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Integration of Solar Cells in Selected Petroleum Refinery Units at Al-Qayarah and Baiji Refineries

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ABSTRACT

The incorporation of renewable energy sources into petroleum refining processes is a critical step towards achieving sustainable industrial processes and reducing the carbon footprint of energy-intensive processes. The study addresses the critical challenge of energy sustainability in Iraq's petroleum refining sector, where conventional energy consumption patterns are a main contributor to greenhouse gas emissions and operational costs. The goal of this research is to study the technical and economic feasibility of the integration of photovoltaic solar power systems in two of the biggest Iraqi oil refineries: Al_Qayarahand the Baiji Northern refinery. The methodology employed involves extensive field data collection, energy consumption modeling of operating refinery units, and careful simulation modeling using the support of PVsyst software for designing grid-connected photovoltaic systems. Energy consumption patterns were analyzed systematically using different processing units, and the overall consumption was 1267 kW for Al_Qayarahrefinery and 18 MW for Northern refinery. Solar system specifications were calculated strictly, requiring 2304 solar panels of 550 Wp capacity each for Al_Qayarahand 32,725 for the Northern refinery, covering 5,889 m² and 83,647 m² areas respectively. The high-level novel results indicate tremendous renewable energy potential, with anticipated annual outputs of 2255.8 MWh for the Al_Qayarahrefinery and 31.838 GWh for the Northern refinery, with performance ratios of 86% and 85.2%, respectively. The validation results guarantee significant environmental benefits, with an approximate reduction in annual carbon dioxide emissions of 47,798.1 tons for Al_Qayarahand 32,799.43 tons for the Northern refinery. These findings prove the technical feasibility and substantial environmental advantage of solar energy's large-scale integration in petroleum refining operations, providing an integrated framework for renewable energy deployment in the industrial process in Iraq.

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تكامل خلايا الطاقة الشمسية في بعض وحدات المصافي النفطية في مصفى القيارة وبيجي

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الملخص

دمج مصادر الطاقة المتجددة في عمليات تكرير النفط يُعد مسارًا حاسمًا نحو تحقيق عمليات صناعية مستدامة وتقليل البصمة الكربونية للعمليات التي تستهلك الطاقة. تتناول هذه الدراسة التحدي الكبير لاستدامة الطاقة في قطاع التكرير النفطي في العراق، حيث تُعد أنماط استهلاك الطاقة التقليدية مساهمًا رئيسيًا في انبعاثات غازات الدفيئة وتكاليف التشغيل. يهدف هذا البحث إلى دراسة الجدوى الفنية والاقتصادية لدمج أنظمة الطاقة الشمسية الكهروضوئية في اثنين من أكبر مصافي النفط العراقية: مصفى القيارة ومصفى بيجي. تعتمد المنهجية المتبعة على جمع بيانات ميدانية شاملة، ونمذجة استهلاك الطاقة لوحدات التكرير العاملة، ومحاكاة التصميم باستخدام برنامج PVsyst لتصميم أنظمة شمسية مرتبطة بالشبكة. تم تحليل أنماط استهلاك الطاقة بطريقة منهجية من خلال وحدات المعالجة المختلفة، وبلغ الاستهلاك الكلي 1267 كيلوواط لمصفاة القيارة و18 ميغاواط للمصفاة الشمالية. تم حساب مواصفات النظام الشمسي بدقة، حيث يحتاج مصفى القيارة إلى 2304 لوحًا شمسيًا بسعة 550 واط لكل لوح، و يحتاج مصفى الشمال إلى 32725 لوحًا، لتغطية مساحات تبلغ 5889 مترًا مربعًا و83647 مترًا مربعًا على التوالي. وتشير النتائج المتقدمة إلى وجود إمكانيات هائلة للطاقة المتجددة، حيث من المتوقع أن يبلغ الإنتاج السنوي 2255.8 ميغاواط ساعة لمصفاة القيارة و31.838 غيغاواط ساعة مصفى الشمال، بنسبة أداء تبلغ 86% و85.2% على التوالي. اظهرت النتائج فوائد بيئية كبيرة، مع تقليل انبعاثات ثاني أكسيد الكربون السنوية بحوالي 47798.1 طنًا في القيارة و32799.43 طن في مصفى الشمال. تثبت هذه النتائج الجدوى الفنية والمكاسب البيئية الكبيرة من دمج الطاقة الشمسية على نطاق واسع في عمليات التكرير، مما يوفر إطارًا متكاملًا لتطبيق الطاقة المتجددة في العمليات الصناعية في العراق.

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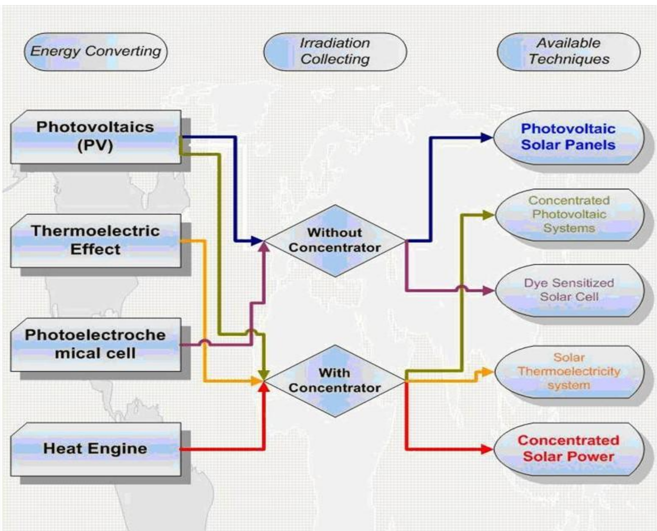
Introduction

The sun delivers more energy to Earth in an hour than the world uses in a year, making it the most abundant and promising renewable resource (Temizel et al., 2018). Yet, fossil fuels still dominate our energy supply, despite their environmental and supply issues (NA et al., 2024). The shift toward clean alternatives is critical, and solar energy—both concentrated solar power (CSP) and photovoltaic (PV)—is leading that transition (Asif et al., 2024). PV panels are especially attractive for being emission-free during operation and based on non-toxic, abundant silicon (Duffie & Beckman, 1980). Thermoelectric systems also offer promise. They're simple, quiet, and need little maintenance, especially useful in harsh environments or for small-scale setups (Lykas et al., 2022). But current materials have low efficiency (a figure of merit between 1.3–2.0), and high-temperature operation requires costly sunlight concentrators and tracking systems (Wang et al., 2023). Materials like bismuth telluride are also expensive and toxic, and maintaining cooling for the system adds to the cost and complexity (Duffie & Beckman, 1980). Figure 1 shows different solar technologies and their foundations. In high-radiation countries like Iraq, with 7 kWh/m² daily solar input, the potential is enormous (Obaid & Abdulkareem, 2024). Solar systems such as parabolic dishes or troughs with concentration ratios up to 100 can be highly effective in this region for power generation and air conditioning (Mostafa & Aboelezz, 2024; Temizel et al., 2018). Around the world, nations are under pressure to reduce fossil fuel use and address climate change (International Energy Agency, 2009).



Photovoltaic Solar Panels	Most commonly used techniques in today's market
Concentrated Photovoltaic Systems	The highest efficiency ever achieved in lab
Dye Sensitized Solar Cell	Biomimics techniques based on cheap organic materials
Solar thermoelectricity system	Based on the application of thermoelectricity materials
Concentrated Solar Power	Commonly used based on the application of mature heat engine

Fig. 1. Overview of Solar Technologies.

Since the Industrial Revolution, fossil fuels have powered growth, but now they pose a threat to sustainability and energy security (May, 1980). Energy loss in the oil industry—from fuel use to system inefficiencies—affects profits and carbon emissions (Danish et al., 2023). Tasks like heating crude oil for transport or processing require massive amounts of energy. For instance, heating 100,000 barrels of crude to 350°C needs about 120 MW—equivalent to burning one barrel of oil to process every ten (Palou-Rivera & Wang, 2010). In the U.S., energy costs make up nearly half of refinery operating expenses. The EU's energy-intensive industries (oil refining, petrochemicals, steel, cement) consume 18% of the region's primary energy (May, 1980). Globally, fossil fuels still accounted for over 81% of energy in 2008, contributing to nearly 30 billion tons of CO_2 emissions (NA et al., 2024). To combat this, many governments are investing in renewables—wind, solar, hydro, and biomass (Wang et al., 2023). Solar energy stands out for its limitless supply and low emissions. Many countries see it as key to reducing fossil fuel dependence and tackling climate change (Temizel et al., 2018; Wang et al., 2023). Oil refineries, in particular, can benefit from solar integration. In areas where natural gas is limited, solar can replace some of the fuel needed for steam and heating (NA et al., 2024). Pilot projects show solar is viable for field operations in oil and gas, helping to pave the way for broader adoption (Temizel et al., 2018). Refinery energy use depends on size, configuration, and crude type. Steam and heat usually account for over 80% of the energy consumed. In the U.S., the main energy sources are refinery gas (45%), natural gas (22%), catalytic coke (17%), and electricity (12%) (Palou-Rivera & Wang, 2010). Heavy crude often needs to be upgraded using fuel-intensive methods before refining, further increasing energy needs (Khaleel et al., 2023). Solar energy offers a practical way to reduce fossil fuel use and environmental impact in refineries, especially where natural gas is restricted (NA et al., 2024). Several upstream pilot projects have successfully integrated solar technologies, showing potential for wider adoption and renewable market growth (Temizel et al., 2018). Refinery energy demand depends on size, complexity, and crude quality, all of which influence processing requirements. Facilities handle between 50,000 and 1,000,000 barrels per day, with energy use per barrel varying accordingly. As shown in Table 1, common refining units have different energy demands based on U.S. refinery data (Palou-Rivera & Wang, 2010). A refinery processing 200,000 barrels daily typically uses about 42,700 terajoules, mostly for heat or steam—making up 80–99% of total energy use. Main energy sources include refinery gas (45%), natural gas (22%), catalytic coke (17%), and purchased electricity (12%). For extra-heavy crude, upgraders located near fields are used to produce synthetic crude. These units—often featuring distillation and delayed coking—are highly energy-intensive, usually powered by onsite coke or fuel oil (Khaleel et al., 2023).

Table 1. Energy Consumption in Selected Refinery Units.

Refinery technology	MJ/barrel
Atmospheric crude distillation	86–196
Vacuum distillation	53–119

	220
Fluid catalytic cracking	
Catalytic hydrocracking,	168–339
Delayed coking	
Catalytic reforming	120–242
	224–360
Alkylation	269–359
Catalytic hydrotreating	64–173
Hydrogen production	66–167

A parabolic trough system was studied to reduce natural gas use in crude heaters by harnessing solar thermal energy. MATLAB simulations helped size the system for year-round operation despite seasonal shifts. Results show yearly savings of 555,515 MMBtu of gas, 30,020 tons of CO_2, and $1.65 million, proving its efficiency and cost benefits (Danish et al., 2023). To meet rising energy demand and cut emissions, a Middle Eastern refinery was modeled for renewable integration. Aspen HYSYS simulated energy use, while linear programming and GAMS optimized solar and wind input. Solar CSP (411 GWh/year), PV, and wind were all viable, with payback periods of 10, 7, and 6 years respectively (Alnifro et al., 2017). A follow-up study confirmed similar findings using the same tools—low LCOE and quick paybacks—further supporting renewable use in refining (Toghyani & Saadat, 2024). Solar energy can cut fossil fuel reliance in refineries, especially where gas use is limited. With Iraq's strong solar potential and aging refineries, this study looks at Al_Qayarahand Baiji as models for reducing costs, boosting energy security, and meeting climate goals.

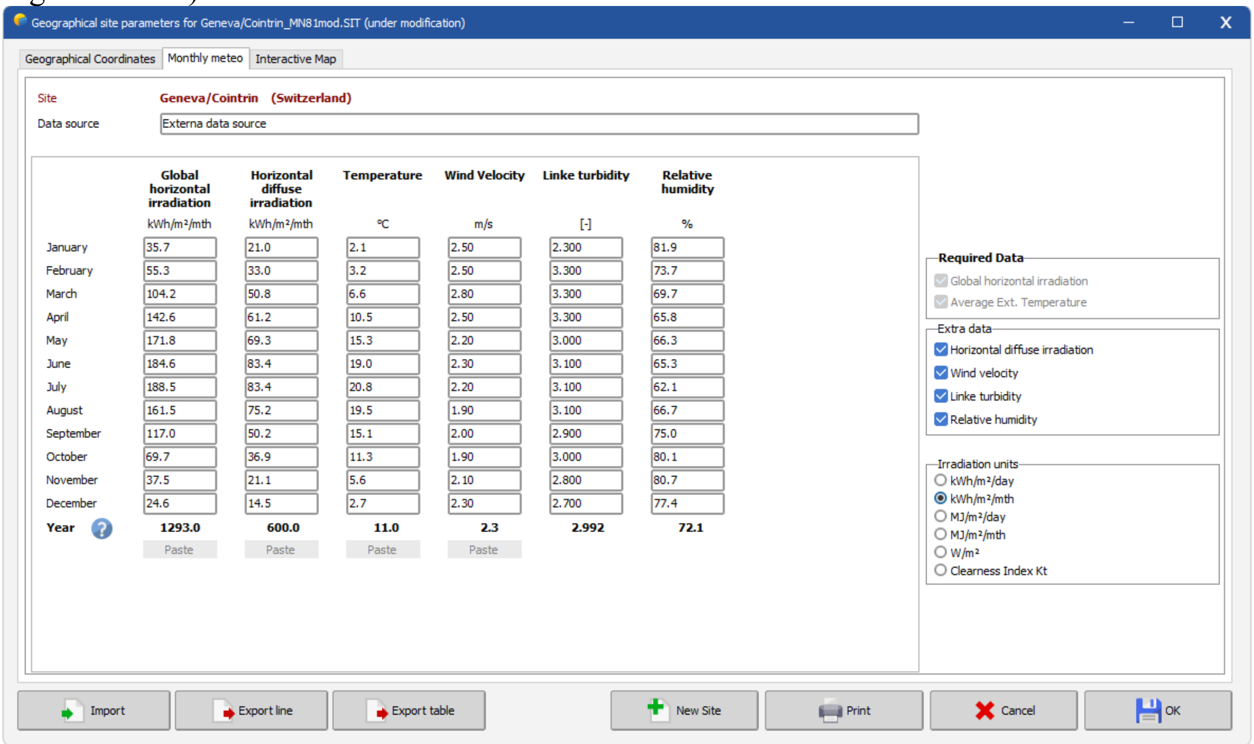
Methodology

Site Visits and Data Collection

In our effort to improve energy efficiency within petroleum refineries, this research focuses on assessing the integration of solar energy systems into refinery operations. To gain a thorough understanding of refinery processes, energy consumption, and potential for renewable energy adoption, we conducted detailed site visits to the Al_Qayarahand Baiji refineries, located in northern and central Iraq, respectively. These visits allowed us to carefully observe refinery facilities, engage with operational personnel, and document the processes and energy demands firsthand (Pouresmaieli et al., 2023). Our investigation included an in-depth review of operational workflows and energy consumption metrics to identify areas where solar energy integration could offer meaningful improvements. To ensure a comprehensive evaluation, we combined these field assessments with data synthesis from previous studies to analyze the feasibility and potential impact of solar energy implementation within these industrial settings (Danish et al., 2023).

Simulation and Modeling with PVsyst

For simulation and modeling purposes, we used PVsyst, a well-established solar energy simulation software widely trusted in the industry for bankability and performance analysis. PVsyst's accuracy in modeling irradiation, system losses, and long-term degradation builds confidence among stakeholders such as developers, engineers, researchers, and financiers. Our collaboration with Pure Power, a key stakeholder experienced in PVsyst, allowed us to leverage this expertise to generate reliable solar energy models tailored for refinery applications. PVsyst enabled us to input essential parameters—including geographical location, solar panel and inverter models, and system configurations—providing detailed insights into expected energy production and losses due to factors like shading, wiring, and inverter inefficiencies (Çinici et al., 2023; Stein et al., 2016). Using Meteonorm data integrated within PVsyst, we set the system orientation towards the south to match the northern hemisphere location and adjusted the tilt angles based on latitude calculations. This ensured optimal solar exposure year-round (see Figure 2 and 3).



	Global horizontal irradiation kWh/m²/mth	Horizontal diffuse irradiation kWh/m²/mth	Temperature °C	Wind Velocity m/s	Linke turbidity [-]	Relative humidity %
January	35.7	21.0	2.1	2.50	2.300	81.9
February	55.3	33.0	3.2	2.50	3.300	73.7
March	104.2	50.8	6.6	2.80	3.300	69.7
April	142.6	61.2	10.5	2.50	3.300	65.8
May	171.8	69.3	15.3	2.20	3.000	66.3
June	184.6	83.4	19.0	2.30	3.100	65.3
July	188.5	83.4	20.8	2.20	3.100	62.1
August	161.5	75.2	19.5	1.90	3.100	66.7
September	117.0	50.2	15.1	2.00	2.900	75.0
October	69.7	36.9	11.3	1.90	3.000	80.1
November	37.5	21.1	5.6	2.10	2.800	80.7
December	24.6	14.5	2.7	2.30	2.700	77.4
Year	**1293.0**	**600.0**	**11.0**	**2.3**	**2.992**	**72.1**
	Paste	Paste	Paste	Paste		

Fig. 2. Geographical Location in PVsyst.

The tilt angle varies according to the latitude of the location (see Figure 3 below), sometimes being two or three degrees more or less, as per the following equation:

*Ideal Angle in winter = Latitude * 0.89 + 24°*

*Ideal Angle in summer = Latitude * 0.92 – 24.3°*

*Ideal Angle year-long = Latitude * 0.98 – 2.3°*

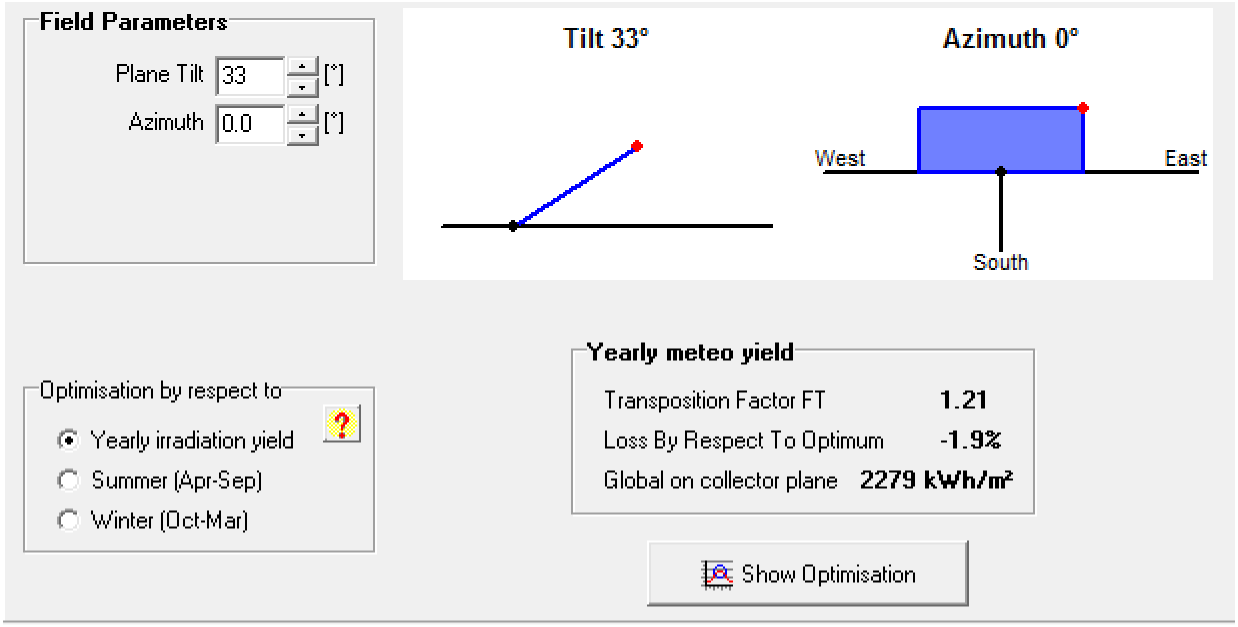


Fig. 3. Field Parameters Selection.

The software interface facilitated selection of suitable solar panels and inverters, confirming ideal system configurations before running simulations (Figures 4 and 5).

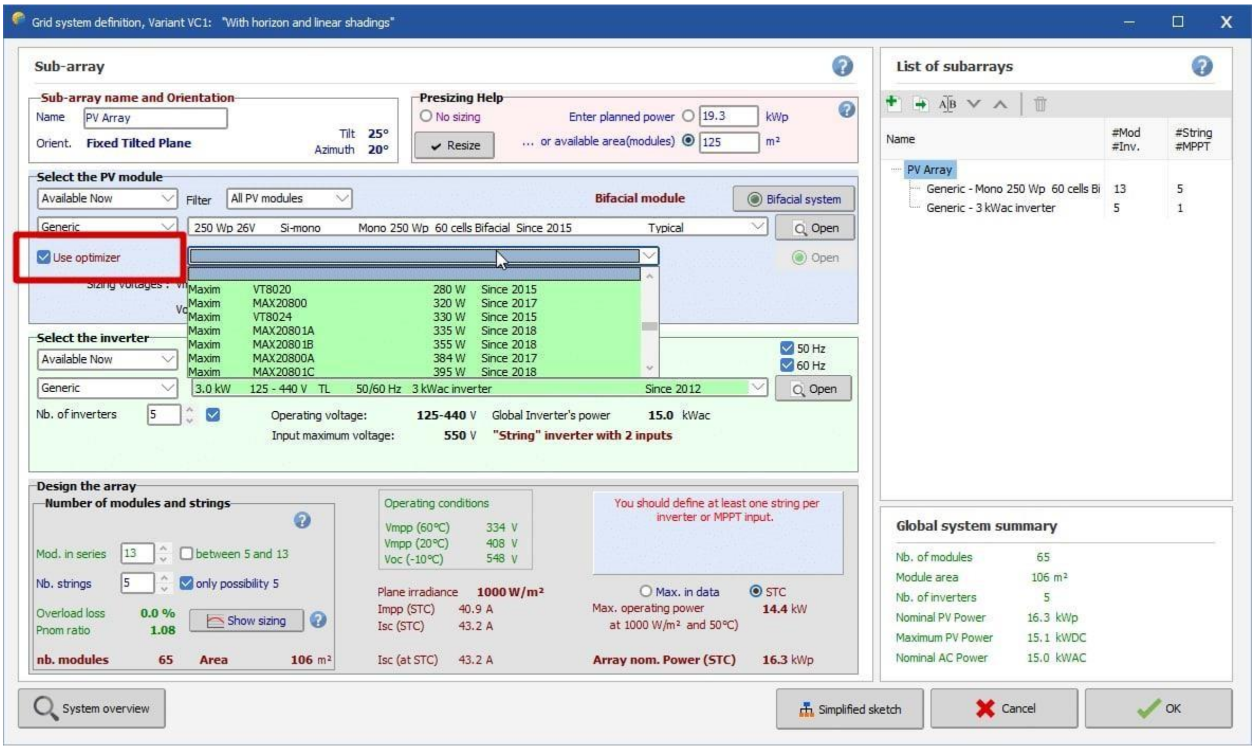


Fig. 4. Grid System Definition.

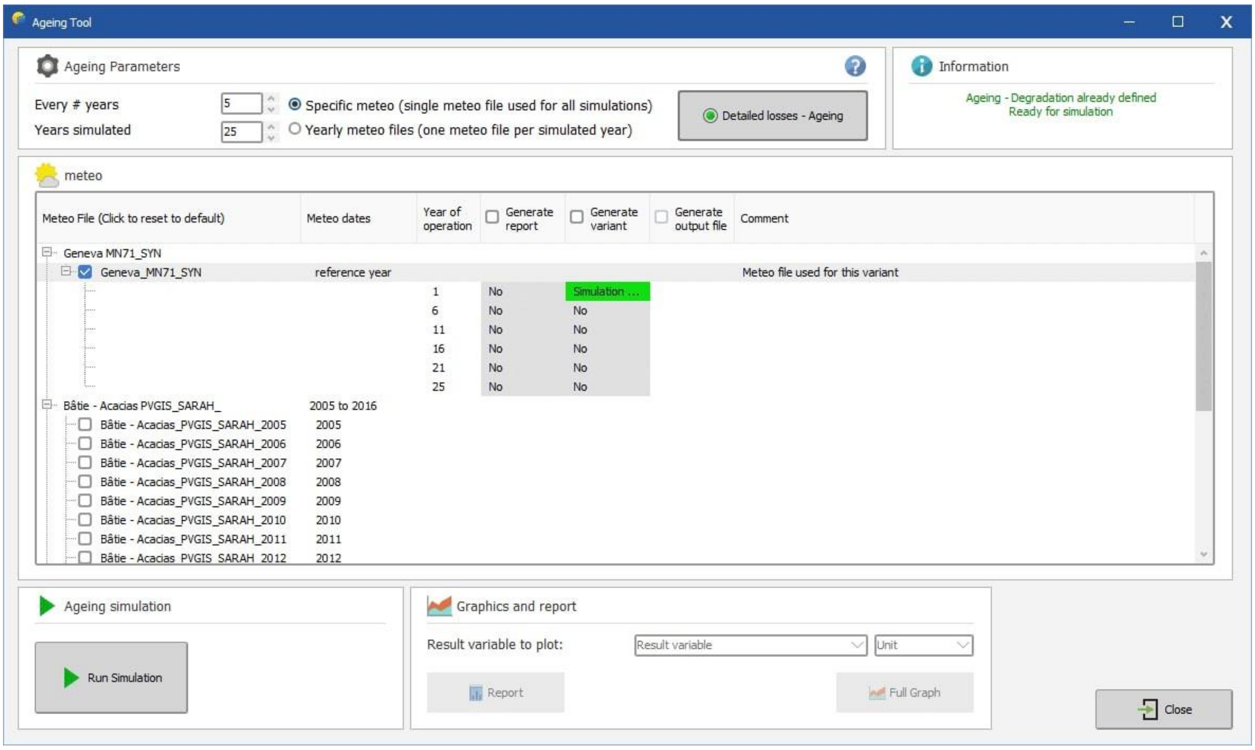


Fig. 5. Running the Simulator.

Qayarah Refinery

The Qayarah refinery was originally built in 1953 by the British LOMS company with just one production unit. Later, between 1978 and 1983, three additional units were added—one by the Italian company ENI in 1978, followed by two more between 1979 and 1983. In 2001, two new units (Units 5 and 6) were constructed to process Kirkuk crude oil, using designs similar to those from Halliburton and installed by the Iraqi Saad General Company. These newer units receive crude oil through the Iraq-Turkey strategic pipeline, while the older asphalt-producing units process crude oil directly from Al_Qayarahfields. Al_Qayarahcrude is known for its high density (0.959) and low API gravity (16–18), with a notably high sulfur content of 7.6%. It also contains hazardous gases like hydrogen sulfide (H_2S), which converts to sulfur dioxide (SO_2) when burned. Some of these gases are treated on-site using separators in the Al_Qayarahfields.

The refinery's six operational units collectively process around 34,000 barrels of crude oil per day. The four older units, producing mainly asphalt, have a combined capacity of 14,000 barrels per day. The fifth and sixth units, designed for lighter products using Kirkuk crude, have a capacity of 20,000 barrels per day, but these units were completely destroyed during recent conflicts. The Ministry of Oil, under Minister Hayyan Abdul Ghani, is actively working on restoring these units. During a site visit, we observed routine maintenance on the fourth unit and examined components such as heat exchangers, trays, and furnace parts (Table 2).

Table 2. Al_QayarahRefinery Processing Units.

Unit	Production Capacity (Barrel/day)	Activity

Unit 1	2000	On
Unit 2	4000	Off
Unit 3	4000	On
Unit 4	4000	On
Unit 5	10000	Off
Unit 6	10000	Off
Total	34000	

Energy consumption is a significant concern for any refinery. At Qayyarah, the active units and supporting facilities consume a total of 970 kW, excluding the inactive Units 2, 5, and 6. Additional energy losses account for approximately 297 kW, bringing the overall consumption to 1,267 kW (Table 3).

Table 3. Energy Consumption in Al_QayarahRefinery.

Units	Energy Consumption (KW)
Unit 1	250
Unit 3	250
Unit 4	250
Pump Station	100
Fire Pump	100
Control Room	20
Total	970

As a case study for renewable integration, a solar energy project was evaluated for the Al_Qayarahrefinery.

* The number of solar panels required for Al_Qayarahoil refinery project: No. of Panels = Total Energy Consumption / Energy Output Per Panel = 1267 / 550 = 2304 panels.

* 2304 Solar panels from Longi Solar of the Model (LR5-72 HPH 550 M) which have 550 Wp and (U mpp = 677 V, I mpp = 1710 A) assembled in 128 strings each string consists of 18 series of boards.

* These 2304 panels require 10 inverters from SMA of the Model (Sunny Highpower SHP100-20-PEAK3) each one serve nominal power of 100kWac resulting in a total inverters power of 1000kWac. The Pnom ratio (DC:AC) where (1.27). Pnom ratio = PV Power / Total Inverter power = 1267 / 1000 = 1.27.

The area needed for the project is 5889m2 as each board take 2.5 m2 (see Figure 6 below). Producing 7 kW of energy from fossil fuels is equivalent to offsetting the carbon dioxide emissions absorbed by 180 mature trees.

Fig. 6. Sky View of Al_QayarahRefinery Project Area.

Baiji Refinery

Baiji refinery, established in 1978, is Iraq's largest refining complex, contributing about one-third of the nation's refinery output. It is located roughly 130 km north of Baghdad in Salah al-Din Governorate and comprises three facilities: Salah al-Din Refinery 1, Salah al-Din Refinery 2, and the Northern Refinery. The Northern Refinery is the most technologically advanced among them. Following severe damage and operational stoppages from 2014 until 2023, the Northern Refinery was reopened in February 2024 with a production capacity of 150,000 barrels per day, complementing the capacities of the other two refineries. It includes six main units: Crude Distillation, Naphtha Hydrotreating, Platforming, Kerosene Hydrotreating, Light Gas Oil Hydrotreating, Vacuum Distillation, and Hydrocracking, all designed to produce high-quality petroleum products with octane ratings up to 90. The Crude Distillation Unit (CDU) leads with 150,000 barrels per day capacity. Other units have capacities ranging from 22,000 to 65,000 barrels per day, all crucial in refining and upgrading processes (Table 4).

Table 4. Northern Refinery Processing Unit.

Unit	Production Capacity (Barrel/day)
Crude Distillation	150,000
Naphtha HDS Unit	41,000
Platforming Unit	22,000
Kerosene HDS Unit	28,000
LGO HDS unit	31,000
Vacuum Distillation Unit	65,000
Hydrocracking Unit	38,000

Energy consumption at Baiji's Northern Refinery totals around 18 MW, with major users including the Distillation Unit (5 MW) and the Hydrogenation Unit (6 MW). The remaining energy is distributed across other processes such as condensation, pumping, and storage. A solar energy project simulation suggests that meeting this 18 MW demand would require 32,725 solar panels of 550 Wp each, occupying roughly 83,647 m². These panels would be arranged into 1,925 strings of 17 panels each, supported by 132 inverters delivering a total of 13,200 kW AC power. The DC-to-AC power ratio here is 1.36. Figure 7 depicts the layout for this solar installation.

* The number of solar panels required for the Northern oil refinery project: No. of Panels = Total Energy Consumption / Energy Output Per Panel = 17999 / 550 = 32725 panel.

* 32725 Solar panels from Longi Solar of the Model (LR5-72 HIH 550 M) which have 550 Wp and (U mpp = 640 V, I mpp = 25723 A) assembled in 1925 strings each string consists of 17 series of boards.

* These 32725 panels require 132 inverters from SMA of the Model (Sunny Highpower SHP100-JP-20-PEAK3) each one serve nominal power of 100kWac resulting in a total inverters power of 13200kWac. The Pnom ratio (DC:AC) where (1.36). Pnom ratio = PV Power / Total Inverter power = 17999 / 13200 = 1.36.

The area needed for the project is 83647m2 as each board take 2.5 m2 (see Figure 7 below).

Fig. 7. Sky View of Northern Refinery (Baiji) Project Area.

Results

In this section, we present a concise analysis of the results of the proposed photovoltaic solar system in the Al_Qayarahrefinery and the Northern refinery of Baiji. The photovoltaic solar system is of the type of system connected to the national grid.

Al_Qayarah Refinery Results

1. The Monthly Average of Solar Radiation

From Table (5), we observe the effective total radiation for 2010.1, while the average ambient temperature is 21.66 degrees Celsius. The output energy of the active matrix is 31838 MWh, the energy injected into the grid is 31311 MWh

Table 5. Monthly Values and Key Results for Al_QayarahRefinery.

Month	GlobHor (kWh/m)	DiffHor (kWh/m²)	T_Amb (°C)	GlobInc (kWh/m)	GlobEff (kWh/m)	EArray (MWh)	E_Grid (MWh)	PR (ratio)
January	80.8	34.15	6.47	127.3	125.8	152.3	149.6	0.927
February	93.1	46.44	9.19	126.1	124.5	149.5	146.7	0.918
March	136.5	61.92	14.31	163.1	160.6	186	182.6	0.884
April	169.8	81.67	19.41	179.5	176.3	200.9	197.2	0.867
May	193.7	97.61	25.61	187	183.3	204.8	201.2	0.849

June	**216.9**	**90.25**	**30.97**	**200.3**	**196.3**	**213.2**	**209.4**	**0.825**
July	**220.2**	**89.91**	**34.27**	**207.9**	**203.9**	**217.6**	**213.9**	**0.812**
August	**200.1**	**83.12**	**33.45**	**205.3**	**201.6**	**215.4**	**211.7**	**0.814**
September	**171.3**	**56.19**	**28.39**	**201.5**	**198.2**	**214.5**	**210.6**	**0.825**
October	**126.1**	**54.83**	**22.74**	**166.9**	**164.8**	**186**	**182.7**	**0.863**
November	**90.4**	**34.07**	**13.51**	**141**	**139.4**	**163.7**	**160.7**	**0.899**
December	**76.8**	**28.22**	**8.02**	**127.7**	**126.5**	**151.8**	**149**	**0.92**
Year	**1775.7**	**758.38**	**20.59**	**2033.5**	**2001**	**2255.8**	**2215.2**	**0.86**

2. Performance Ratio

The performance ratio is a key metric for assessing photovoltaic system efficiency, defined as the final system yield divided by the reference yield. In the simulation, it is 86%, indicating that 14% of radiation is lost due to temperature effects, incomplete radiation use, or system inefficiencies show Figure (8**).**

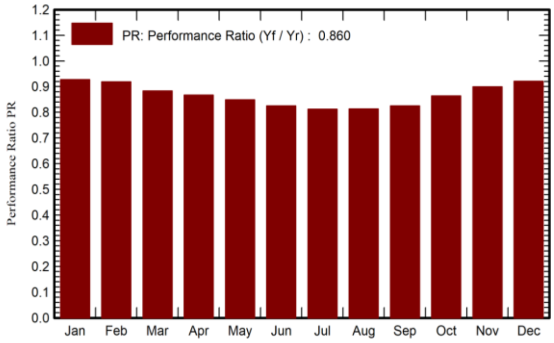


Fig. 8. Annual PR for Al_Qayarahrefinery.

3. CO_2Emission Balance

The carbon footprint can be defined as the total amount of greenhouse gases produced to support human activities, both directly and indirectly, usually expressed in equivalent tons of carbon dioxide. The carbon footprint is the sum of all carbon dioxide emissions resulting from activities within a specific timeframe, typically one year. By installing a photovoltaic solar panel, there will be a reduction in carbon dioxide emissions, which will help make the environment pollution-free. Figure (9) below depicts the simulation result of carbon emissions through the system for the next 30 years.

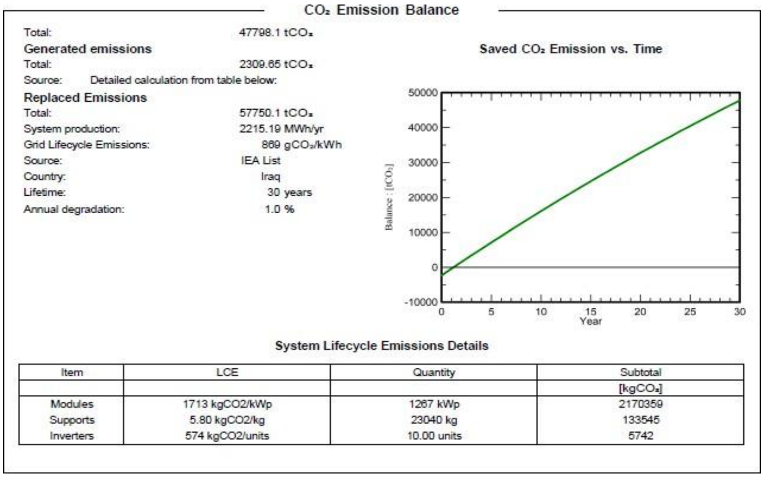


Fig. 9. Carbon emission simulation for Al_Qayarahrefinery.

Northern Refinery Results

1. The Monthly Average of Solar Radiation

From Table (6), we observe the effective total radiation for 2010.1, while the average ambient temperature is 21.66 degrees Celsius. The output energy of the active matrix is 31838 MWh, the energy injected into the grid is 31311 MWh.

2. Performance Ratio

We observe from Figure (10) that

the performance ratio is 85.2% in the simulation environment, meaning that 14.8% of the radiation is not converted into useful energy, thus this percentage represent the total losses of the system.

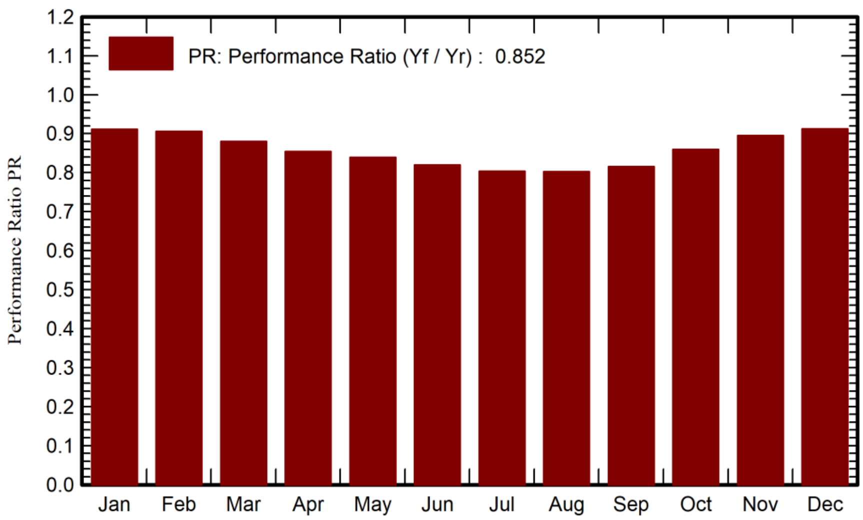


Fig. 10. Annual PR for Northern refiner.

Table 6. Shows monthly values and key results for Northern refinery.

Month	GlobHo (kWh/m²	DiffHor (kWh/m²)	T_Amb (°C)	GlobInc (kWh/m²)	GlobEff (kWh/m²)	EArray (GWh)	E_Grid (GWh)	PR (ratio)
January	86.9	32.8	8.03	135.6	133.9	2.263	2.224	0.911
February	96.6	49.2	10.78	128.1	126.4	2.125	2.089	0.906
March	140.5	71.64	15.76	165.8	163.2	2.672	2.627	0.88
April	171.5	82.7	20.59	182.4	179.3	2.854	2.806	0.855
May	196.4	96.05	26.75	190.7	187.2	2.929	2.881	0.839
June	216	92.07	31.59	201.4	197.5	3.02	2.971	0.82
July	216.1	95.91	34.78	205.4	201.5	3.022	2.973	0.804
August	200.2	85.1	34.05	205.5	201.8	3.018	2.97	0.803
September	167.6	60.89	29.23	194.3	191.1	2.899	2.851	0.815
October	125.9	56.96	23.79	163.1	160.9	2.563	2.521	0.859
November	93.4	37.86	14.38	140	138.3	2.295	2.256	0.895
December	80	28	9.45	130.4	129.1	2.18	2.141	0.912
Year	1791.3	789.19	21.66	2042.8	2010.1	31.838	31.311	0.852

3. CO_2 Emission Balance

Figure (11) below depicts the simulation result of carbon emissions through the system for the next 30 years

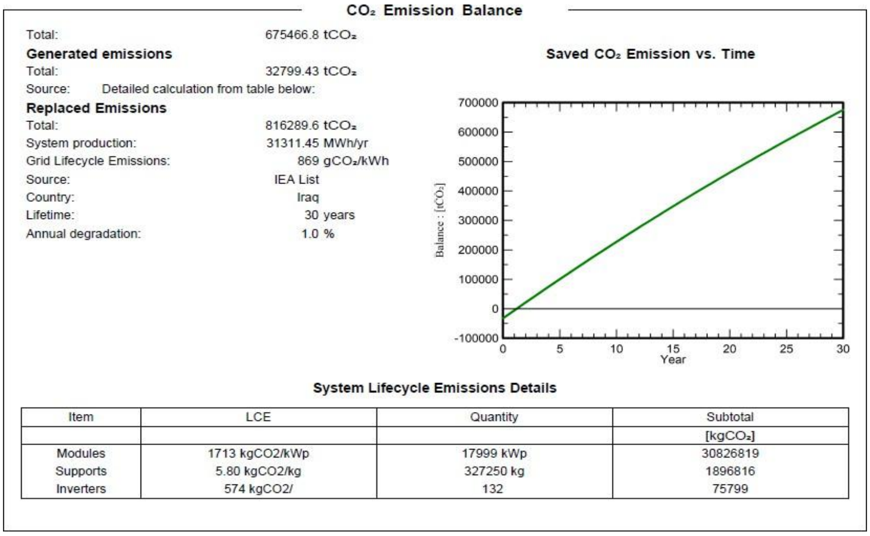


Fig. 11. Carbon emission simulation for Northern refinery.

Conclusions

The simulation of grid-connected photovoltaic solar energy systems at the Al_Qayarahrefinery and the Northern refinery in Baiji demonstrated significant potential. For the Al_Qayarahrefinery, the system showed an effective array energy production of 2255.8 MWh/year with a performance ratio of 86%. This is projected to lead to an approximate reduction of 47798.1 tons of carbon dioxide emissions annually. For the Northern refinery in Baiji, the simulated system indicated an effective array energy production of 31.838 GWh/year with a performance ratio of 85.2%, resulting in an estimated reduction of 32799.43 tons of carbon dioxide emissions. These findings confirm the technical feasibility and substantial environmental advantages of implementing such solar energy installations within the petroleum industry in Iraq. The integration of solar power can contribute significantly to reducing the carbon footprint of refinery operations and enhancing energy sustainability.

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