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Analytical Study of Power Generation by Photovoltaic System for Al-Riyadh and Al-Jubail Regions in Saudi Arabia

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Abstract This paper presents an analytical study of photovoltaic (PV) power generation of two regions in Saudi Arabia. Renewable energy resources have recently been acknowledged as a vital component of global economic stability, particularly in countries like Saudi Arabia. Saudi Arabia is a vibrant country that is experiencing significant population increase, which has resulted in high electricity usage. Because of the strong solar radiation, huge rainless area, and lengthy sunlight, Saudi Arabia has a bright future in terms of using solar energy more broadly. As a result, the Saudi Arabian government has invested billions of dollars in large-scale renewable and sustainable energy projects around the country, backed by strong funding. Saudi Arabia wants to boost solar power output to meet a large amount of the country's prospective energy needs. Various installations and research projects are currently being carried out throughout the kingdom to meet its solar power ambitions. As a result, it is critical to keep up with the latest developments in the solar business in the country. Development and Research (R&D). In this work a simulation (*PVsyst 7.1*) software program to simulate the installation of PV cells on two regions of Saudi Arabia including Al-Al-Riyadh and Al-Jubail regions. Also, the possibility of using the tracker system to track the sunshine and generate more power from PV systems is discussed. This paper presents, however, is a partnership and it intends to examine the existing state, growth, potential, resources, sustainability performance, and prospects of renewable energy in Saudi Arabia in accordance with Saudi Vision 2030.

Keywords: *PV, solar, cells, renewable, Saudi Arabia*

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1. Introduction

In Saudi Arabia, the electric power generation aims to raise the capacity to 120 GW through 2032 by fast growth of the country's economy over the last decade. The current high loads necessitate proper and sufficient power generation However, hazardous gas emissions such as nitrogen oxides (NO, NO_2 & N_2O), sulfur oxides (SO_2 & SO_3), and carbon oxides (CO_2 & CO_3) are well known to be a major cause of pollution and have a severe impact on human health due to conventional production utilizing fossil fuels (CO & CO_2). Globally, there are significant diversifications in energy sources, as well as the strengthening of renewable energy possibilities. The most essential motivations for such endeavors are environmental preservation, increased energy production, and economic growth. Indeed, it is no exaggeration to argue that the world is gradually transitioning from a hydrocarbon-dependent economy to a sustainable one. However, it is worth noting that the prospect of renewable energy in major oil producers, particularly in countries that are heavily reliant on oil, has received relatively little attention [1]. As a result, there has been an associated paucity of research. These countries should not only recognize specific renewable energy resources to secure their energy and economic futures, but they should also not overlook their potential essential role in achieving a healthier future for future generations. The Saudi Arabia's main oil powerhouse is an interesting case to be considered in this regard [1].

As a result, it is critical to discover a new strategy to support Saudi Arabia's present conventional generating while simultaneously protecting the environment and human health. Saudi Arabia has become one of the major solar PV energy producers because to its advantageous location in the so-called sun belt, which includes vast desert area and year-round clear sky. Saudi Arabia receives an average of 2200 thermal kWh/m^2 of energy from the sun [1]. Figure 1 shows the Solar resource maps of Saudi Arabia.

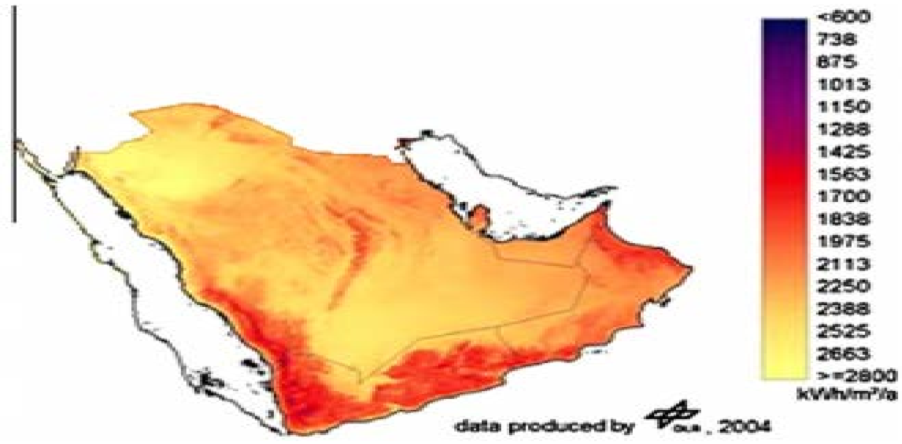

Figure 1. Solar resource maps of Saudi Arabia

Saudi Arabia is in the heart of one of the world's most productive solar power zones, receiving the most powerful type of sunlight [4]. Saudi Arabia is a huge country, covering 2.3 million square kilometers. It is a reasonably wealthy country, and electricity demand is increasing at a pace of roughly 5% per year [5]. The cost of conventional generating including indirect charges, as determined by the government, is around 0.32 SR/kWh by 2015, or by 2020 under the worst-case scenario of high solar energy costs, the latest amount will be competitive with PV projects as shown in Figure 2. The total price of conventional generation, including indirect costs, vs solar energy is represented by the last approach to comparison. When prices are not subsidized by the government and indirect expenses are included in, solar energy is currently more cost-effective than traditional generating. As a result, strategy C is the most convenient state because it is comparable to Saudi Arabia's current energy policy. By 2020, solar energy is predicted to be cost competitive with conventional power sources [6].

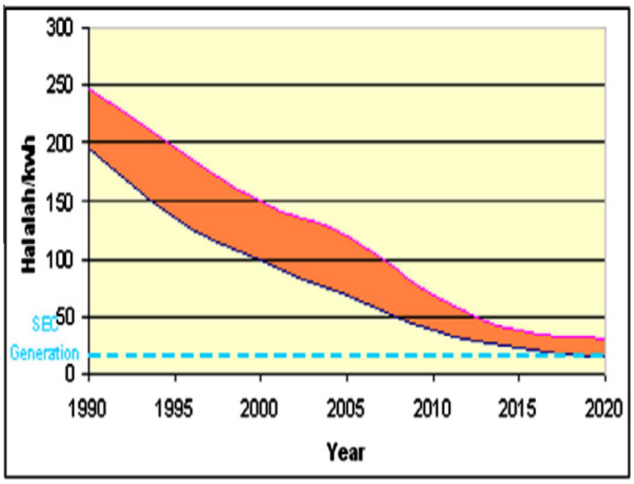

Figure 2. Forecasting of PV-generated electricity cost (100 Hallas = 1 Saudi riyal)

2. Research Problem

The buildings consume half of the world's energy production in developing countries. PV arrays, rather than large-scale projects like solar plants, could be beneficial to both customers and the country when used in the construction of individual buildings. PV technology will assist communities in reducing pollution while also assisting the power grid during periods of heavy demand [8]. Saudi Arabia's electricity demand is increasing at a rate of 5.8% per year [9], owing to a variety of factors including fast-growing economies, population expansion, low electricity prices, and a lack of interest in energy conservation [10]. In 2008, the country consumed 35 GW and was unable to meet all peak-time demand, resulting in power shortages in some locations; by 2023, this volume is predicted to climb to 70 GW [11]. Saudi Arabia's development boom and population explosion have resulted in a rise in electricity demand. The constant high demands necessitate an adequate and sufficient power supply. This clearly contributes to the depletion of fossil fuels, causing environmental concerns. However, environmental pollutant gases such as nitric oxide, nitrogen dioxide, and nitrous oxide, as well as carbon oxides, are believed to be the primary cause of environmental contamination and the repercussions for human health from traditional fossil fuels. As a result, there is a significant national desire for alternative energy sources that are environmentally sustainable and can easily supply the country's demands in the post-oil period. In Saudi Arabia, an alternative strategy to support current traditional Saudi generations that also protects the environment and human health should be established. This entails devising some new strategies for dealing with rising statistics.

Small, distributed operations throughout Saudi Arabia demonstrated the efficiency and operating efficiency of PV systems in extracting electricity in the 1970s, demonstrating their compatibility for local climates. Solar energy is a renewable and infinite form of electricity generation. It was shown to offer numerous advantages and significant economic benefits, as well as being prospective for future application. Saudi Arabia's annual population expansion exacerbates energy consumption, ensuring that the residential sector consumes more than half of the country's annual power output [12].

3. Saudi Arabia's Electricity Generation

Saudi Arabia is the OPEC's largest oil producer, accounting for roughly one-fifth of the world's proven oil reserves (Organization of Petroleum Exporting Countries). Saudi Arabia is poised to remain the world's greatest net oil exporter, thanks to significant investments in the oil sector and low production costs. Saudi oil output in 2011 was 544 million tons (Mt), with net exports of 355 Mt in the same year (IEA, 2012). Saudi Arabia's power generation capacity is expected to reach 120 GW in the next two decades (GWe) as shown in Figure 3. The need for energy utilities has increased because of Saudi Arabia's fast rising population and industrial infrastructure, as well as low electricity costs (averaging 8 percent annual growth over the period). In certain sections of the country, this rapid load increase has resulted in shortages, brownouts, blackouts, and power rationing. Electricity demand, which is currently around 50 GWe (roughly 200 TWh) of annual production, is expected to rise from 80 GWe by 2020 to more than 120 GWe by 2030, according to the government [13].

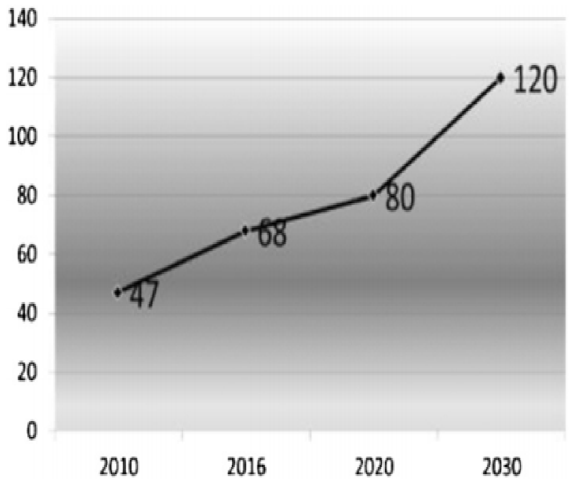

Figure 3. Increase of power production

4. Sumilation and Analysis

The first site studied for installing PV stations in this work was on Al-Riyadh. The installation of PV systems is near a power plants 10 of Saudi Electricity Company. That makes the connection of PV systems directly with grid and with small distance of distribution lines. All calculations and simulation have been accomplished by (PVsyst 7.1) program and GLOBAL SOLAR ATLAS. The estimated power generation for each site is 200 MWp. The coordinates of this study in Al-Riyadh are (Latitude 24.413684 °N, Longitude, 47.008009 °E) and Altitude is 511 meters. Figure 4 (a,b) shows the Solar path at Al-Riyadh from JAN to DEC & location map.

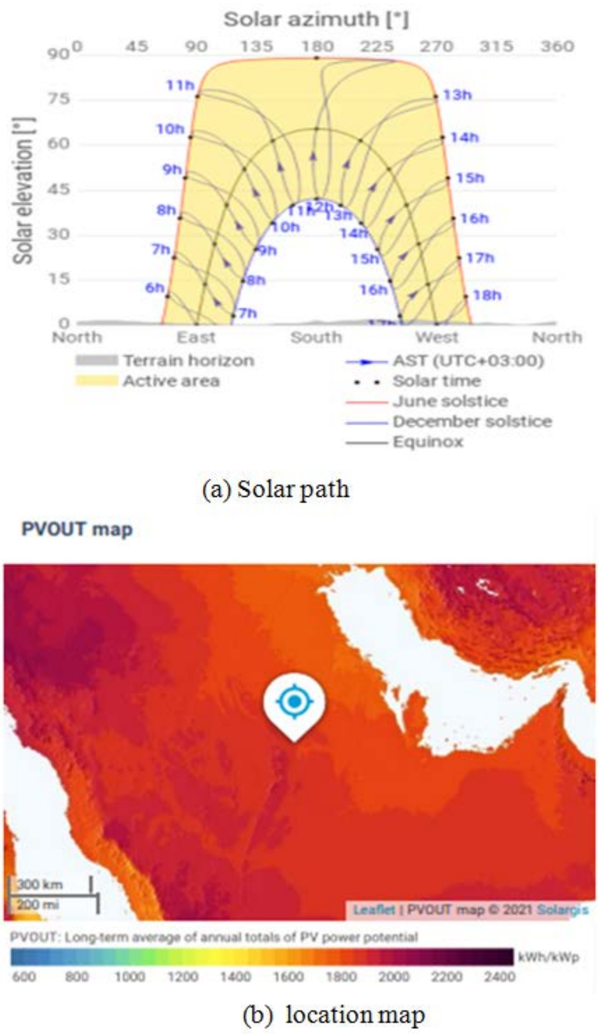

Figure 4. Solar path at Al-Riyadh from JAN to DEC & location map

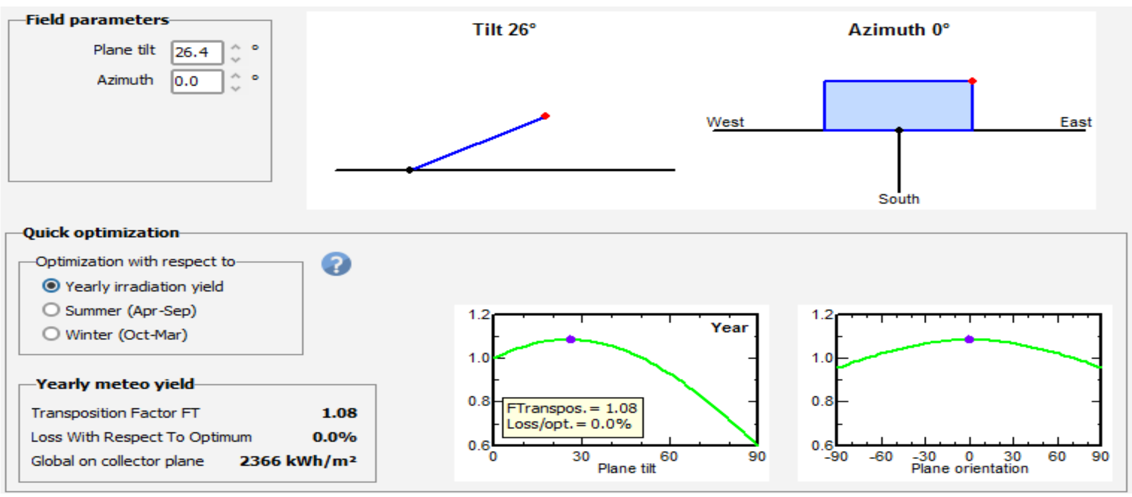

Figure 5. Tilt and Azimuth angle for Al-Riyadh site

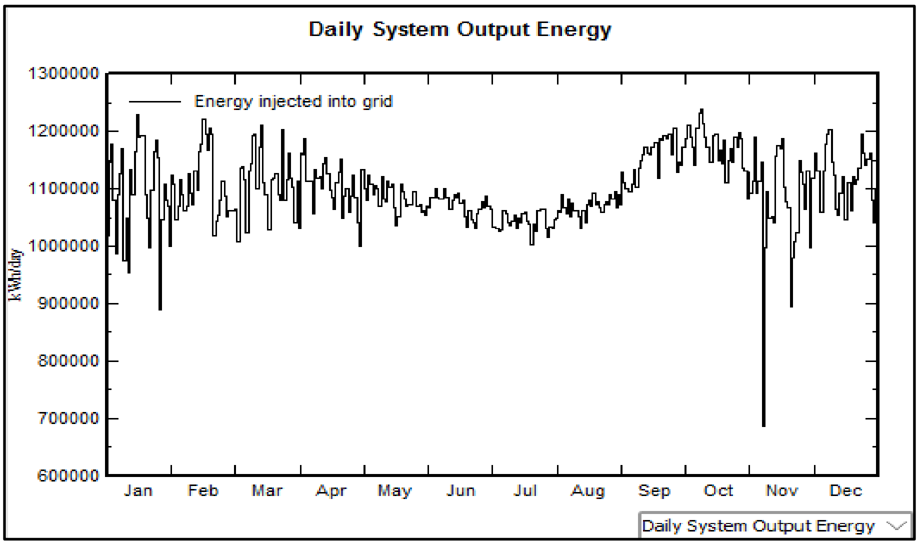

Figure 6. The daily system output energy of Al-Riyadh site

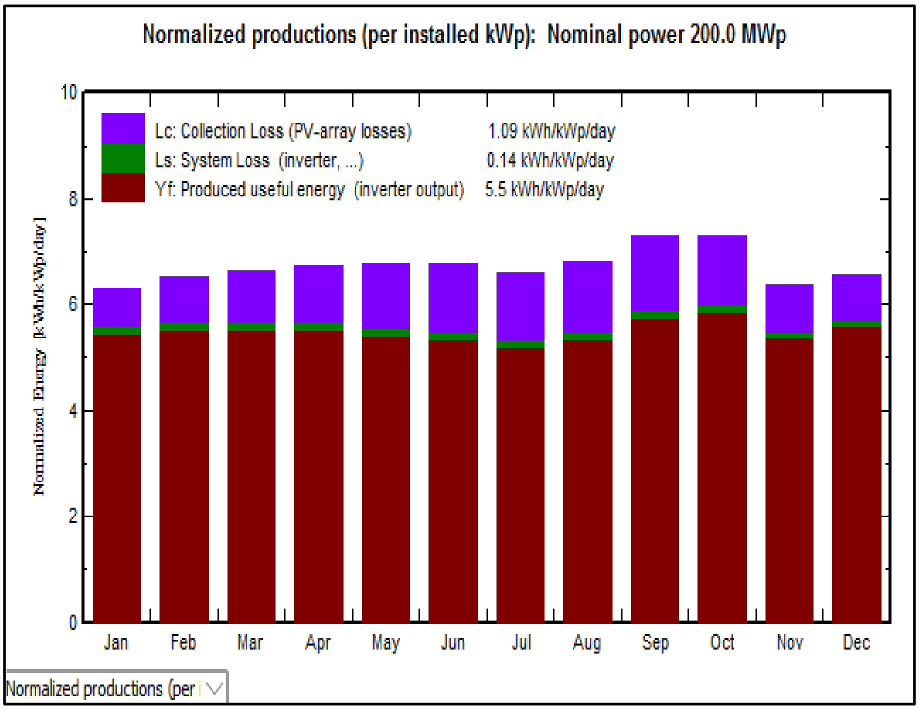

Figure 7. Normalized productions/KWp Al-Riyadh site

Table 1. Total power generation of Al-Riyadh project

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	137.1	37.9	13.89	195.2	193.1	34717	33901	0.868
February	145.0	50.5	17.18	182.4	180.4	31817	31048	0.851
March	184.4	72.7	22.32	205.4	202.8	35259	34349	0.837
April	203.2	83.5	27.47	202.1	198.7	34034	33217	0.822
May	232.3	92.4	33.85	210.2	206.1	34454	33613	0.800
June	233.0	104.4	35.77	202.9	198.5	32976	32168	0.793
July	231.6	88.0	37.51	204.6	200.2	33099	32285	0.789
August	220.6	90.0	37.49	201.8	207.1	33973	33165	0.786
September	203.8	51.7	33.49	219.0	215.8	35423	34562	0.789
October	184.7	42.9	28.64	226.6	223.8	37182	36287	0.801
November	139.2	38.4	20.88	191.0	189.0	33014	32208	0.843
December	136.9	29.3	15.83	203.5	201.5	35536	34688	0.852
Year	2251.9	781.7	27.08	2453.7	2416.9	411484	401535	0.818

Figure 5 shows the best tilt and Azimuth angle for Al-Riyadh site, the best tilt angle is 30.0 degree that give maximum power from PV panels. The data of sun path are collected from Metronome program. Figure 6 shows the daily system output energy of Al-Riyadh site. Figure 7 shows the Normalized productions/KWp Al-Riyadh site.

In this system will use around (363636) PV modules with unit nominal power (550wp) that generate 200MWp, also the design connection of modules will be (25974 strings) * (14 series). Table 1 shows the total power generation of Al-Riyadh project is 401535 MWh with performance ratio (81.8).

The CO_2 emissions saved from this project equal 250654.719 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 6.26 million tons of CO_2 emissions as shown in Figure 8.

Al-Riyadh site with two axis tracking 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 9 shows the best tilt and Azimuth angle for Al-Riyadh 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 10 shows the reference incident energy in collector plane of Al-Riyadh site with two axis tracking system. Figure 11 shows the Normalized production and loss factors & Normalized production of Al-Riyadh site with two axis tracking system. Figure 12 shows the Daily input/output diagram (kwh/m^2/day) & Daily system output Energy (kwh/day) of Al-Riyadh PV project with two axis tracking system. Figure 13 shows the Array power distribution of Al-Riyadh site with two axis tracking system.

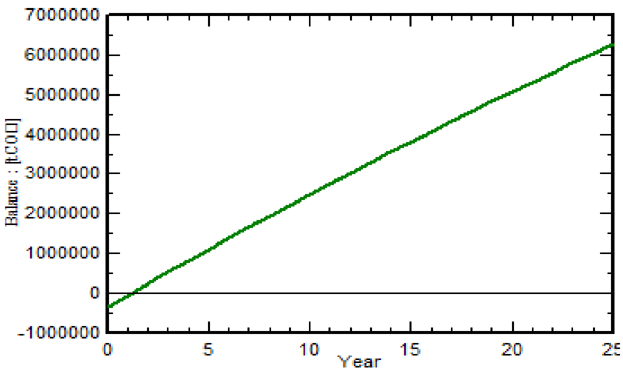

Figure 8. CO_2 emissions saved at Al-Riyadh project

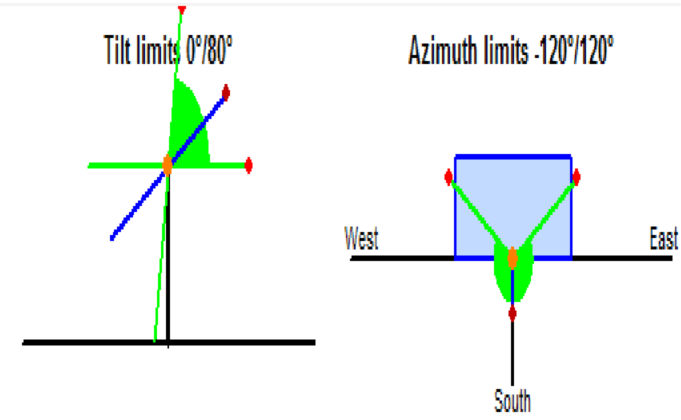

Figure 9. Tilt angle limits degree and Azimuth limits

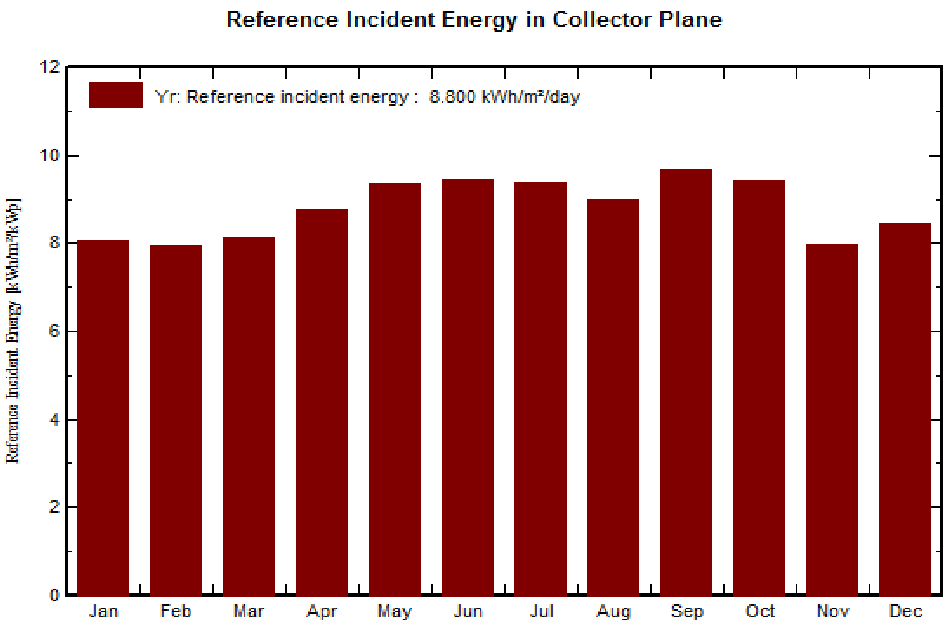

Figure 10. Reference incident energy in collector plane of Al-Riyadh site with two axis tracking system

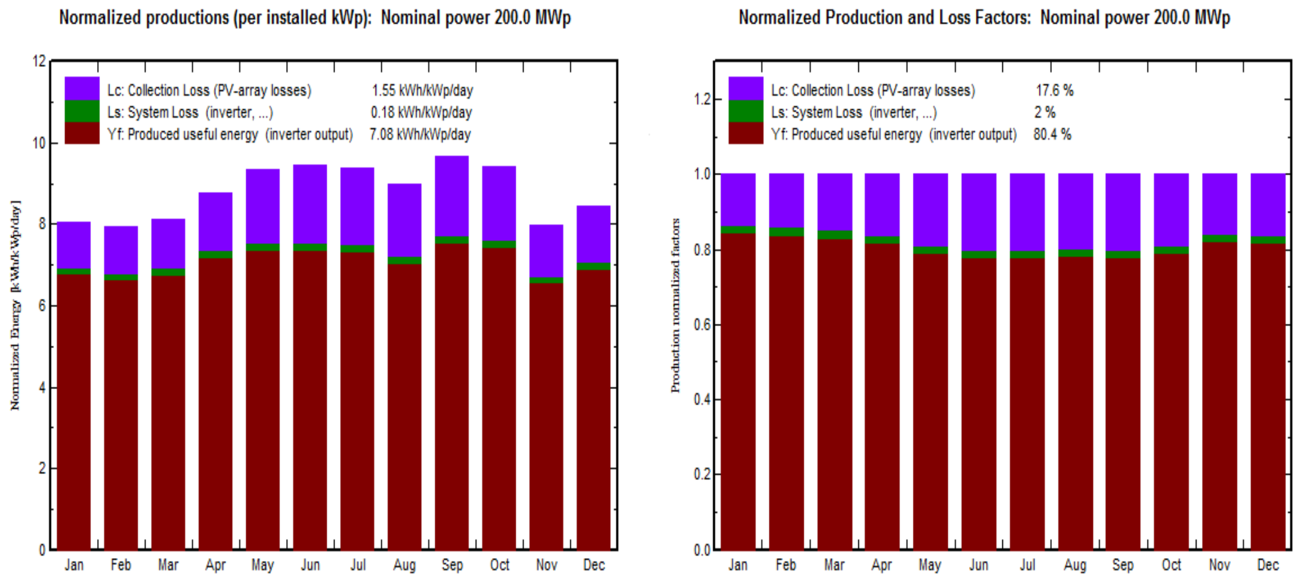

Figure 11. Normalized production and loss factors & Normalized production of Al-Riyadh site with two axis tracking system

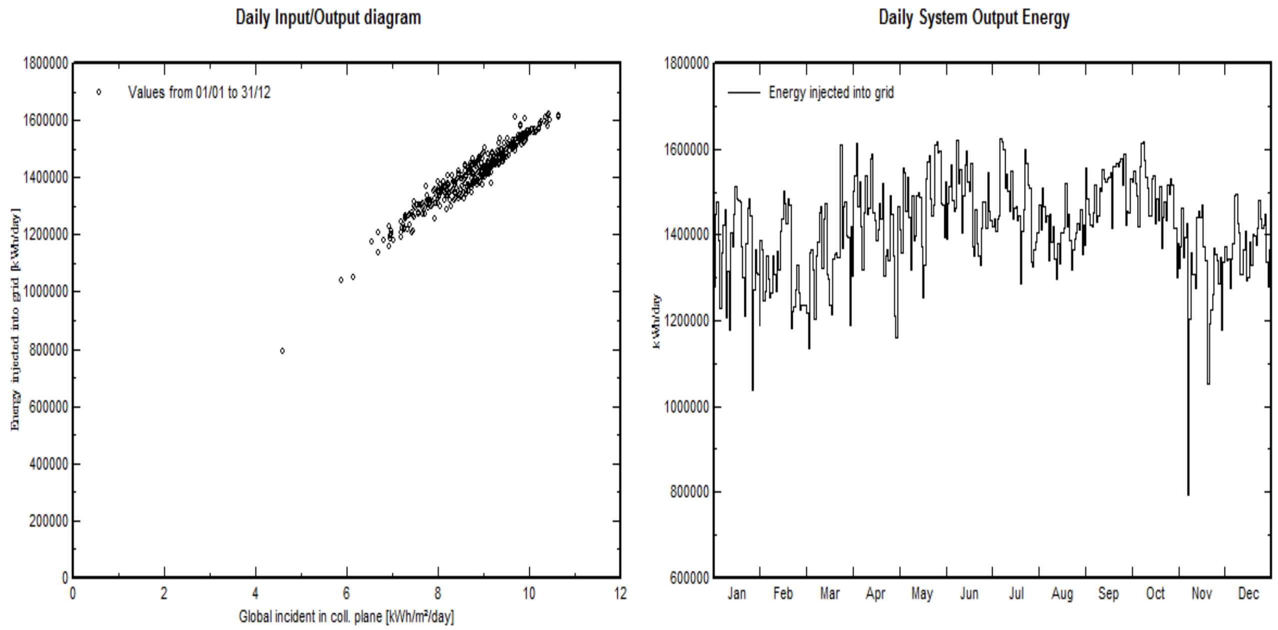

Figure 12. Daily input/output diagram (kwh/m^2/day) & Daily system output Energy (kwh/day) of Al-Riyadh PV project with two axis tracking system

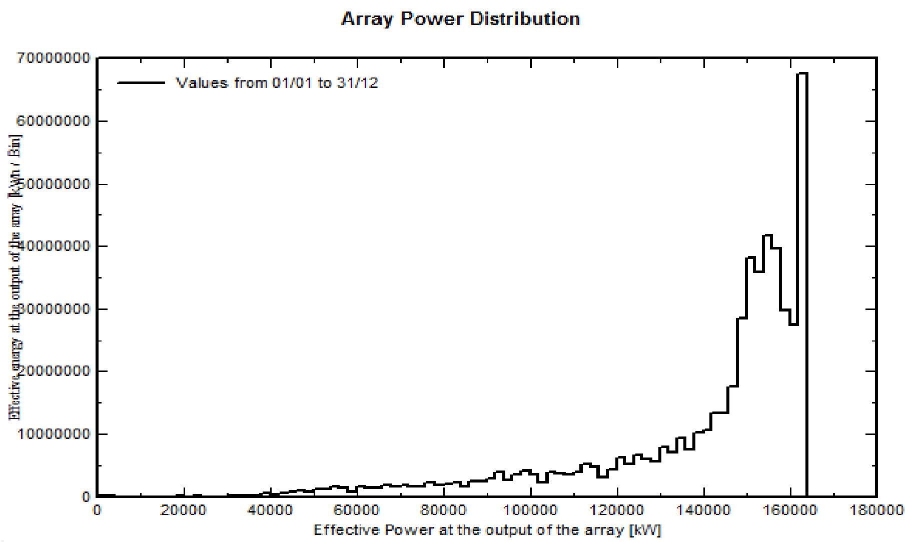

Figure 13. Array power distribution of Al-Riyadh site with two axis tracking system

Table 2 shows the total power generation of Al-Riyadh project is 516498 MWh with performance ratio (80.4%).

Table 2. Total power generation of Al-Riyadh project with two axis tracking system

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	137.1	37.9	13.89	249.3	248.5	43110	42078	0.844
February	145.0	50.5	17.18	221.9	221.0	38131	37215	0.838
March	184.4	72.7	22.32	252.3	251.2	42980	41931	0.831
April	203.2	83.5	27.47	263.2	262.0	44116	43057	0.818
May	232.3	92.4	33.85	289.7	288.4	46830	45704	0.789
June	233.0	104.4	35.77	283.2	281.7	45245	44149	0.780
July	231.6	88.0	37.51	290.9	289.7	46523	45413	0.781
August	220.6	90.0	37.49	278.9	277.6	44683	43618	0.782
September	203.8	51.7	33.49	289.6	288.8	46317	45193	0.780
October	184.7	42.9	28.64	291.7	290.9	47169	46024	0.789
November	139.2	38.4	20.88	239.7	238.9	40370	39381	0.822
December	136.9	29.3	15.83	261.7	261.0	43800	42738	0.817
Year	2251.9	781.7	27.08	3212.1	3199.6	529276	516500	0.804

The CO_2 emissions saved from this project equal 323683.808 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 8.09 million tons of CO_2 emissions as shown in Figure 14. Figure 15 shows the Array temperature distribution during running of Yanbu project.

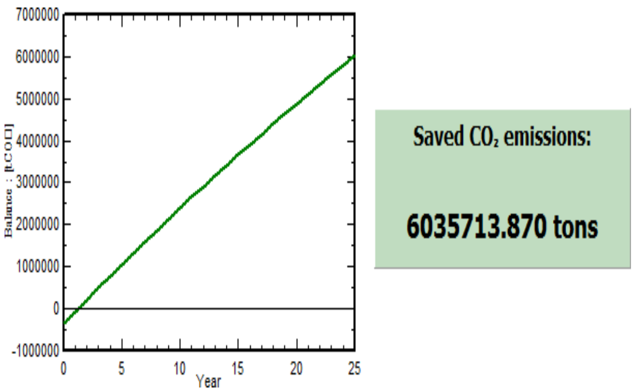

Figure 14. CO_2 emissions saved at Al-Riyadh site with two axis tracking system

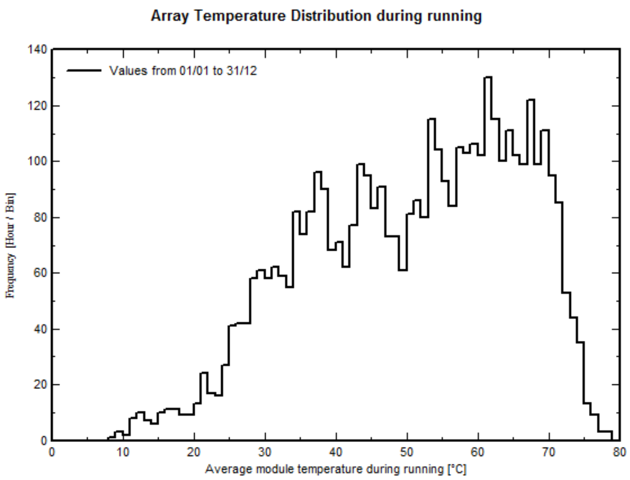

Figure 15. Array temperature distribution during running of Yanbu project

The CO_2 emissions saved from this project equal 241428.5 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 6 million tons of CO_2 emissions as shown in Figure 16.

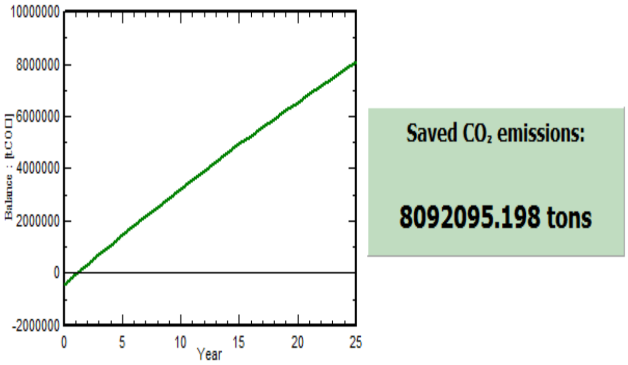

Figure 16. CO_2 emissions saved at Yanbu project

The second site studied for installing PV station on is in Al-Jubail city. Al-Jubail city is located near the Saudi Electricity Company that is easy to connect PV systems directly with grid and with small distance of distribution lines. Figure 17 shows the Solar path at Al-Jubail from JAN to DEC & location map.

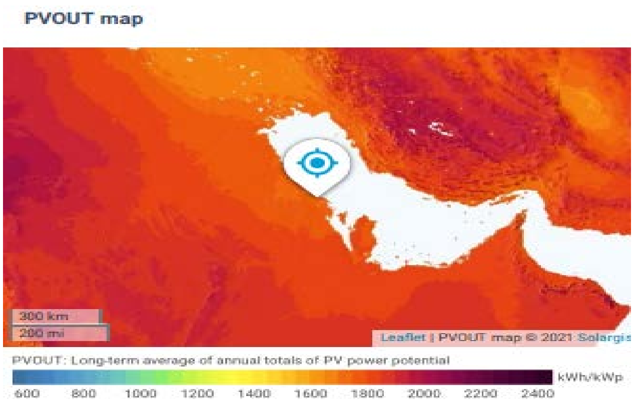

Figure 17. Solar path at Al-Jubail from JAN to DEC & location map

Figure 18 shows the best tilt and Azimuth angle for Al-Jubail site, the best tilt angle is 29.0 degree with zero-degree Azimuth that give maximum power from PV panels.

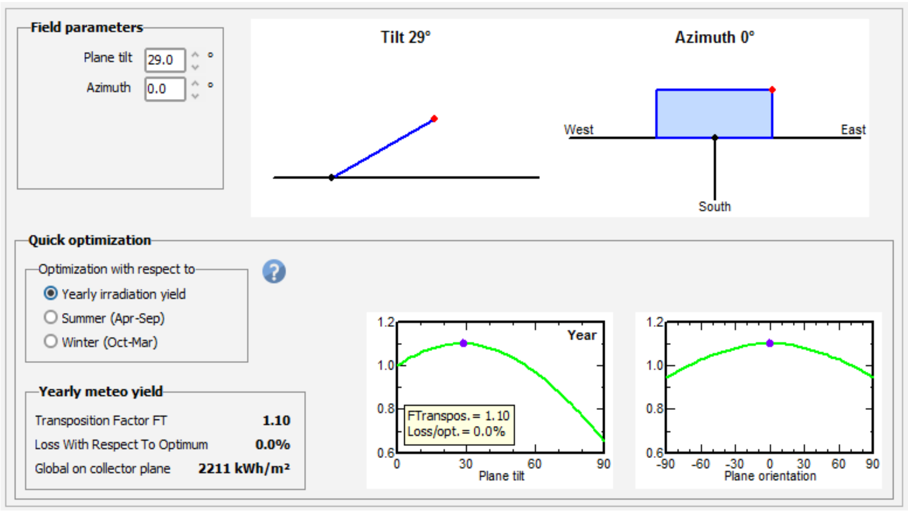

Figure 18. Tilt and Azimuth angle for Al-Jubail site

In this system will use around (363636) PV modules with unit nominal power (550wp) that generate 200MWp, also the design connection of modules will be (25974 strings) *(14 series). Figure 19 shows the Normalized production and loss factors & Normalized production of Al-Jubail project. Figure 20 shows the Daily input/output diagram (kwh/m^2/day) & Daily system output Energy (kwh/day) of Al-Jubail PV project. Figure 21 shows the output distribution on grid for Al-Jubail site.

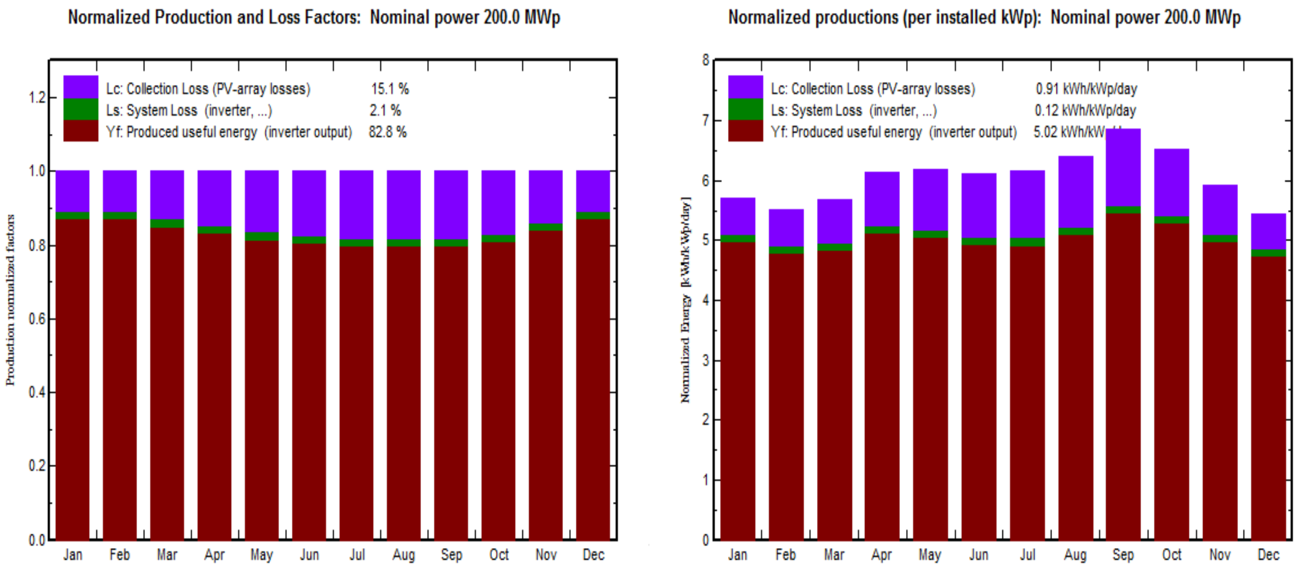

Figure 19. Normalized production and loss factors & Normalized production of Al-Jubail project

Table 3 shows the total power generation of Al-Jubail project is 366186 MWh with performance ratio (82.8%).

Table 3. Total power generation of Al-Jubail project

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	124.3	41.2	14.45	176.9	175.0	31610	30861	0.871
February	125.5	62.5	16.68	154.1	152.1	27527	26869	0.871
March	159.4	82.5	21.40	176.2	173.6	30703	29951	0.850
April	182.5	93.5	26.47	184.4	181.4	31478	30710	0.833
May	205.8	104.3	32.76	191.9	188.4	32038	31265	0.815
June	203.4	107.6	35.39	183.5	180.1	30312	29585	0.807
July	208.6	105.3	37.20	190.9	187.3	31241	30486	0.799
August	202.9	97.1	36.64	198.5	195.1	32398	31606	0.797
September	188.1	64.8	32.59	205.4	202.5	33539	32725	0.797
October	165.2	57.6	28.92	202.4	199.9	33651	32839	0.811
November	129.3	41.9	21.97	177.7	175.9	30671	29908	0.841
December	116.1	40.2	16.75	168.4	166.8	30115	29382	0.871
Year	2011.0	898.4	26.82	2210.2	2178.1	375284	366186	0.828

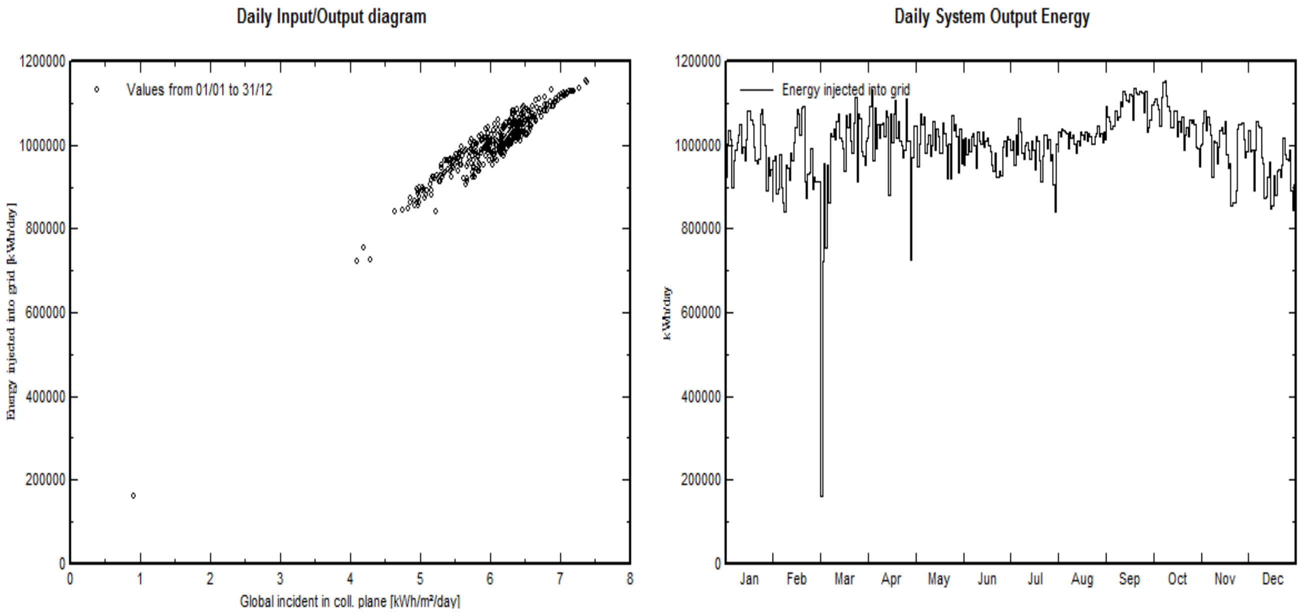

Figure 20. Daily input/output diagram (kwh/m^2/day) & Daily system output Energy (kwh/day) of Al-Jubail PV project

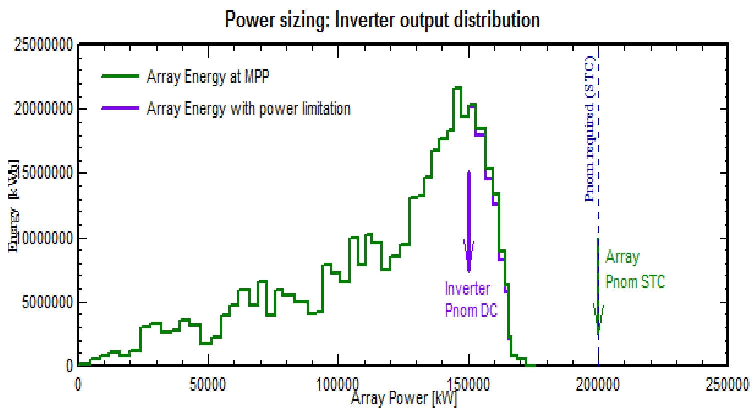

Figure 21. Output distribution on grid for Al-Jubail site

The CO_2 emissions saved from this project equal 227317.934 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 5.68 million tons of CO_2 emissions. Figure 22 shows the CO_2 emissions saved at Al-Jubail site.

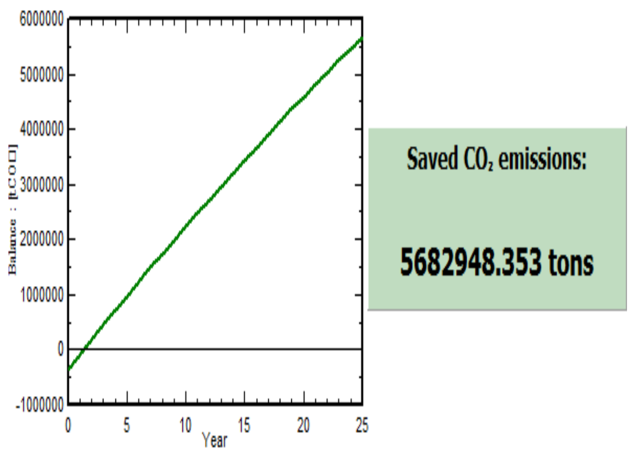

Figure 22. CO_2 emissions saved at Al-Jubail site

Al-Jubail site was also studied to generate the power using PV system with two axis tracking system. 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 23 shows the best tilt and Azimuth angle for Al-Jubail site, the best tilt angle limits is (0/80) degree and Azimuth limits is (-120/120) degree that give maximum power from PV panels. Figure 24 shows the Array power distribution & Array voltage distribution of Al-Jubail site with two axis tracking system. Figure 25 shows the Daily input/output diagram (kwh/m^2/day) & Daily system output Energy (kwh/day) of Al-Jubail PV project with two axis tracking system.

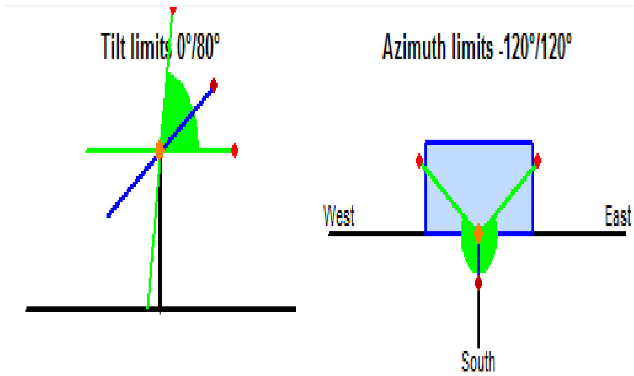

Figure 23. Tilt angle limits degree and Azimuth limits

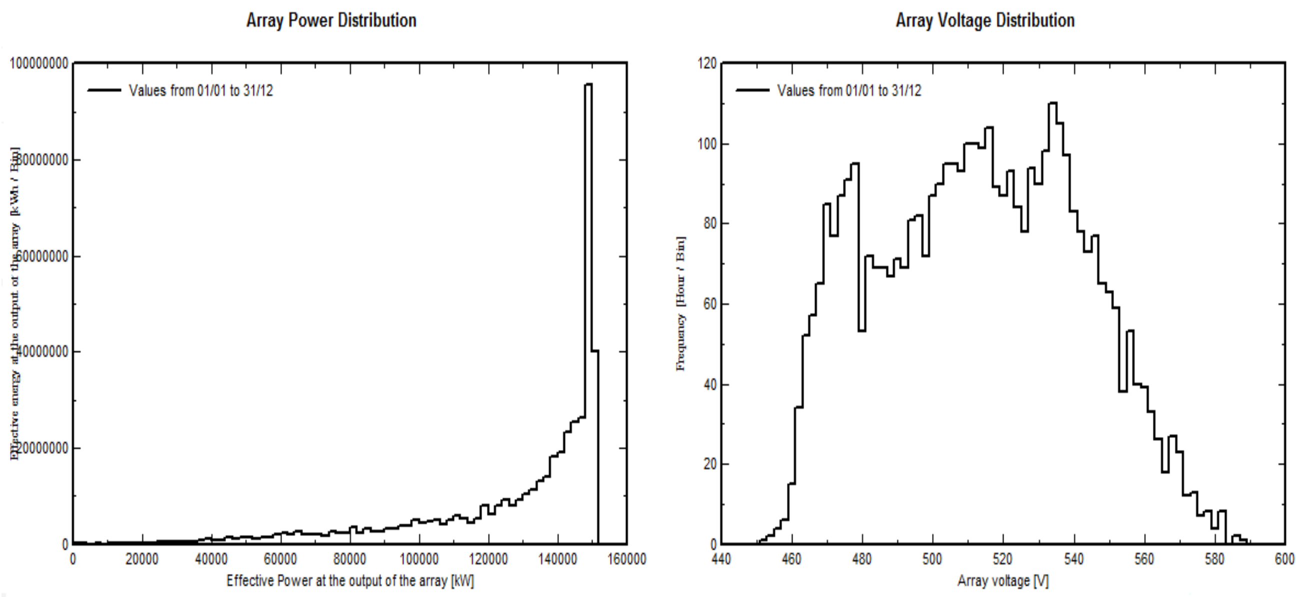

Figure 24. Array power distribution & Array voltage distribution of Al-Jubail site with two axis tracking system

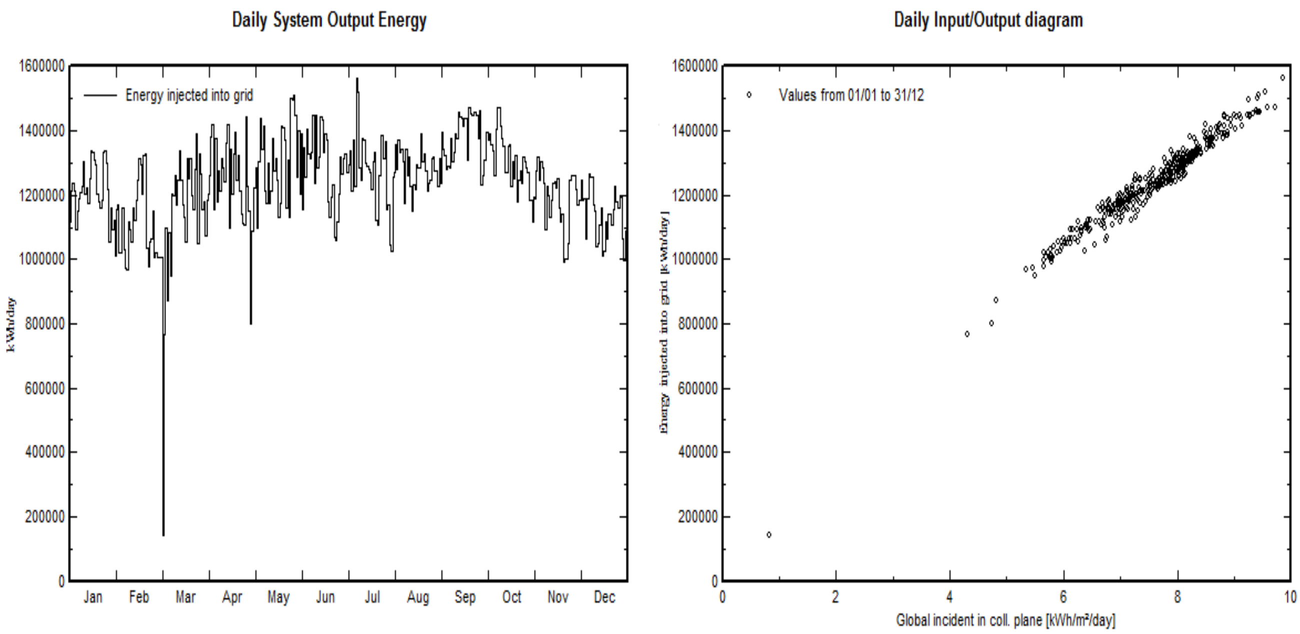

Figure 25. Daily input/output diagram (kwh/m^2/day) & Daily system output Energy (kwh/day) of Al-Jubail PV project with two axis tracking system

Table 4 shows the total power generation of Al-Jubail project is 452439 MWh with performance ratio (81.7%).

Table 4. Total power generation of Al-Jubail project with two axis tracking system

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	ratio
January	124.3	41.2	14.45	223.4	222.5	38356256	37440951	0.838
February	125.5	62.5	16.68	180.9	179.8	32005446	31245110	0.863
March	159.4	82.5	21.40	208.1	206.7	36136468	35264174	0.847
April	182.5	93.5	26.47	225.1	223.7	38256844	37330603	0.829
May	205.8	104.3	32.76	249.1	247.6	41481395	40482975	0.812
June	203.4	107.6	35.39	239.8	238.3	39470547	38524119	0.803
July	208.6	105.3	37.20	249.1	247.6	40644423	39666874	0.796
August	202.9	97.1	36.64	249.5	248.1	40713418	39739512	0.796
September	188.1	64.8	32.59	262.4	261.3	42440891	41409332	0.789
October	165.2	57.6	28.92	252.2	251.2	41357469	40354585	0.800
November	129.3	41.9	21.97	219.8	218.9	36598068	35698863	0.812
December	116.1	40.2	16.75	210.1	209.3	36154386	35282557	0.840
Year	2011.0	898.4	26.82	2769.5	2755.2	463615613	452439656	0.817

The CO_2 emissions saved from this project equal 281388.831 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 7.03 million tons of CO_2 emissions. Figure 26 shows the CO_2 emissions saved at Al-Jubail site with two axis tracking system.

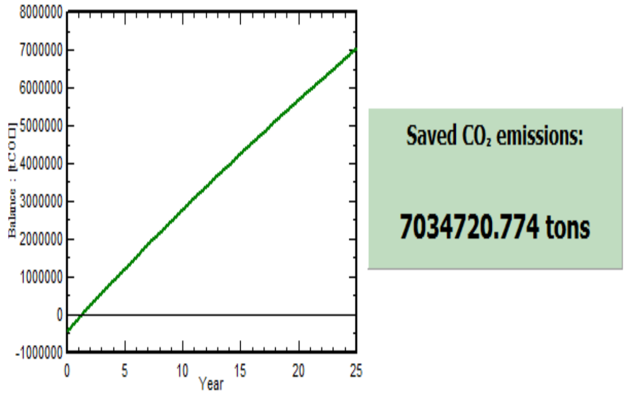

Figure 26. CO_2 emissions saved at Al-Jubail site with two axis tracking system

5. Conclusion

An analytical analysis of utilizing PV system energy in two Saudi Arabian locations was reported in this paper. The research investigated the potential of connecting the PV system to the grid, as well as calculating the amount of CO_2 emissions that may be avoided by using renewable energy to generate electricity. The installation of PV cells on two regions in Saudi Arabia was simulated using a modeling tool. It was considered whether the tracker system could be used to follow the sun and generate more power from PV systems. The findings of this study revealed that installing PV panels near power plants in two places in Saudi Arabia will reduce the country's reliance on oil. Furthermore, CO_2 emissions will be reduced. Without the tracking system, the total generated electricity from the Al-Riyadh PV station is estimated to be 401535 MW/h, while with the tracking system, it will be 516498876 KW/h for 25 years period. The total generated electricity from the Al-Jubail PV station is estimated to be 366186 MW/h without the tracking system and 452439656 KW/h for 25 years period.

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