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Beyond Barrels and Generators: Solar Power Economics and Market Potential in Iraq

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ABSTRACT

Iraq faces a critical electricity deficit, with generation capacity of approximately 18,000 MW against demand exceeding 30,000 MW. Despite possessing the world's one of the largest oil reserves, the country experiences daily power outages lasting 8-18 hours. This comprehensive review examines the techno-economic viability of solar photovoltaic (PV) systems as a sustainable solution to Iraq's energy crisis. The Levelized Cost of Energy (LCOE)-defined as the per-unit cost of electricity over a system's lifetime, calculated by dividing total lifetime costs (capital, O&M, financing) by total electricity generated-for solar projects in Iraq ranges from utility scale PV LCOE $0.03-0.05/kWh, significantly lower than fossil fuel alternatives at $0.08-0.12/kWh. This review synthesizes findings from previous studies and presents economic calculation models including Net Present Value (NPV), Internal Rate of Return (IRR), and payback period analyses. Regional analysis reveals solar irradiance varies from 1,522 kWh/m²/year in northern provinces to 2,120 kWh/m²/year in southern regions. Hybrid PV-battery storage systems demonstrate payback periods of 3.6-7 years under various conditions. The study identifies policy frameworks, financing mechanisms, and institutional barriers affecting solar adoption, providing a roadmap for Iraq's transition toward its 12 GW solar capacity target by 2030.

Introduction

Iraq's electricity sector faces unprecedented challenges characterized by chronic supply shortages, aging infrastructure, and heavy dependence on fossil fuels. According to Al-Rikabi (2025), thermal power plants account for 96.6% of total electricity production, while hydropower contributes 3.39% and solar a mere 0.059% [1,2]. The cumulative impacts of decades of conflict have devastated energy infrastructure, leading to daily power outages that significantly affect economic productivity and quality of life [3].

The reliance on neighborhood diesel generators (NDGs) as a stopgap solution has created significant economic and environmental burdens. The research by Tahir et al. (The research conducted by (2025) employed a Delphi survey which involved 20 energy experts to establish that 85% of participants backed an immediate substitution of diesel generators with solar photovoltaic systems [4]. Iraq's dependence on Iranian gas imports-approximately 50 million cubic meters per day-and electricity supplies further compounds energy security concerns . As noted by the Baker Institute (2025), Iraq pays Iran $8 per million BTU for gas while domestic production would cost less than $2 BTU [5].

Paradoxically, Iraq possesses exceptional solar energy resources that remain largely untapped. Hassan et al. (2022) reported that Iraq receives average daily solar irradiation of approximately 5.6 kWh/m², with annual sunshine duration ranging from 2,800 to 3,000 hours [6]. This positions Iraq among countries with the highest solar potential globally, comparable to leading solar markets in the Middle East and North Africa (MENA) region.

1. Literature Review

1.1 Iraq's Electricity Crisis

The Middle East region experiences one of its most severe and longest-running infrastructure breakdowns through Iraq's electricity sector. The nation holds the fifth-largest proven crude oil reserves worldwide yet faces ongoing power shortages that started after the 1991 Gulf War. The power sector infrastructure has suffered from multiple conflicts and economic sanctions and poor management which has caused major deterioration of power plants and transmission systems [7,8]. The 1990–1991 Gulf War shelling destroyed 75% of Iraq's power generation capacity which stood at 9,300 MW leaving only 2,300 MW operational[4].

The Middle East reports Iraq as its leader for electrical transmission and distribution loss rates because the country loses more than 40% of its electricity output before billing occurs due to inefficient systems [4]. The current billing system fails to collect more than half of the issued invoices which results in financial revenue from electricity sales being limited to less than 30% of total power generation [4]. The electricity shortage leads to daily power cuts which impact all Iraqi homes while summer peak demand causes 12-18 hour power interruptions that occur when temperatures reach above 45°C [7,9].

1.2 The Parallel Generator Economy

The ongoing grid failures in Iraq have led to the creation of an independent parallel energy system which relies on private diesel generators for power generation. The estimated 55,000 to 150,000 medium-sized neighborhood diesel generators (NDG) with 100 to 500 kVA ratings provide electricity to more than 90-95% of Iraqi households which meet 20-30% of their power requirements [4,7]. The generators operate through separate distribution systems to provide electricity to residential areas for lighting and fan operation and small appliance use when the public power grid is down. The generator supplies power to customers through a single radial live conductor which requires customers to pay for electricity through a monthly fee based on their ampere usage [7].

The monthly cost for neighborhood diesel generator services amounts to $8.40 per ampere when operated for 8 hours daily which results in $100 monthly costs for continuous 6-ampere power supply throughout the day . The cost of NDG services for 15 amperes of power exceeds $300 per month because this amount of power is required to run air conditioning during temperatures above 45°C [4]. The dual-supply system operates with specific pricing rules which determine how solar energy affects Iraq's economic situation. The actual cost of dependable electricity in generator-based areas amounts to $0.10–0.20/kWh because of subsidized grid power and generator backup requirements [10].

1.3 Iraq's Solar Resource Potential

The country of Iraq holds the distinction of having among the world's most abundant solar resources. The Global Horizontal Irradiance (GHI) in Iraq measures 4.6 kWh/m²/day in northern cities like Mosul and reaches 5.19 kWh/m²/day in western locations such as Rutba while Baghdad experiences 5.02

kWh/m²/day[6]. The solar radiation intensity reaches its highest point at 833 W/m² during June while it reaches its lowest at 416 W/m² during January and Iraq demonstrates better sunshine conditions than Spain [11]. The annual photovoltaic power output in northern regions (Erbil) reaches 1,514 kWh/kilowatt-peak (kWp) but optimal western locations (Al-Rutba) achieve 1,745 kWh/kWp [12].

The levelized cost of energy from photovoltaic systems in Iraq residential PV LCOE ranges between $0.079–0.093/kWh based on location according to [12]while hybrid PV plus BESS LCOE other studies show optimized systems can achieve costs between $0.025–0.063/kWh [13][14]. The environmental advantages of photovoltaic systems in Iraq are substantial because a 1 MWp installation would prevent 2.17–2.55 tons of CO_2 emissions per kWp each year [12]. The country benefits from excellent renewable energy conditions yet it has not developed its renewable energy capacity because the electricity sector continues to rely on fossil fuels [11].

1.4 Research Gap and Objectives

Research studies have investigated solar system performance in particular Iraqi locations and specific applications, but no study has evaluated the complete economic feasibility and market readiness of different energy systems throughout Iraq. The dual-tariff market system of Iraq requires a complete analysis of multiple studies because its official grid prices do not show the actual cost of reliable electricity. The research conducts four main objectives to achieve its goals. The research combines data about solar power system financial performance in Iraqi deployment sites and theoretical deployment locations. The research evaluates solar power economic performance by comparing it to conventional power sources which include diesel and gasoline generators. The research evaluates technical performance of solar systems through Iraqi climate data by measuring their capacity factors and yields and operational efficiency. The research determines which market areas show the highest potential for solar energy implementation.

Figure (1) presents the typical residential solar PV architecture in Iraq, where a PV array supplies a hybrid inverter that interfaces with the utility grid and supports household loads, with optional battery storage for backup and load shifting. In practice, these components are offered by many suppliers in the Iraqi market, but the dominant share of commonly available inverters, batteries, and balance of system equipment is provided by Indian and Chinese manufacturers through local distributors.

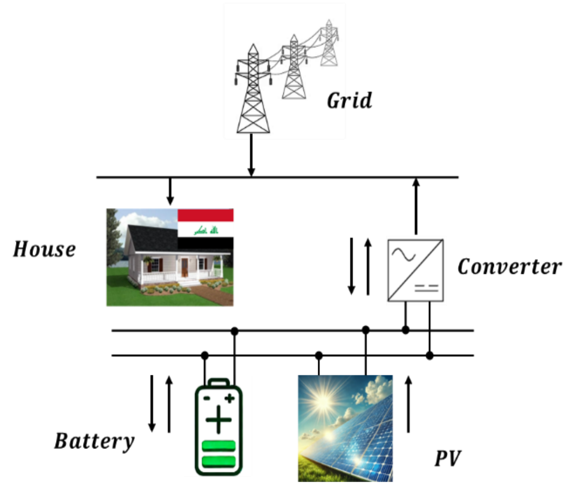

Figure (1): Typical residential PV system architecture in Iraq

2. Methods

2.1 Search Strategy and Selection Criteria

The research included studies that met the following criteria: (1) The studies needed to appear in peer-reviewed journals or conference proceedings. (2) The studies needed to investigate solar power systems which either operated in Iraq or researchers used for Iraqi deployment analysis. (3) The studies needed to present economic data including levelized cost of energy and net present cost/value and payback period and technical performance data including energy output and capacity factor and efficiency. The research needed to present original findings based on primary data or simulation results. The research team excluded all non-peer-reviewed sources together with news articles and reports.

2.2 Data Extraction and Synthesis

The data extraction process retrieved information about study locations and system types and capacity levels and economic data including LCOE and net present cost and payback period and technical performance data such as capacity factor and yield and efficiency and environmental data about CO_2 emissions reduction. The analysis of different system types and scales and metrics required a narrative synthesis with additional tabular presentation of essential data points.

2.3 Economic Calculation Models

2.3.1 Net Present Value (NPV)

Net Present Value quantifies the profitability of an investment by calculating the difference between the present value of cash inflows and outflows over the project lifetime [15]:

$$NPV = \Sigma[C_t / (1+r)^t] - C_0$$

Where C_t = net cash flow at time t, r = discount rate, and C_0 = initial investment. Aziz et al. (2020) reported NPC (Net Present Cost) of $29,713 for an optimized PV/battery system in Baghdad [9]. Mohammed et al. (2022) found NPC of $33,747 for a grid-connected PV/battery hybrid using modified dispatch strategy [16].

2.3.2 Internal Rate of Return (IRR) and Payback Period

Studies of Iraqi solar installations in table 1 demonstrate varying economic returns. Ali and Alomar (2023) reported payback periods of 7 years when considering government electricity rates, reducing to 4 years when including savings from avoiding diesel generator costs[14]. The IRR for grid-connected systems was found to be approximately 13%, with ROI around 9% [16]. Tahir et al. (2025) demonstrated that grid-connected hybrid microgrid systems achieve payback periods as low as 3.6 years under optimal conditions [4].

Table 1: Economic Parameters from Iraqi Solar PV Studies

Parameter	**Value**	**Location**	**Source**
LCOE (Grid-connected PV)	$0.063/kWh	Zakho	[14]
LCOE (Hybrid PV/WT/BESS/DG)	$0.052/kWh	Baghdad	[17]
LCOE (Hybrid microgrid)	$0.098/kWh	Basra	[18]
NPC (PV/Battery)	$29,713	Baghdad	[9]
NPC (Modified dispatch)	$33,747	Iraq	[16]
NPC (Hybrid system)	$40,681	Baghdad	[17]
Payback (Grid-connected)	7 years	Zakho	[14]
Payback (with DG savings)	4 years	Zakho	[14]
Payback (Hybrid HMGS)	3.6 years	Iraq	[4]
Payback (Residential PV)	4.5 years	Duhok	[19]

3. Results

3.1 Characteristics of Included Studies

The research analyzed peer-reviewed articles about solar power systems in Iraq which scientific journals published between 2019 and 2025. The research investigated different power system configurations which spanned from large-scale grid-based facilities (20 MW) to small-scale residential systems (2–5 kW) and solar-based water heating systems. The research spanned across different Iraqi locations including Baghdad and Diyala and Al-Anbar and Zakho (Kurdistan Region) and Kirkuk and Duhok and Basra and Nasiriyah. The research investigated three different power system configurations which included standard PV grid connection and hybrid microgrid systems with batteries and solar water heating systems.

3.2 Provincial Solar Resource Analysis

Table 2 presents a comprehensive provincial analysis of solar resources across Iraq's governorates, compiled from multiple studies including Hassan et al. [6] and data from the Global Solar Atlas.

Table 2: Provincial Solar Resource Assessment in Iraq

Province/Region	**GHI (kWh/m²/year)**	**Daily Avg (kWh/m²/day)**	**Yield (kWh/kWp)**	**Source**
Basra (South)	2,120	5.81	1,850	[1,6]
Al-Muthanna	2,050	5.62	1,790	[1]
Rutba (Al-Anbar)	1,980	5.19	1,730	[6]
Baghdad	1,825	5.02	1,595	[6,20]
Diyala	1,780	4.88	1,555	[10]
Zakho (Kurdistan)	1,680	4.60	1,554	[13,14]
Mosul (Nineveh)	1,522	4.65	1,330	[6]

3.3 Economic Performance

The economic assessments conducted in different studies demonstrated that solar systems provide better cost performance than traditional power generation systems. The levelized cost of energy from solar installations spanned from $0.025/kWh for optimized utility-scale systems to \$0.093/kWh for residential installations while most PV systems operated at \$0.052–0.063/kWh [12,14,17].

The research by Hassan et al. [4]involved 20 experts in a Delphi survey who reached 85% agreement about switching from diesel generators to solar PV systems and achieved 90% or higher consensus on all questions about NDG inadequacy and SPV replacement suitability. The techno-economic study by Hassan et al. [4] demonstrated that a grid-connected hybrid microgrid system (HMGS) using SPV and battery storage represents the most cost-effective solution because it provides the shortest payback period of 3.6 years in the optimal scenario[4].

The study by Ali and Alomar [14] showed that a 3.15 MW system at University of Zakho would need 7 years to pay back when using government grid electricity but the period decreased to 4 years when local generators were operational. The solar system produced electricity at a cost of 6.3¢ per kilowatt hour. The 5 kWp hybrid system studied by Falih et al. [10] produced different payback periods from 5 to 15.5 years based on tariff systems while minimum tariffs of \$0.10/kWh and optimal returns of \$0.12/kWh led to a 10-year payback period.

Mohammad and Ismael [21] conducted a study which demonstrated that a 3 kW PV system would cost 12.27% less than combined neighborhood and household generators throughout five years because of Iraq's deteriorating electricity sector. Daabo et al. [19] studied Duhok City to show that PV solar systems would pay back their initial expenses within 4.5 years compared to local diesel generators while delivering clean and noiseless energy after that period.

The study by Qasim et al. [17] showed that hybrid PV/wind/battery/diesel systems produced the lowest LCOE of \$0.0521/kWh and net present cost of \$40,681 for remote communities while achieving 99.3% renewable energy usage. The system produced 90.113 MWh of energy during one year with PV arrays generating 71.7% of the total output and diesel generators producing 0.475% of the total output.

3.4 Technical Performance

The research studies showed performance data which confirmed that Iraq benefits from outstanding solar resources through its capacity factors and energy production levels. The 3.15 MW University of Zakho grid-connected system operated at 17.7% capacity factor while generating 1,554 kWh/kW annually for a total of 5,205 MWh [14]. The study by Hassan et al. [6] assessed 20 MW power systems in four Iraqi cities which produced between 29,000–34,000 MWh of energy per year based on tracking system designs and site locations.

The 5 kWp hybrid system located in Diyala province generated 8.9 MWh of electricity throughout the year while achieving 12.6% array efficiency and 0.66 performance ratio [5]. The system produced 6.1 MWh of reference energy but only 3.88 MWh of array energy which resulted in 3.99 MWh of final energy output. Suwaed et al. [22] studied solar heating systems with evacuated tube collectors which achieved an 86% solar fraction to fulfill 1,430 kWh of energy requirements in Kirkuk.

The study by Hassan et al. [12] evaluated 21 Iraqi locations to determine yield energy values between 1,514 kWh/kWp in Erbil and 1,745 kWh/kWp in Al-Rutba. The research shows that western Iraq's Al-Rutba city produces the best results but Erbil city in northern Iraq generates the lowest results because of different geographical conditions and weather patterns.

3.5 Hybrid PV-Storage System Techno-Economic Analysis

3.5.1 System Configurations and Optimization

Given Iraq’s unreliable grid infrastructure, hybrid systems combining PV with battery energy storage systems (BESS) offer superior reliability. Multiple studies have employed HOMER Pro software for optimization. Aziz et al. (2020) analyzed PV microgrids for Baghdad households, finding that allowing grid-battery charging achieved the lowest NPC while preventing grid charging maximized renewable fraction at 64.9% [9].

A 2025 study on hybrid power systems for remote Iraqi communities using HOMER Pro found the PV/WT/BESS/DG configuration optimal, generating 90.113 MWh annually with: PV contributing 71.7% (64.652 MWh/year), wind turbines 27.8% (25.033 MWh/year), and diesel generators only 0.475% [17]. This achieved LCOE of \$0.0521/kWh, NPC of \$40,681, and 99.3% renewable fraction.

3.5.2 Battery Storage Economics and Sensitivity Analysis

Abbas et al. (2025) conducted techno-economic assessment of hybrid systems for a date molasses factory using HOMER Pro, finding optimal configuration with 980 kW PV, 500 kW biogas generators, 180 kW fuel cells, and 272 batteries achieved LCOE of \$0.0978/kWh [18]. Haqi et al. (2023) optimized microgrid sizing for Basra using meta-heuristic algorithms, achieving LCOE of $0.1192/kWh [23].

IRENA (2024) reports that battery storage costs have declined by 93% since 2010, reaching $192/kWh for utility-scale systems [24]. Sensitivity analyses show that 25% reduction in BESS costs could yield payback periods under 5 years across multiple Iraqi scenarios [25].

3.6 Comparison with Existing Energy Sources

The evaluation of solar systems revealed they outperformed traditional power systems through their superior cost-effectiveness and operational excellence and environmental sustainability. Aziz et al.[9] conducted a study on hybrid PV microgrid systems for Baghdad which proved that standalone PV grid systems failed to meet load requirements because of daily power outages so hybrid systems with storage became necessary. The hybrid microgrid system operated at 64.9% renewable energy usage while producing the lowest CO_2 emissions of 4,533 kg/year when it prevented grid power usage. The addition of diesel backup systems decreased net present costs by 11.6% but resulted in a 32.7% increase of emissions which demonstrates how financial benefits affect environmental sustainability.

The research by Hassan et al. [13] demonstrated that PV systems operated at 10 times lower expenses than Zakho city fossil fuel power plants while requiring 7 years to return initial costs and 2 years to recover embedded energy. The implementation of PV plants results in annual CO_2 emission reductions ranging from 600 to 2000 tonnes. The research studies demonstrated that PV installations produce annual CO_2 emission reductions between 2.17–2.55 tCO_2/kWp [12] and solar heating systems prevent between 689–1316 kg/year of CO_2 emissions [22].

4. Discussion

4.1 Resolving the Economic Paradox

Research indicates that solar power systems provide 3.6-4/year return on investment when they replace diesel generators, but studies also show that grid tariffs must reach $0.10/kWh to make solar power competitive with subsidized grid electricity[4,10]. The seemingly contradictory results stem from different market conditions. The full cost of reliability through generator usage leads to fast solar payback when households must bear the entire expense at rates between $0.10-0.20/kWh. The economic viability of solar power depends on additional policies when grid electricity receives price subsidies.

The market structure becomes evident through this system. The most profitable market segment includes households and businesses that face regular power outages and heavy reliance on generators since these customers make up most of Iraq's population and can expect solar energy payback within 3.6 to 7 years [4,14]. The study by Hassan et al. [4] established that solar energy needs prices between $0.106 and $0.078 per kWh to compete with subsidized grid electricity while exceeding current Iraqi market rates.

4.2 Technical Feasibility Across Applications

The technical performance data shows that the system works well at both 3 kW residential and 20 MW utility-scale power levels. The system operates at 18% capacity while producing 1,514–1,745 kWh/kWp of electricity from its 0.66 performance ratio which matches the solar resource conditions in Iraq [10,12,14]. The need for hybrid systems with storage units becomes essential because grid reliability issues affect critical power consumption. The study by Aziz et al. [9] demonstrated that grid-connected systems without battery storage cannot solve blackouts which extend from 12 to 18 hours per day thus restricting their market potential.

The research by Qasim et al. [17] showed that hybrid systems containing PV panels and WT generators and BESS storage and DG units reached 99.3% renewable energy usage while preserving grid stability. The system operated at 426 kg/year CO_2 emissions which proved superior to PV/BESS/DG systems that produced 33,384 kg/year of emissions through suboptimal system design.

4.3 Strategic Market Positioning

The evidence supports a tiered market development strategy:

First tier: Households and businesses with high generator dependence achieve 3.6–7 year paybacks by replacing expensive NDG electricity. This segment requires no subsidies and represents the most immediate market opportunity. Hassan et al. [4] achieved strong expert consensus (85–90%) on the necessity and suitability of this transition.

Second tier: Areas with moderate grid reliability can benefit from hybrid systems that reduce but do not eliminate generator costs. Economic returns are slower (10–15 years) but acceptable with declining solar equipment costs [10].

Third tier: Locations with reliable subsidized grid supply require policy support through feed-in tariffs above $0.10/kWh for reasonable paybacks [4,10].

4.4 Environmental Benefits

The environmental advantages of solar installations in Iraq become quantifiable through their ability to decrease CO_2 emissions. The research by Hassan et al. [12] demonstrated that utility-scale PV installations produce annual CO_2 emission reductions between 2.17–2.55 tCO_2/kWp(kilowatt-peak). The research by Hassan et al. [13] demonstrated that PV plant deployment results in annual CO_2 emission reductions ranging from 600 to 2,000 tons for each 1 MW installation. The research by Suwaed et al. [22] showed that residential solar heating systems prevent between 689 and 1316 kilograms of CO_2 from entering the atmosphere each year. The research by Qasim et al. [17] showed that hybrid systems operating at their best point decreased CO_2 emissions to 426 kg/year which was substantially lower than diesel-based systems.

Conclusion

The research shows that solar photovoltaic systems offer functional deployment options and economic benefits which help solve Iraq's current power shortage. The country of Iraq receives abundant solar energy because its provinces receive between 1,522 to 2,120 kWh/m²/year of annual irradiation which enables both high energy production and stable power generation.

The economic analysis of the studied research shows that PV systems generate electricity at prices which match market rates because the reported LCOE values range from \$0.03 to \$0.063/kWh when using optimal conditions and suitable system sizes. The reported PV ranges in different configurations and financing options and site conditions reach up to \$0.093/kWh. The financial results of PV projects demonstrate outstanding performance because their IRR values reach above 13% while their payback periods span between 3.6 and 7 years. The economic success of these projects depends on three essential elements which consist of local tariff rates and power outage durations and the selection of backup power sources from alternative energy systems.

The research studies we evaluated show Hybrid PV battery systems achieve their best performance in reliability-limited areas because they provide outstanding results through their \$0.052/kWh low LCOE and their ability to reach more than 99% renewable energy usage in optimized system configurations. The research demonstrates that hybrid systems with appropriate design solutions Iraq's electricity reliability issues through budget-friendly power delivery which minimizes environmental pollution when scientists apply identical economic parameters and initial conditions.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Zaid Ali: Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation.

Hamed Athari Writing – review & editing, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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