and the step by step arising cognizance about natural corruption have given the primary goal to the utilization of sustainable energy assets in the 21st century [2].

Saudi Arabia is situated in the core of one of the world's most useful sun powered districts, which get the strongest sort of sunlight [4]. Saudi Arabia is an enormous country with a space of 2.3 million km^2. It is a moderately rich and demand for electricity is becoming grow at around 5% every year.

Over the course of the following 25 years, it is assessed that US$117 billion will be invested in the country's power sector [5]. Lately, Saudi Arabia has set up various bodies to animate the take-up of sunlight energy the most significant of which is the King Abdullah City for Atomic and Renewable Energy (KCARE) arrangement in 2010. The government has set an objective of having 41 GW of sunlight power by 2032 adding to 30% of the absolute energy needs [6].

Saudi Arabia looks to fundamentally build the commitment of environmentally friendly power in its power energy blend, to enhance its economy, decrease emissions and using the fossil fuel in its power generation.

In building a worldwide center point for environmentally friendly power, the Realm plans to future-evidence its economy by depending less on oil trade incomes and drawing in new innovations into the locale. Saudi Arabia is outstanding amongst other set nations to bridle sun powered energy, with the absolute most elevated sun-based radiation levels on the world [7].

PV cells convert sunlight-based energy straightforwardly into power. They include a few sunlight's based boards that permit global horizontal irradiance (GHI) to be changed over straightforwardly into power. Figure 2 shows that the normal worldwide flat irradiance in Saudi Arabia arrived at its most elevated territorial normal point in 2016 at 2,297 kWh/m^2 for the year. Somewhere in the range of 2013 and 2017, the least yearly normal was in the eastern locale, at around 2,000 kWh/m^2. The GHI in this space diminished to 1,819 kWh/m^2 in 2017. The eastern district gets lower radiation than different locales in Saudi Arabia due its geographic area. The most noteworthy GHI was in the focal locale, where the climate is dry and dampness level is low, at more than 2,200 kWh/m^2 [7].

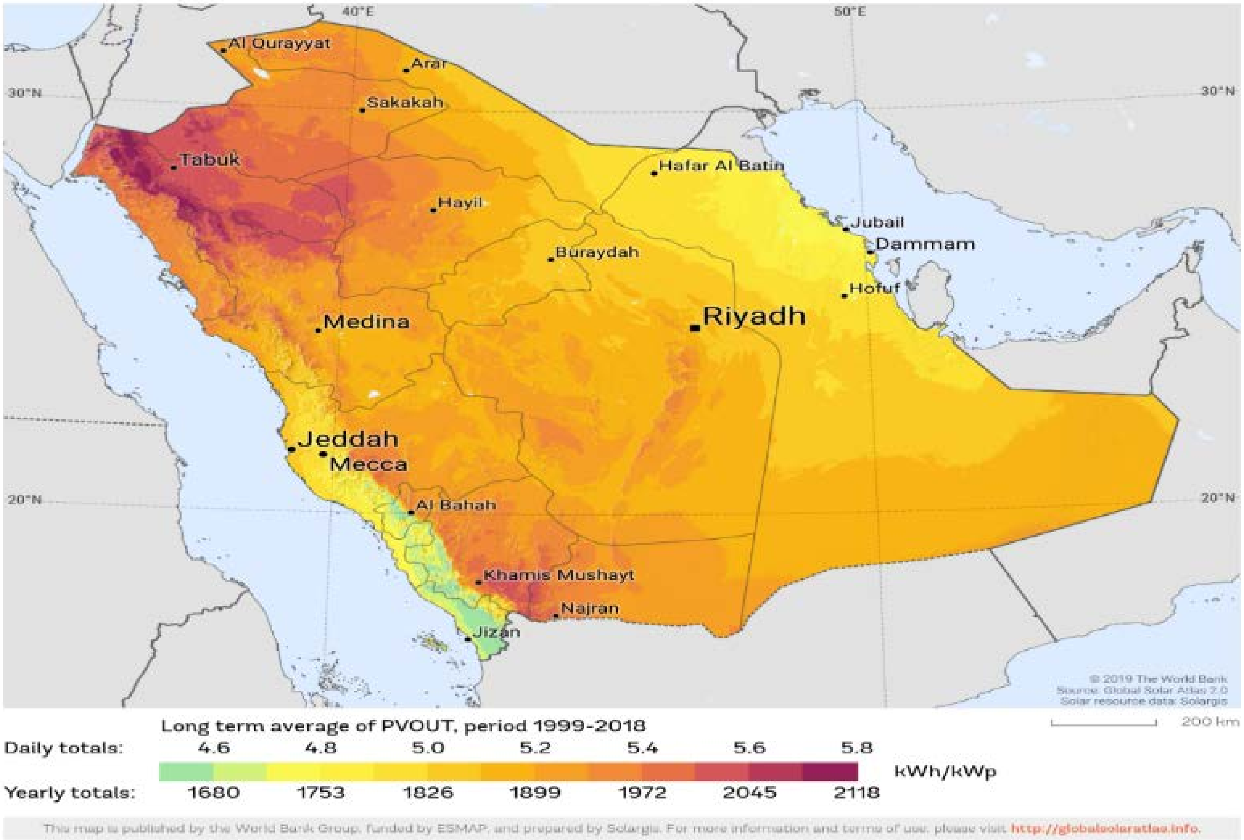

Figure 1. Solar resource maps of Saudi Arabia [3]

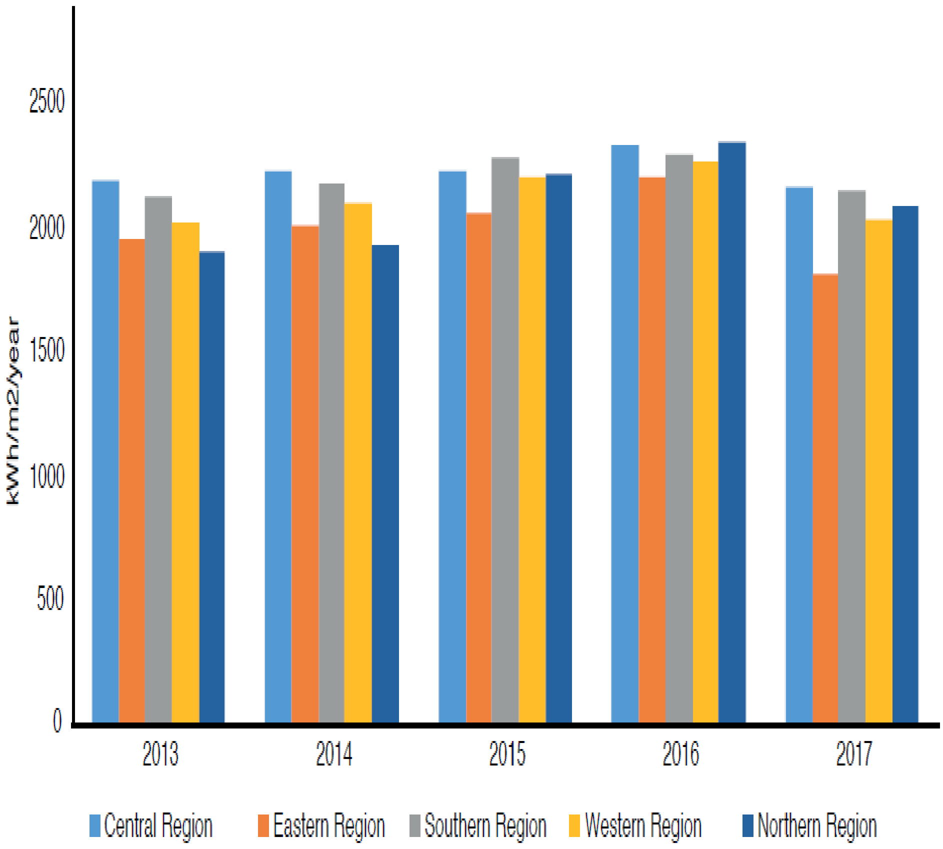

Figure 2. Annual average of global horizontal irradiance (GHI) used to produce PV power [7]

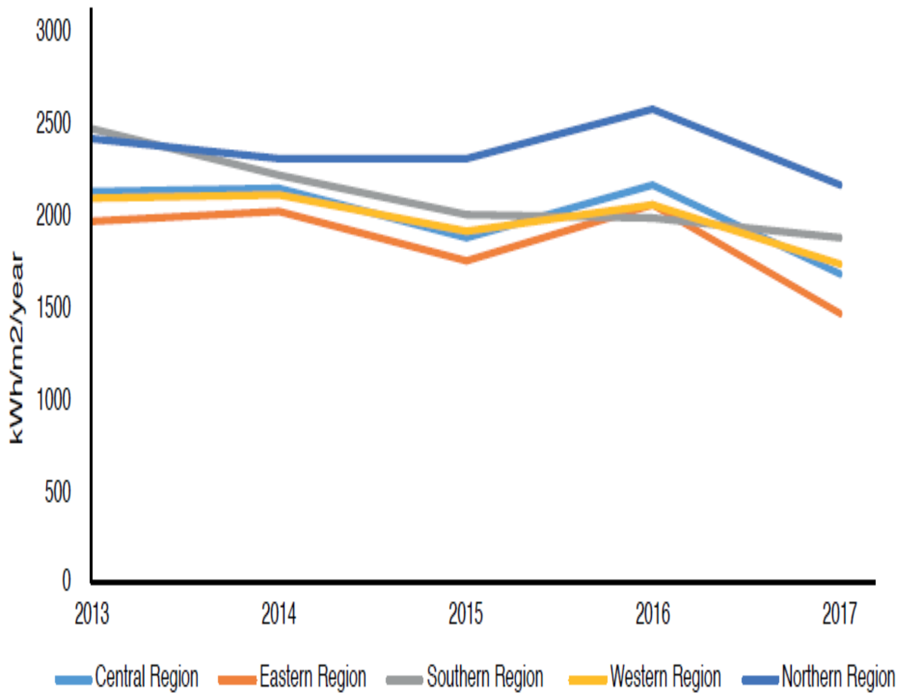

Figure 3. Annual average of direct normal irradiance (DNI) used to generate concentrated solar power in Saudi Arabia [7]

Concentrated sunlight based warm/power (CSP) changes over the sun's radiation into heat. It produces power by utilizing mirrors or focal points to focus the warmth communicated by daylight onto a little region. That warmth would then be able to be put away in a gadget or promptly moved to create steam that goes through turbines to produce power. As demonstrated in Figure 3, the normal of direct ordinary irradiance consistently diminished from 2,219 kWh/m^2 in 2013 to around 1,800 kWh/m^2 in 2017. The least yearly normal DNI was in the eastern district. An examination distributed in Energy and Natural Science surveyed the effects of environmental change on future PV and CSP energy yield. It found that PV yield is probably going to diminish by a couple of percent in Saudi Arabia somewhere in the range of 2010 and 2080 [7].

Figure 4 shows more than 40 stations were established to measure the solar energy.

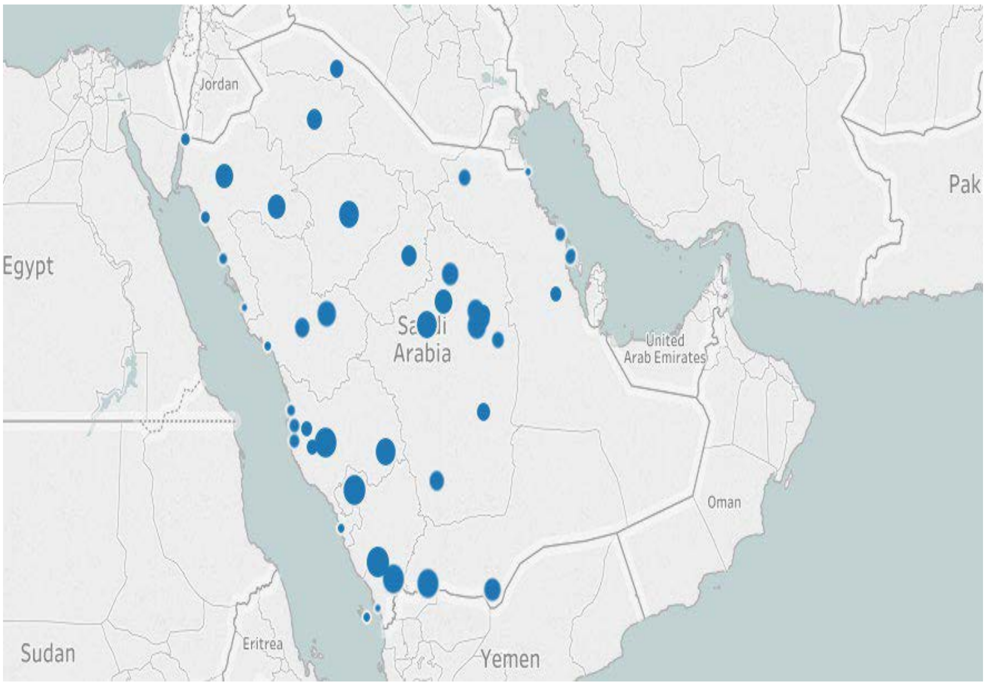

Figure 4. Solar energy stations in Saudi Arabia [7]

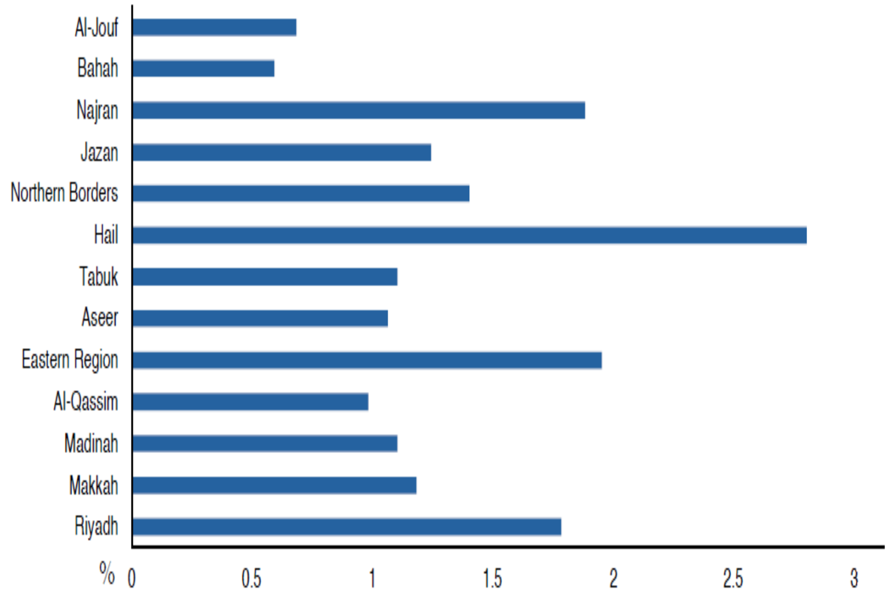

Figure 5. Percentage of households using solar energy [7]

In 2018, around 1.45% of families in Saudi Arabia utilized sunlight energy. This number is expected to rise due to the rapid increase in renewable projects. Toward the finish of 2019, Saudi Arabia's first utility-scale sunlight PV project was associated with the grid. Sakaka 300 MW solar power station, at the time of its foundation, accomplished new advancement price for PV system. Sakaka PV project, which was pre-created and offered by the Service of Energy's Environmentally friendly power Undertaking Advancement Office, was the main venture dispatched under the National Renewable Energy Program (NREP). The NREP will send a progression of utility-scale independent power generation projects to the worldwide market in a bid to keep up internationally aggressive costs and advancements. A further 2.67 gigawatts of sunlight-based PV have been offered to the market in 2019 and 2020, involving projects across the Saudi Arabia going from 20-700 MW. Figure 5 shows the percentage of households using solar energy in different cities in Saudi Arabia.

2. Saudi Arabia's Electricity Generation

In 2018, Saudi Arabia's power generation has been at 384 TWh. It represented 55% of absolute GCC power generation, and 2% of worldwide power generation [13]. In 2018, its electricity peak load reached more than 61,000 MW, and its power generation capacity around 53,500 MW [13]. Figure 6 Saudi Arabia's electricity generation (2018) [13].

Saudi Arabia is a significant user of energy, with rapidly growing domestic demand. Complete power utilization in 2018 was around 289.8 TWh, a slight increment of around 0.42% from the 2017 degree of around 288.6 TWh. The areas that had recognizable changes somewhere in the range of 2017 and 2018 were the residential area, with a 9% fall, and the industrial area, with an increase of 8.3% as shown in Figure 7 [14].

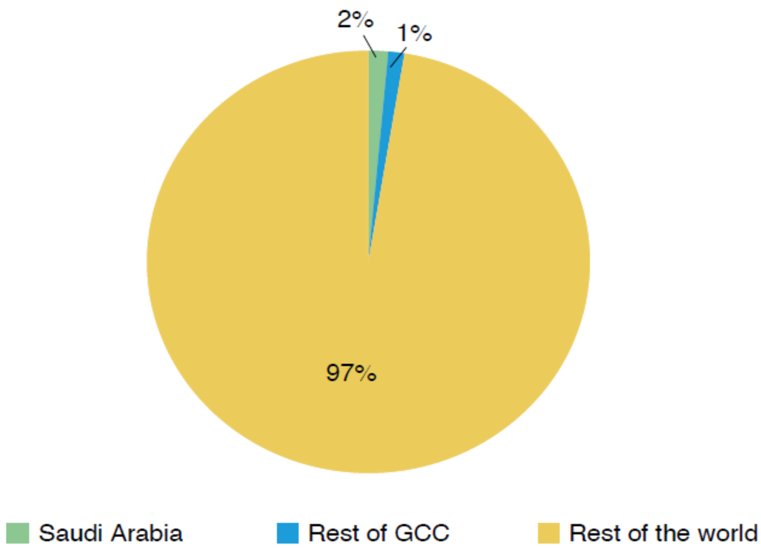

Figure 6. Saudi Arabia's electricity generation (2018) [13]

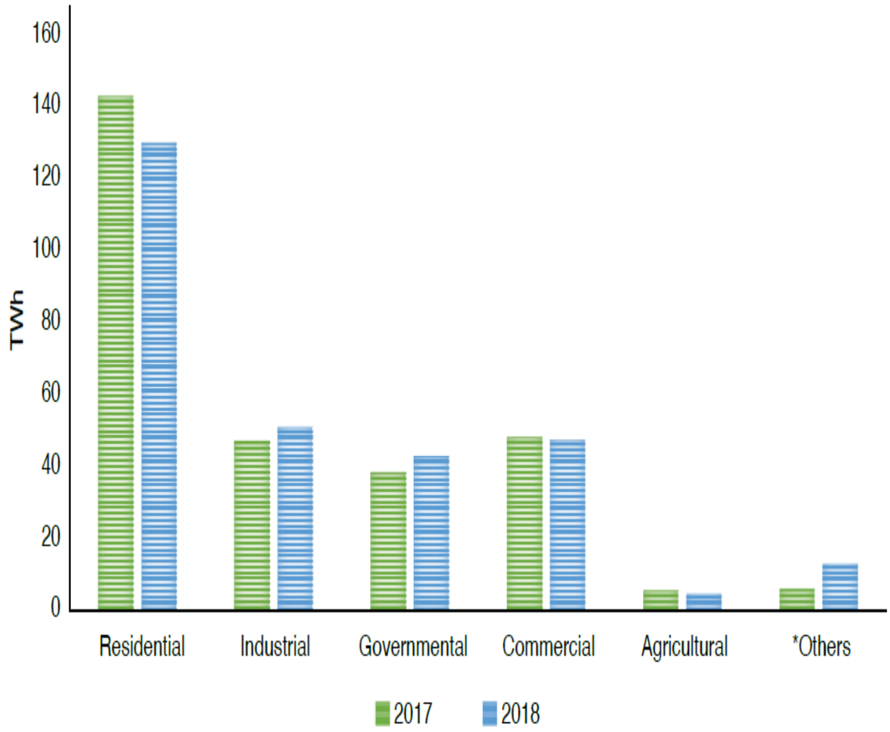

Figure 7. Electricity consumption by sector (2017-2018) [14]

Figure 8. Available electricity capacity and peak load (2017-2018)[14]

In 2018, Saudi Arabia's all out power generation limit was around 85 GW, which incorporates cement plants, treatment facilities, autonomous force makers or independent power producers, and thermal desalination plants.

The grid capacity was 68.8 GW, somewhere near 1.2 GW from 2017 (70 GW). In 2017, Saudi Arabia's pinnacle power load was 62 GW, diminishing marginally to 61 GW in 2018. Figure 8 shows Saudi Arabia's power generation capacity and pinnacle or peak load for 2017 and 2018.

3. Simulation & Analysis

3.1. PV Stations on Yanbu Site

The studied PV systems in this work was demonstrated for two locations in Saudi Arabia, Yanbu and Rabigh. These two locations are near the power plants of Saudi Electricity Company. This makes the PV systems installation easy to be connected directly with grid and with small distance of distribution lines. In this work, the calculations and simulation have been accomplished by

PVsyst 7.1 program and GLOBAL SOLAR ATLAS. The estimated power generation for each site was 200 MWp. The Yanbu site coordinates are (Latitude 23.92 °N, Longitude 38.34 °E) and Altitude is 5 meters.

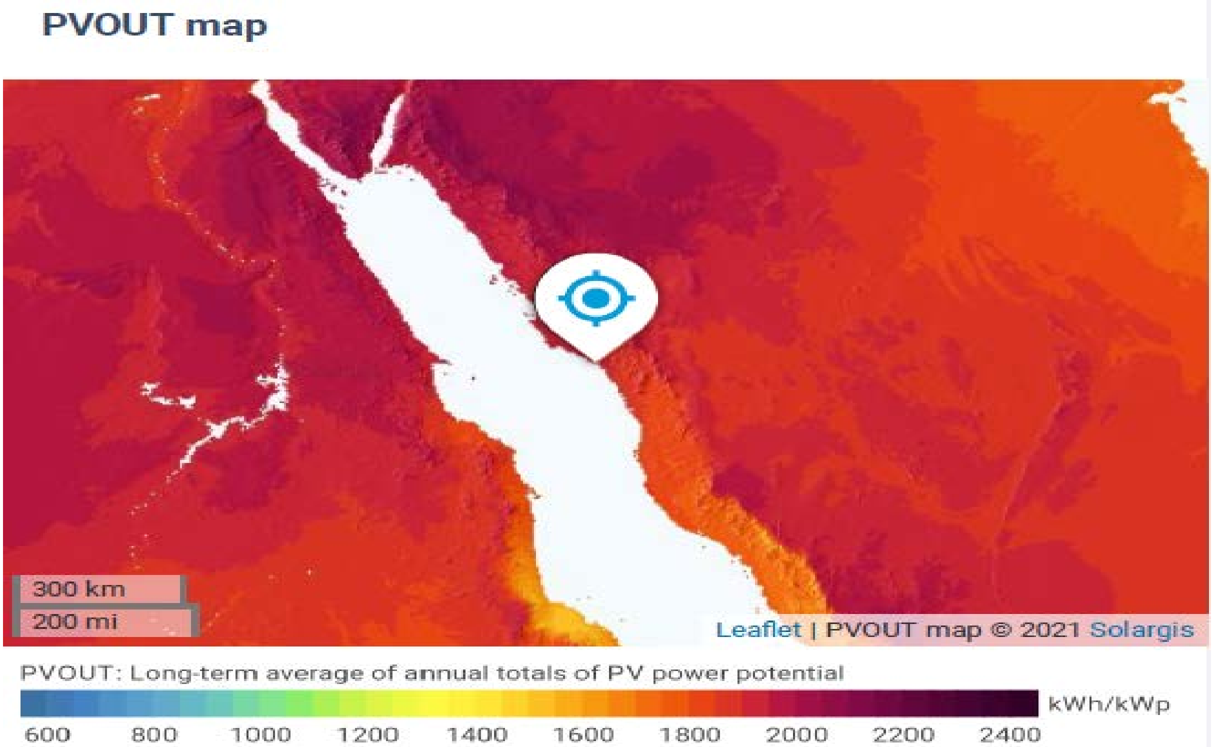

Figure 9. PV_{OUT} map of Yanbu site [15]

The best tilt and Azimuth angle for Yanbu site, the best tilt angle was found to be 26.4 degree that give maximum power from PV panels. Figure 9 shows the PV_{OUT} map of Yanbu site.

The data of sun path were collected from Metronome program, it is an unparalleled combination of reliable data and advanced calculation materials. From this data can be access to exact historical and information's for all time of year.

In this system will use around (363636) PV modules with unit nominal power (550 wp) that generate 200 MWp, also the design connection of modules will be (25974 strings) *(14 series). Table 1 shows the total power generation of Yanbu project is 387559 MWh with performance ratio (0.82).

Figure 10 shows the Normalized production and loss factors. The PV array losses is 16%, the system losses are around 2% and production useful energy is 82%.

Table 1. Total power generation of Yanbu project

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	140.1	34.81	19.11	192.8	190.8	33378	32551	0.844
February	149.9	43.78	20.94	186.9	184.7	31689	30919	0.827
March	182.6	70.78	24.69	202.8	199.9	34452	33626	0.829
April	207.7	70.40	28.19	208.9	205.6	34798	33931	0.812
May	234.3	75.55	32.12	215.3	211.4	35544	34679	0.805
June	226.0	83.26	33.22	200.2	196.3	33186	32390	0.809
July	224.9	86.49	34.36	202.8	198.9	33556	32750	0.807
August	198.3	95.25	34.48	192.6	189.4	31984	31202	0.810
September	184.8	71.73	32.19	197.4	194.5	32715	31912	0.808
October	172.7	54.62	29.82	206.6	204.0	34269	33435	0.809
November	137.6	42.34	25.25	182.9	180.7	31241	30490	0.833
December	125.6	40.34	21.46	174.4	172.5	30412	29673	0.851
Year	2184.4	769.35	28.02	2363.7	2328.8	397224	387559	0.820

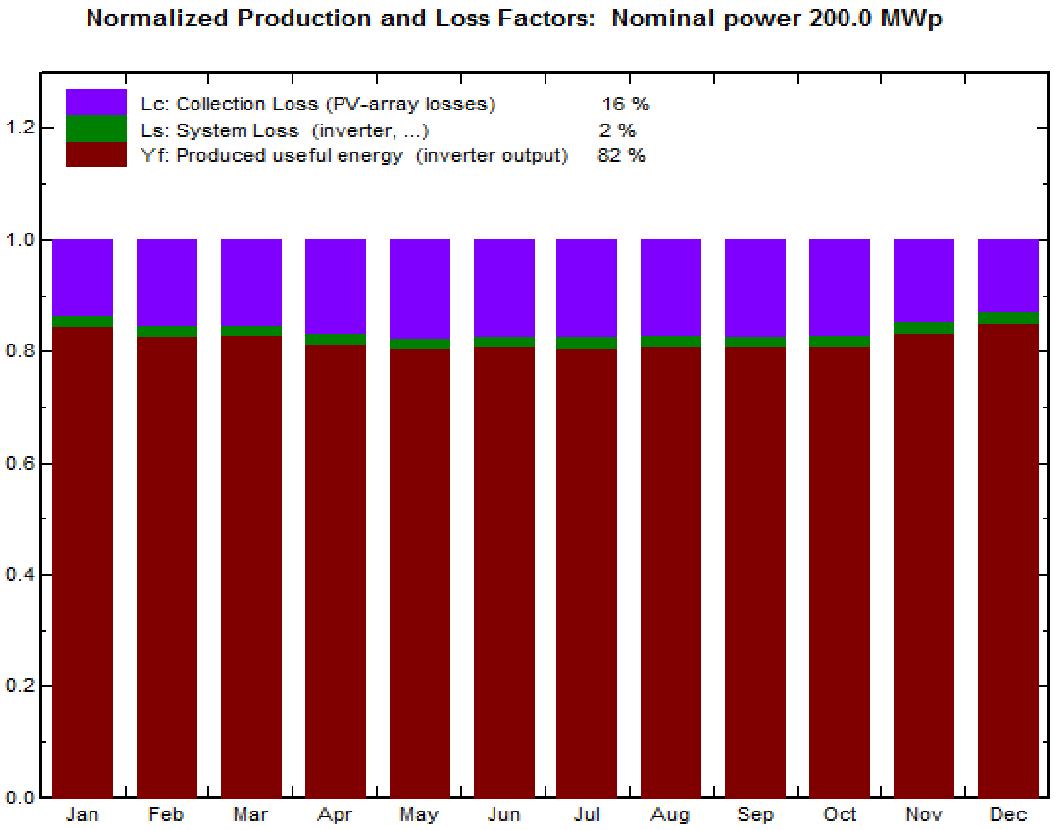

Figure 10. Normalized production and loss factors of Yanbu site

Figure 11 shows the Incident irradiation distribution of Yanbu PV project, all data calculated from January to December. Figure 12 shows the Array temperature & Effective irradiation of Yanbu PV project. Figure 13 shows the Array temperature distribution during running of Yanbu project

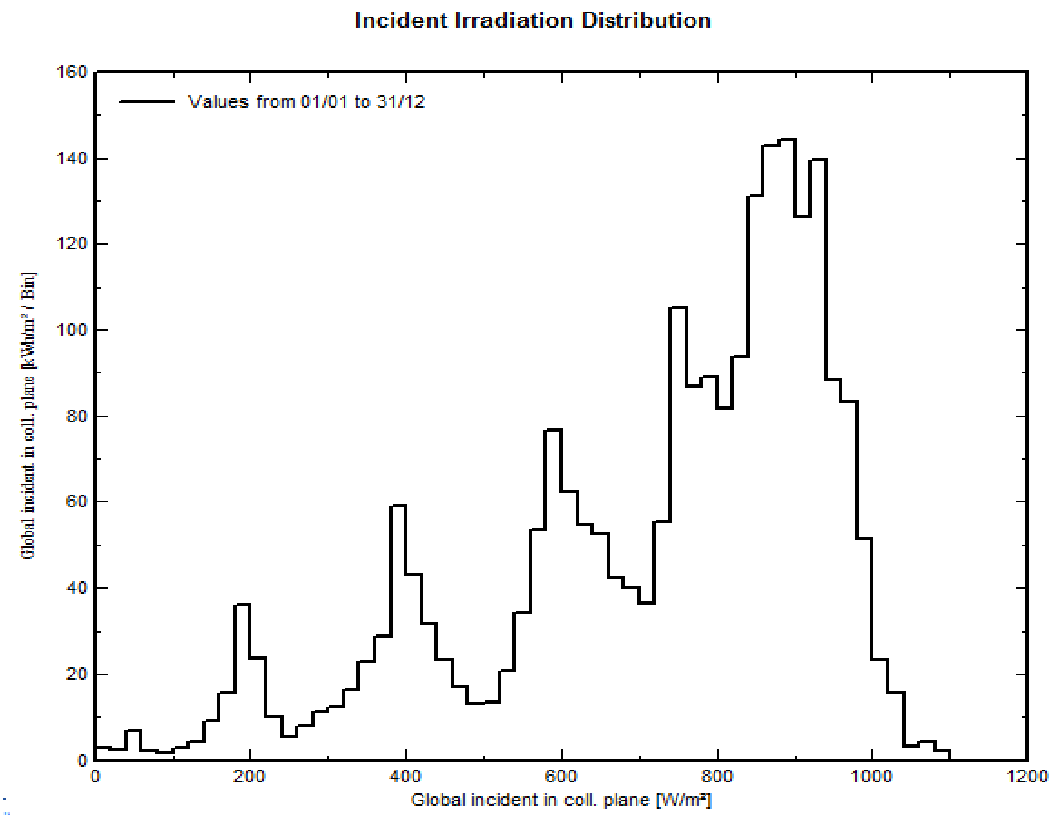

Figure 11. Incident irradiation distribution of Yanbu PV project

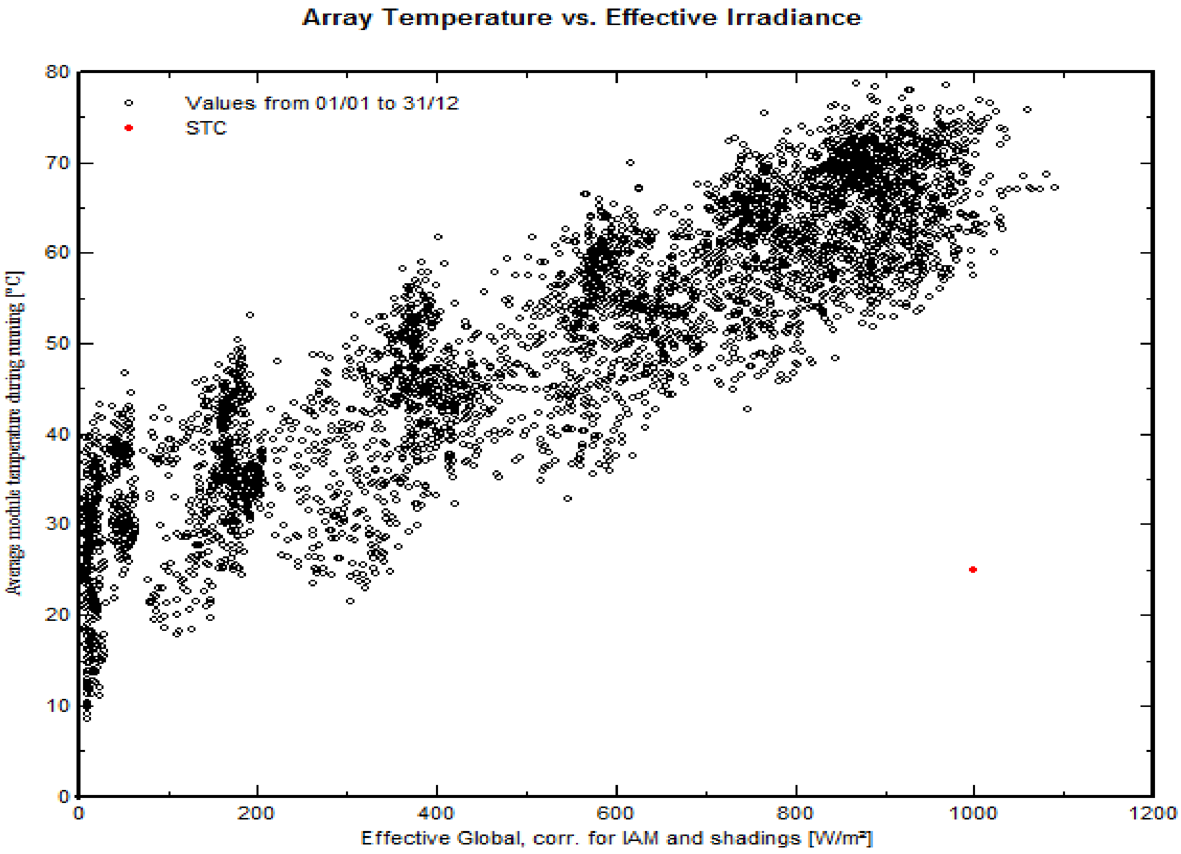

Figure 12. Array temperature & Effective irradiation of Yanbu PV project

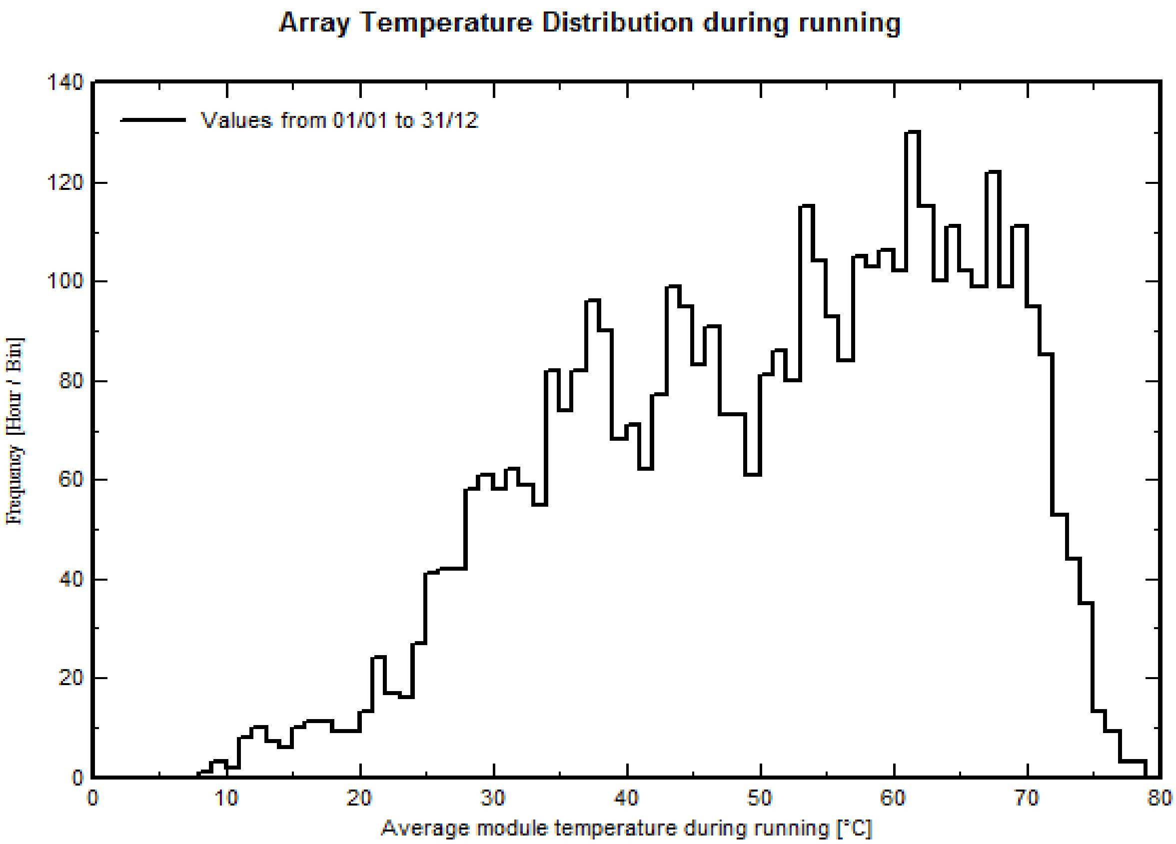

Figure 13. Array temperature distribution during running of Yanbu project

The CO_2 emissions saved for 25 years of lifetime of this project is 6.035713 million tons of CO_2 emissions as shown in Figure 14.

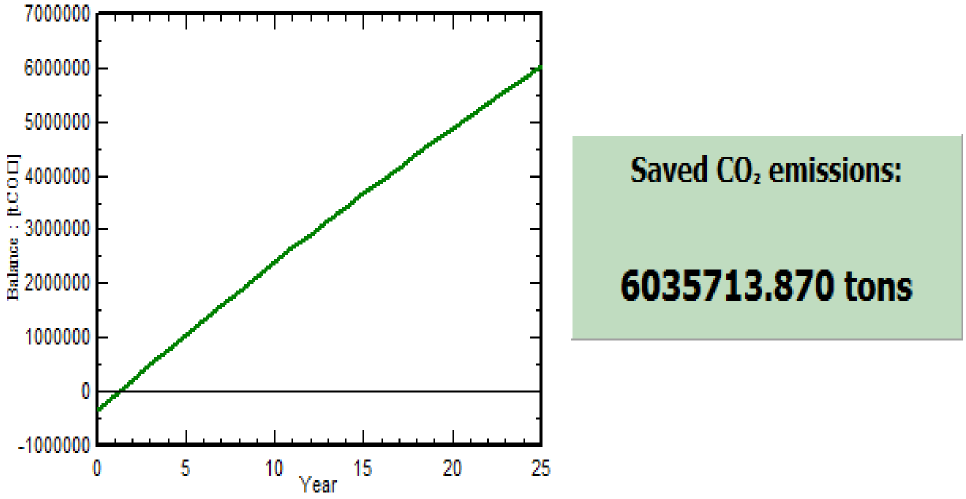

Figure 14. CO_2 emissions curve of Yanbu site

The installation of the two-axis tracking PV system was also demonstrated on Yanbu site. This system will show the total energy production from the same amount or size PV farm by using the two-tracking axis of sun light and how much CO_2 emission saved. Figure 15 shows for Yanbu site, the best tilt angle limits are (0/80) degree and Azimuth limits is (-120/120) degree that give maximum power from PV panels.

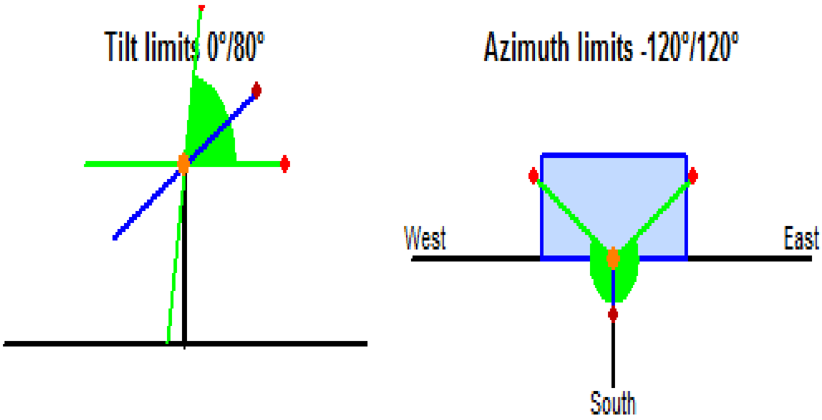

Figure 15. Tilt angle limits degree and Azimuth limits

Table 2. Total power generation of Yanbu project is 500437 MWh with performance ratio (80.5%)

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	140.1	34.81	19.11	247.9	247.2	40955086	39950541	0.806
February	149.9	43.78	20.94	234.3	233.5	38638366	37690763	0.804
March	182.6	70.78	24.69	256.4	255.3	43265373	42225629	0.823
April	207.7	70.40	28.19	274.4	273.4	44971075	43872625	0.799
May	234.3	75.55	32.12	305.1	304.0	49259520	48055611	0.788
June	226.0	83.26	33.22	289.8	288.7	47241792	46105336	0.795
July	224.9	86.49	34.36	291.5	290.3	47808216	46661981	0.800
August	198.3	95.25	34.48	242.6	241.2	40179145	39204261	0.808
September	184.8	71.73	32.19	250.7	249.6	41322655	40332389	0.805
October	172.7	54.62	29.82	260.2	259.2	42539589	41504702	0.798
November	137.6	42.34	25.25	235.5	234.7	39245174	38297681	0.813
December	125.6	40.34	21.46	221.8	221.0	37446893	36536138	0.824
Year	2184.4	769.35	28.02	3110.2	3098.0	512872885	500437657	0.805

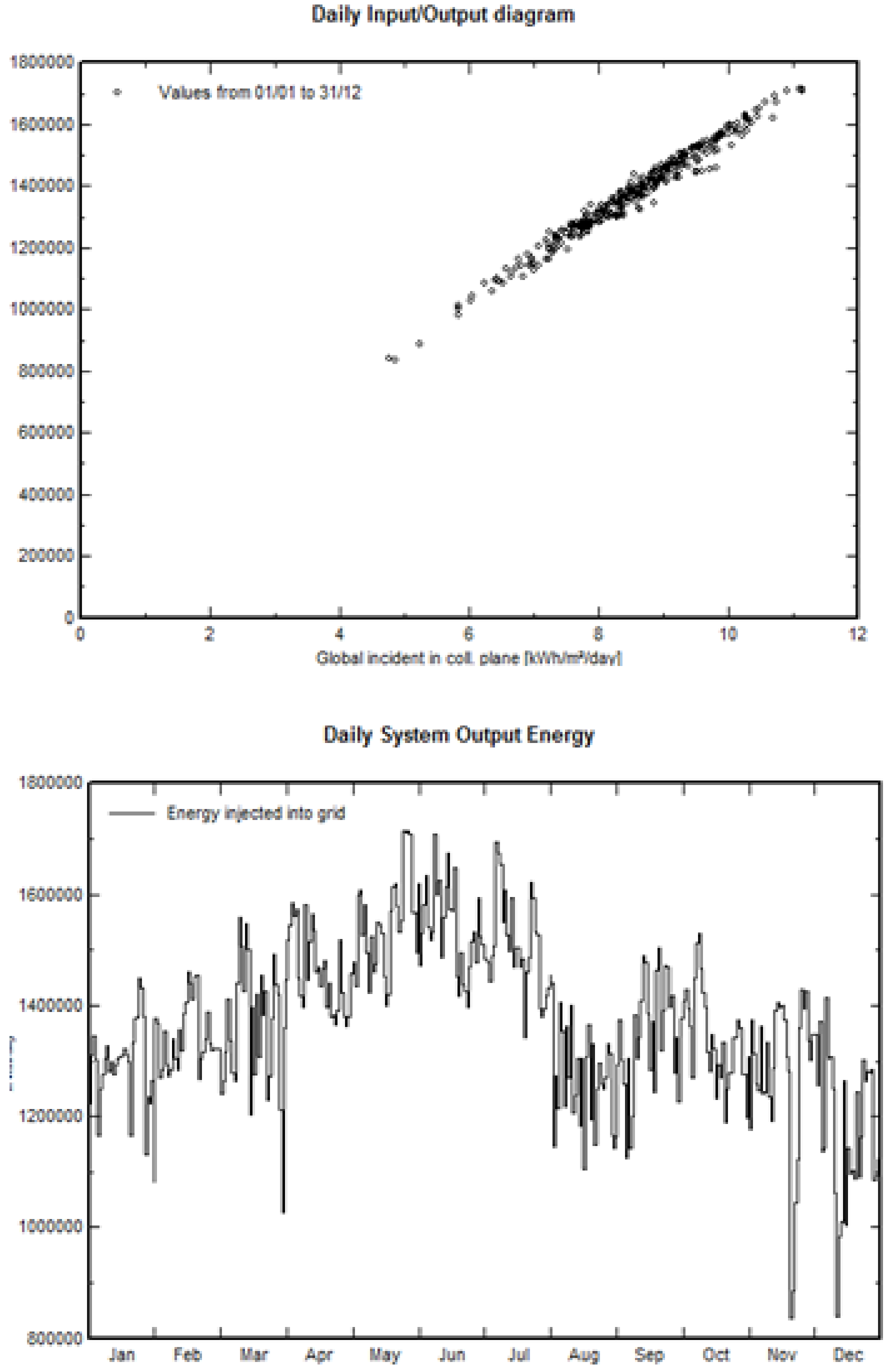

Figure 16. Daily input/output diagram & Daily system output Energy of Yanbu PV project

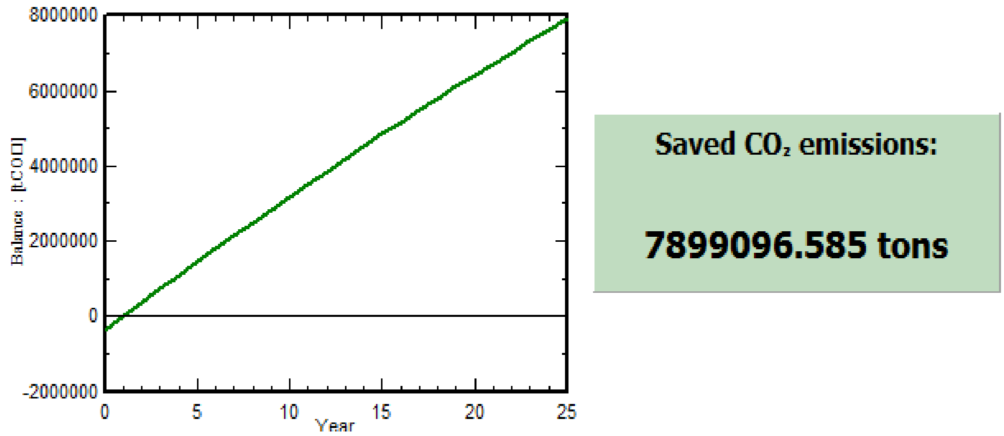

Figure 17. CO_2 emissions curve of Yanbu site with two axis tracking system

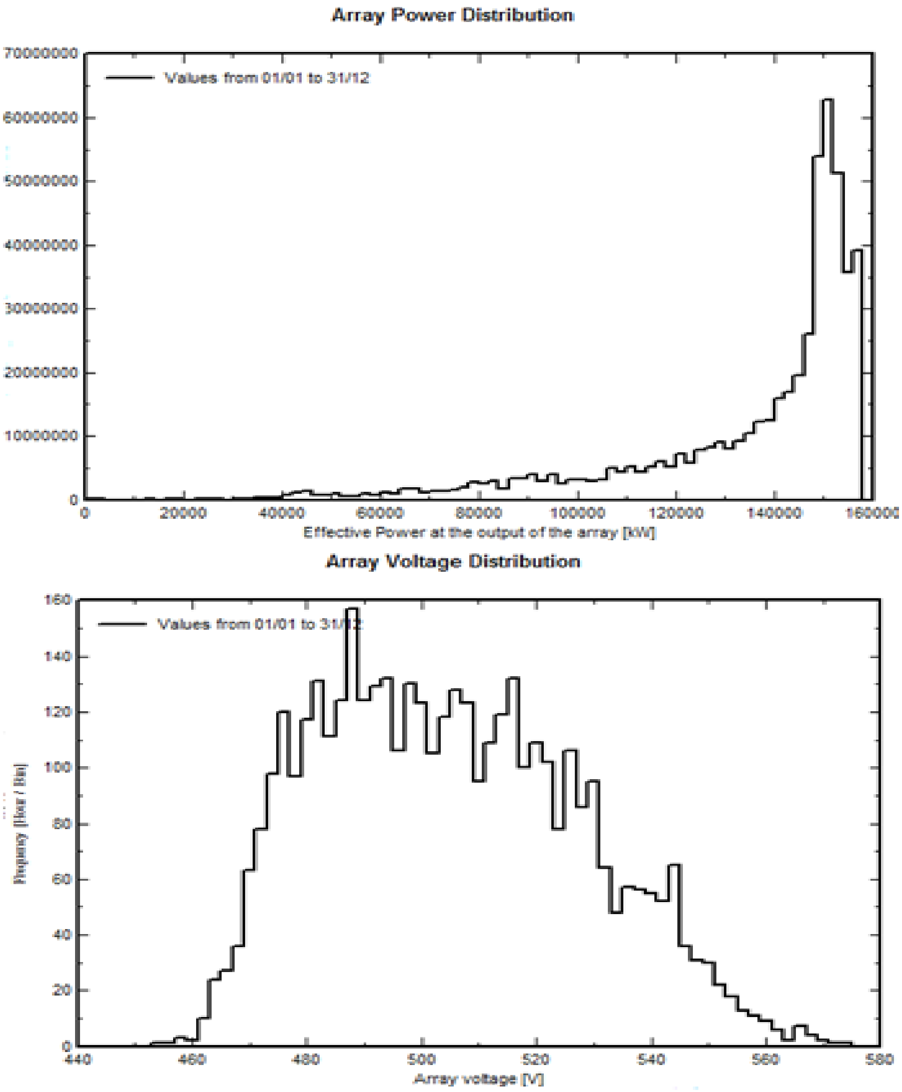

Figure 18. Array power distribution & Array voltage distribution of Yanbu site with two axis tracking system

Figure 16 shows the Daily input/output diagram (kwh/m^2/day) & Daily system output Energy (kwh/day) of Yanbu PV project with two axis tracking system. Figure 17 shows the CO_2 emissions curve of Yanbu site with two axis tracking system. Figure 18 shows Array power distribution & Array voltage distribution of Yanbu site with two axis tracking system. All data in this diagram are calculated from all days of year (January to December). The CO_2 emissions saved from this project equal 315963.863 tCO_2 per year, and the lifetime of PV system is between 25 to 30 years. For 25 years of lifetime the project can save around 7.89 million tons of CO_2 emissions.

3.2. PV stations on Rabigh Site

The second location studied in this work was Rabigh. Rabigh coordinates are (Latitude 22.6538°N, Longitude 39.0557 °E) and Altitude is 14 meters as shown in Figure 19. For Rabigh site, the best tilt angle is 25.8 degree with zero-degree Azimuth that give maximum power from PV panels. The data of sun path are collected from Meteonorm program, it is an unparalleled combination of reliable data and advanced calculation materials. From this data can be access to exact historical and information's for all time of year.

In this system will use around (363636) PV modules with unit nominal power (550 wp) that generate 200 MWp, also the design connection of modules will be (20202 strings)*(18 series). Figure 20 shows the inverter output distribution, the P_{nom} is 200 MWp and the maximum total power is about 151 MWac.

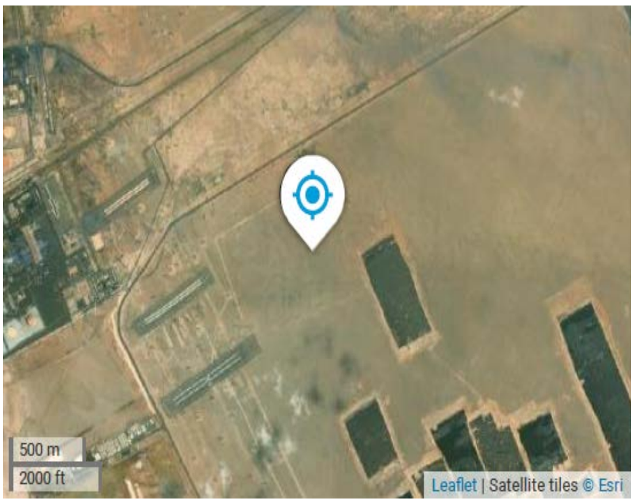

Figure 19. Location map of Rabigh site [15]

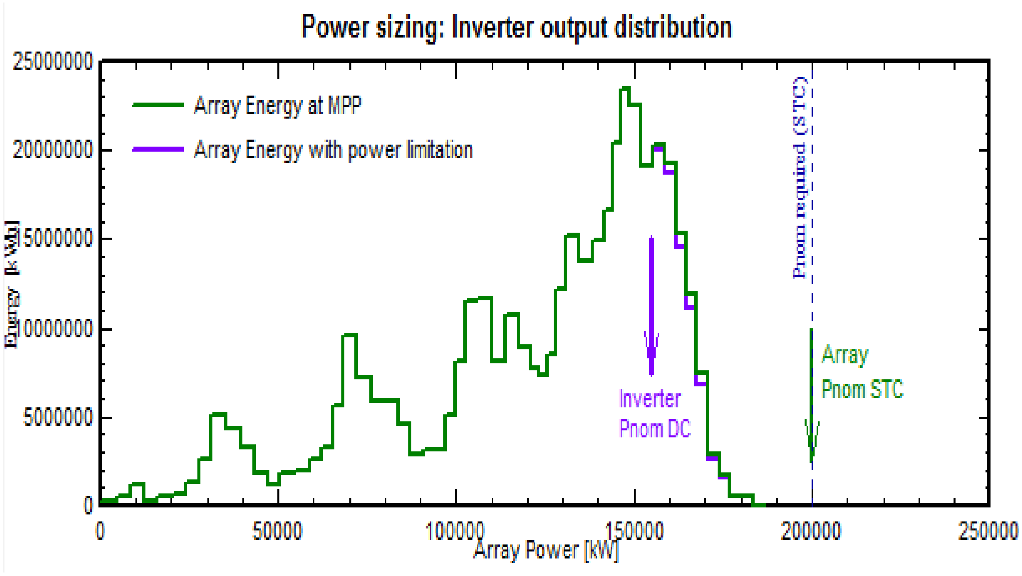

Figure 20. Inverter output distribution of Rabigh project

Figure 21 shows the total power injected to grid was around 151 MW of Rabigh project.

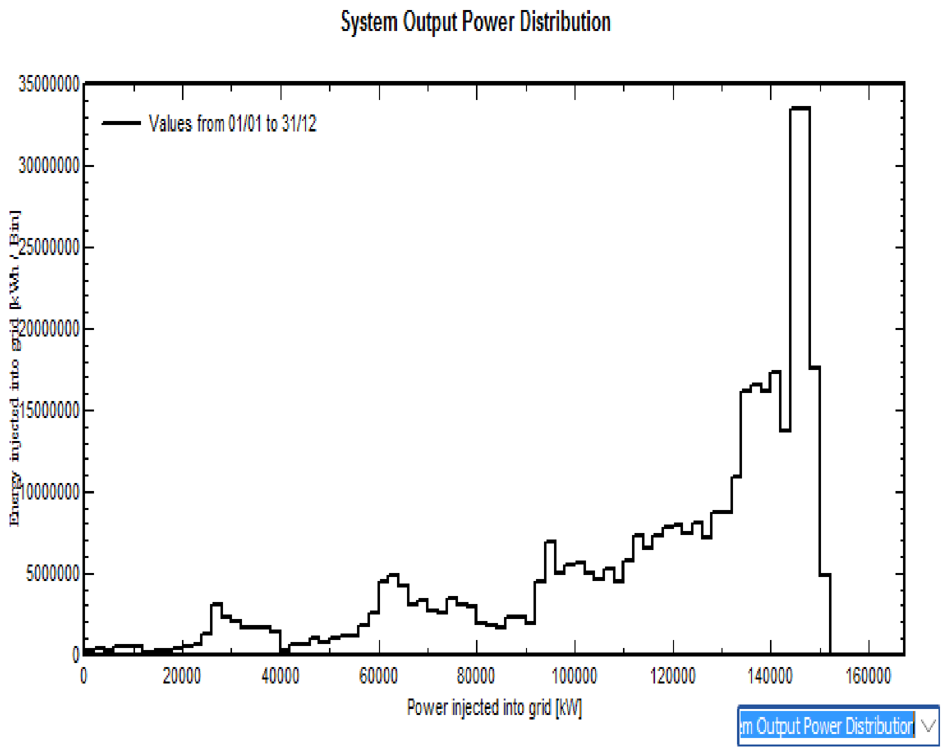

Figure 21. System output power distribution of Rabigh project

Table 3 shows the total power generation of Rabigh project of 385249 MWh with performance ratio (82.25%).

According of International Energy Agency (IEA) studies of CO_2 emission country factors, the CO_2 emissions saved from Rabigh project equal (236292.153) tCO_2 per year, and the lifetime of PV system is between 25 to 30 years. For 25 years of lifetime the project can save around 5.99 million tons of CO_2 emissions as shown in Figure 22.

The installation of the two-axis tracking PV system was also demonstrated on Rabigh site. This system showed the total energy production from the same amount or size PV farm by using the two-tracking axis of sun light and how much CO_2 emission saved. Figure 23 shows the best tilt and Azimuth angle for Rabigh site, the best tilt angle limits are (0/80) degree and Azimuth limits is (-120/120) degree that give maximum power from PV panels.

Figure 24 shows the Daily input/output diagram (kwh/m^2/day) & Daily system output Energy (kwh/day) of Rabigh PV project with two axis tracking system. Table 4 shows the total power generation of Rabigh project of 491931 MWh with performance ratio (80.6%).

The CO_2 emissions saved from this project equal 305067.784 tCO_2 per year, and the lifetime of PV system was between 25 to 30 years. For 25 years of lifetime the project can save around 9.15 million tons of CO_2 emissions as shown in Figure 25.

Table 3. Total power generation of Rabigh project of 385249 MWh with performance ratio (82.25%)

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	146.9	34.27	21.73	198.5	196.6	33694	33092	0.833
February	152.2	47.65	22.91	186.7	184.5	31366	30822	0.825
March	178.9	72.35	25.59	195.7	192.7	33121	32536	0.831
April	206.9	73.73	28.72	206.8	203.5	34363	33714	0.815
May	232.1	79.70	31.75	213.0	209.0	35213	34542	0.811
June	221.9	90.23	32.64	196.7	192.9	32731	32111	0.816
July	218.9	92.56	34.25	197.6	193.8	32766	32138	0.813
August	198.2	96.83	33.93	191.7	188.5	31895	31274	0.816
September	185.8	74.30	31.53	196.7	193.8	32667	32052	0.815
October	175.6	57.62	29.73	207.0	204.6	34176	33542	0.810
November	139.1	45.93	26.50	181.2	179.0	30817	30274	0.835
December	126.0	46.94	23.77	170.3	168.2	29671	29150	0.856
Year	2182.4	812.11	28.62	2342.0	2307.2	392480	385249	0.822

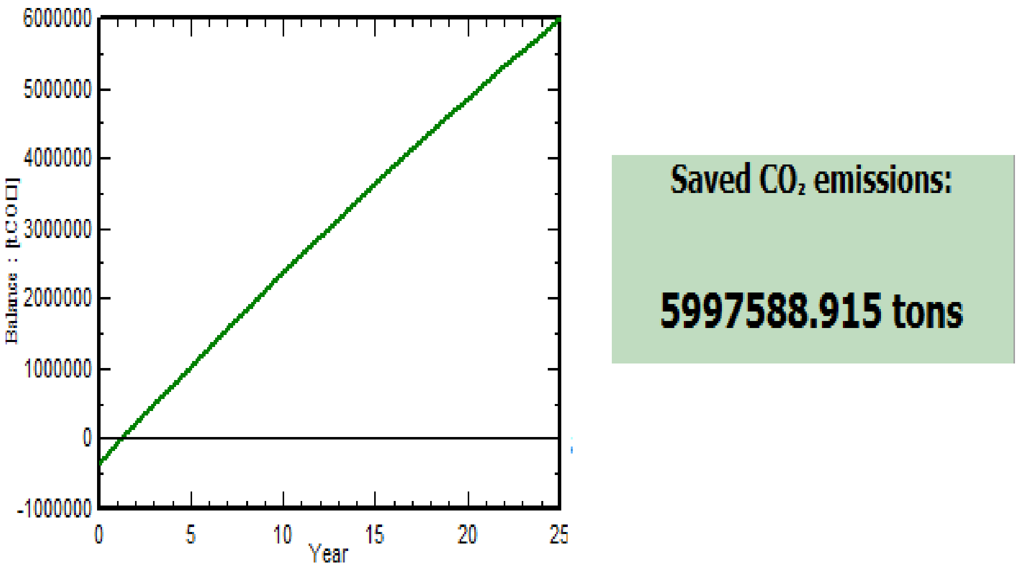

Figure 22. CO_2 emissions saved at Rabigh project

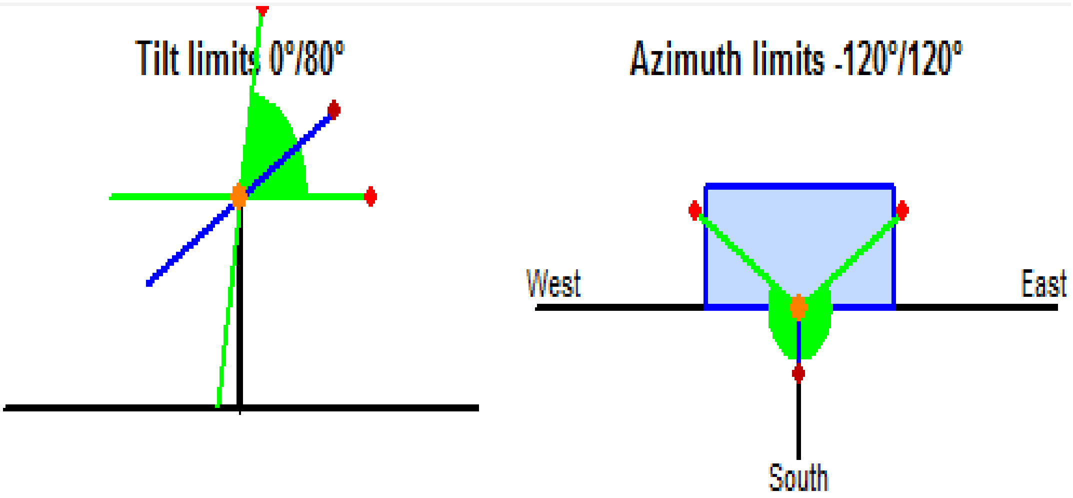

Figure 23. Tilt angle limits degree and Azimuth limits

Table 4. Total power generation of Rabigh project of 491931 MWh with performance ratio (80.6%)

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	146.9	34.27	21.73	252.6	251.8	40527	39834	0.788
February	152.2	47.65	22.91	234.1	233.2	38291	37634	0.804
March	178.9	72.35	25.59	247.9	246.7	41569	40847	0.824
April	206.9	73.73	28.72	271.1	270.0	44220	43429	0.801
May	232.1	79.70	31.75	296.9	295.8	47721	46844	0.789
June	221.9	90.23	32.64	279.7	278.5	45662	44831	0.801
July	218.9	92.56	34.25	277.2	275.9	45653	44808	0.808
August	198.2	96.83	33.93	239.1	237.7	39630	38880	0.813
September	185.8	74.30	31.53	248.0	246.9	40926	40187	0.810
October	175.6	57.62	29.73	257.6	256.6	41770	41019	0.796
November	139.1	45.93	26.50	230.4	229.5	38208	37542	0.815
December	126.0	46.94	23.77	216.2	215.2	36712	36077	0.835
Year	2182.4	812.11	28.62	3050.7	3038.0	500890	491932	0.806

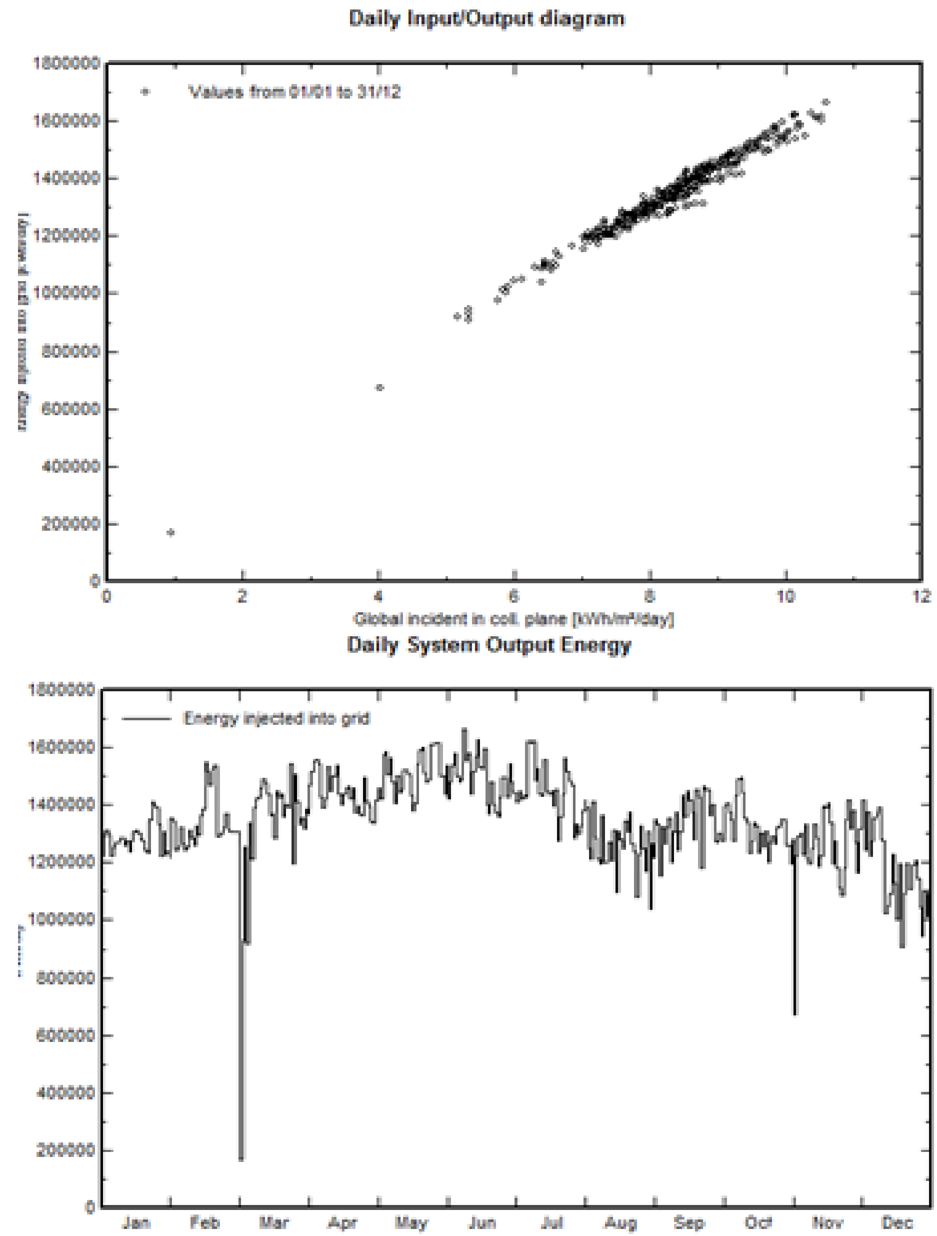

Figure 24. Daily input/output diagram & Daily system output Energy of Rabigh PV

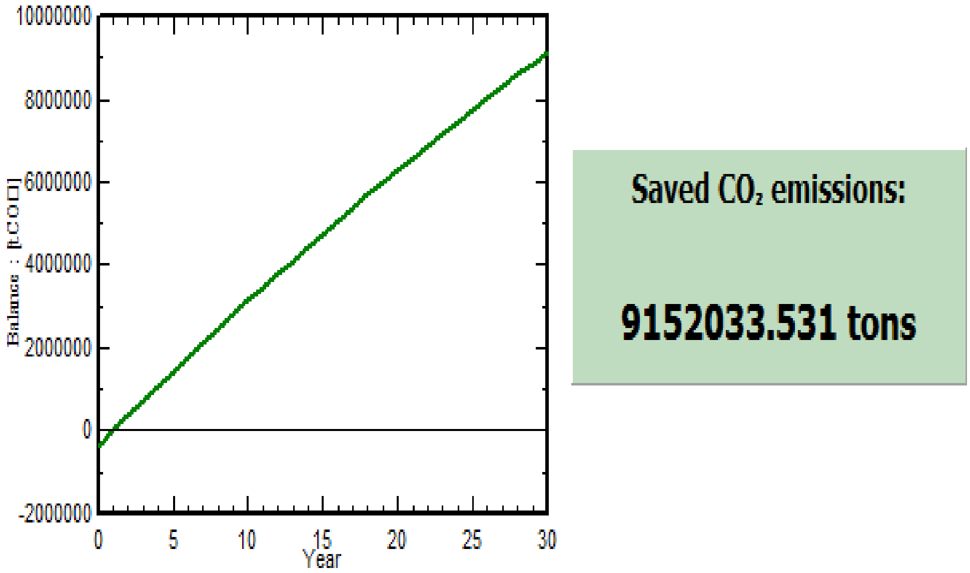

Figure 25. CO_2 emissions saved from Rabigh site with two axis tracking system

4. Conclusion

In this work, an analytical study of using PV system energy in two sites of Saudi Arabia was presented. The work discussed the possibility of connecting the PV system with the grid, while reducing the amount of reducing CO_2 emissions during the production of electricity through clean energy. a simulation program was used to simulate the installation of PV cells on two regions in Saudi Arabia. The possibility to use the tracker system to track the sunshine and generate more power from PV systems was discussed. The results of this study showed that the use of PV systems near the power plants in two locations in Saudi Ariba will reduce the dependence of the oil. Moreover, it will reduce the CO_2 emissions. The expected total generated power from Yanbu PV station is 388 GW/h without the tracking system for 25 years lifetime and 500 GW/h for the tracking system. The expected total generated power from Rabigh PV station is 385 GW/h without the tracking system and 491 GW/h for the tracking system for 25 years lifetime.

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