

RESEARCH ARTICLE



A Case Study on Sustainable Transition as Strategic Policies for Solar Energy

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Abstract: Production of electricity by burning fossil fuels like natural gas to generate electricity releases carbon dioxide (CO₂) into the atmosphere. The combustion process produces CO₂, which is trapped to lead to global warming and climate change. Different fossil fuels release different amounts of CO₂ based on carbon content and the amount of energy released. This paper gives techno-economic analysis of photovoltaic (PV) solar systems as a mitigation option at the grand scale, as well as data-intensive analysis of CO₂ emissions in Bahrain's fossil fuel-dominated power sector. One observation of major importance is that there is a net abatement of 1.2 ± 0.15 metric tons CO₂/MWh and leveled cost savings of 27% if PV deployment is combined with innovative storage for replacing 38–42% of conventional generation. Technical feasibility of PV is supported by cross-validation of the records of past emissions using quadratic multinomial regression, which yields strong predictive correlations ($p < 0.05$, $R^2 = 0.89$). The evidence indicates that policymakers enhance the application of PV in Gulf Cooperation Council member states while advancing socioeconomic goals in national visions (e.g., Bahrain's Vision 2030) and climate goals in the Paris Agreement. Two strategic scenarios were proposed and evaluated in this study: the first is based on Bahrain Vision 2030, and the second is based on Bahrain Vision 2050. Scenario-based projections extract a feasible roadmap for decarbonization that aims at 2060 as the year to produce carbon-neutral electricity and 45% of renewable energy integration by 2030. Finally, the second scenario will help Bahrain by the year 2060 to reach net-zero emissions.

Keywords: carbon dioxide, electrical energy, photovoltaic, solar balls, solar power, sustainable power.

1. Introduction

The energy and industrial sectors are the primary causes of environmental deterioration, and the increasing rate of atmospheric carbon dioxide (CO₂) emissions is making global climate change worse. According to the most recent data, anthropogenic CO₂ emissions increased by 0.9% in 2022, reaching 321 million metric tons. However, this trend was reversed by the growing use of renewable energy technologies, primarily utility-scale solar photovoltaic (PV) and wind power, which reduced emissions by an estimated 465 million metric tons. An additional 85 million metric tons of CO₂ emissions were reduced by complementary mitigation, which included the use of electrified transportation and efficient heating solutions.

This study highlights the need to deeply analyze CO₂ emission pathways in order to create effective decarbonization policies. Looking at the whole system helps integrate and evaluate electricity generation and provide low-carbon energy options that help guide the energy system transitions toward international climate obligations and sustainable development policies.

In order to formulate a good strategy, we must have a thorough analysis of trends in CO₂ emissions. This includes building an accurate database of CO₂ emissions by sector, source, and geography.

It also includes building mechanisms for tracking and measuring carbon performance over time, which will fill the gaps and accelerate response. By that time, decarbonization of the power sector will be inevitable. This can help by transitioning to support and moving toward clean energy. In addition, achieve this by enacting policies that activate investment in clean power, particularly solar PV and wind. Also, move the industrial economy toward efficiency and clean energy. This is, however, achieved by putting in place strict industrial emission standards, particularly in priority sectors such as cement, steel, and petrochemicals. A policy should also encourage green hydrogen and carbon capture and storage and fund scientific research on industrial low-carbon technologies and their commercialization. It should also enable electric transport and clean infrastructure by improving public transport based on clean and efficient sources such as electric vehicles (EVs). Right policies and supporting policies consist of pricing carbon via carbon taxes or emission trading schemes, externalizing environmental costs as part of the cost-benefit analysis of large projects, and mobilizing climate finance in order to facilitate sustainable infrastructure development in developing nations. A supporting policy is promoting research and innovation partnerships that allow the guidance of investment into energy efficiency, energy storage, and zero-waste technology R&D. Finally, also important is the need to develop international partnerships to share technology and know-how between countries with different resources and institute awareness and training programs to ready workers in transition-affected industries.

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2. Literature Review

The problems to understand the quantitative link between energy production and carbon emissions emphasize the role of renewable energy in minimizing the carbon footprint. Two strategic scenarios are examined, with the second scenario recommended as the optimal pathway to achieve zero CO₂ emissions. A number of studies have been conducted in the literature review presented.

Jaiyeoba et al. [1] in their article summarize the integration of thermoelectric generators in solar energy systems to enhance performance and efficiency. It is common knowledge that thermoelectric generators produce electricity directly from heat using the Seebeck effect, a thermoelectric phenomenon, and when combined with PV systems, they assist in the utilization of waste heat, thus maximizing energy output. The research summarizes recent research and classifies applications into three major categories. The first is the hybrid PV-thermoelectric generator systems, which use thermoelectric generators and PV panels to convert solar heat into extra electricity, boosting energy conversion efficiency. The second is the solar water heating systems using thermoelectric generators to recover waste heat from solar collectors and provide both water heating and ancillary electricity generation. The third is the solar thermal desalination and water purification units that utilize thermoelectric generators to convert waste heat to generate electricity used to power desalination, enhancing efficiency and sustainability in remote areas. Therefore, out of the three categories, the use of thermoelectric generators always improves solar system function, energy efficiency, and sustainability.

This academic work has greatly improved our understanding of integrated solar technologies and how the energy system performs during conversions. A significant meta-study by Hasan et al. [2] examines hybrid solar structures. It highlights three main technological areas: (i) PV arrays in crystalline and thin-film structures, (ii) concentrated solar thermal systems, and (iii) multi-scale energy storage methods.

Parallel research by Shaikh et al. [3] develops a first-principles physics of solar conversion analysis and suggests a new tripartite categorization system for radiative-to-electrical conversion, spectral utilization pathways (thermophotovoltaic hybrid systems), and sector-coupling applications (power-to-X integration matrices). The research provides unparalleled spatial mapping of global solar potential, which places 47 exajoules/year of technically harvestable energy in built environments alone.

Obatola [4] in the study reviews the reliability and performance of grid-connected PV systems, emphasizing the importance of component dependability for stable energy production. The study includes a number of key points. These points are PV systems, which are widely used due to consistent solar irradiation, but their output is variable and affected by temperature and sunlight levels. Additionally, simulation tools like MATLAB/Simulink are used and considered as a second point for system design and reliability testing before deployment. The next point is studying and analyzing failure rates and reliability of critical components – PV modules, inverters, switchgears, transformers, and capacitors – using Weibull analysis and failure modes and effects analysis. Then, the overall system reliability is found to be approximately 80%, based on modeling and collected data. The key reliability factors are the next point, which includes environmental conditions, component quality and design, and maintenance strategies. The last point is that the study emphasizes the importance of identifying failure modes, implementing predictive maintenance to detect issues early, and optimizing maintenance schedules to reduce costs. Finally, the study highlights that

ensuring the reliability of each system component through proper design, monitoring, and maintenance is crucial for the efficient and stable operation of grid-connected solar PV systems.

Chitransh and Kalyan [5] present an important study on geography gaps. They find that solar adoption rates in low-income energy countries fall behind those in industrialized economies by 8–12 years, even though these countries receive insolation values that are 40% higher. They use a two-method approach, combining thermodynamic modeling of hybrid PV-thermal collectors with geospatial analysis of decentralized deployment examples.

Mamodiya and Tiwari [6] in their study review solar energy, a clean and efficient form of energy generated from sunlight. Though mistakenly called nonrenewable, it is actually a renewable and eco-friendly resource. It notes that enough solar energy reaches the equator each hour to meet India's annual energy needs. With rising electricity demand due to population growth and technology use, solar energy is applied in industrial, commercial, and residential sectors. The paper covers how solar energy works, types of solar panels, PV panel modeling, and solar concrete collectors. It also discusses the advantages, limitations, applications, and future prospects of solar energy.

According to the study by Serat et al. [7], the majority of these companies highly rely on a reliable and stable power source in order to continue operating. Nevertheless, the energy system within Ghazni is lackluster as far as energy security is concerned, with the conventional source of energy being costly. As a consequence, the majority of such institutions have resorted to the use of diesel generators as a source of their energy requirements. It was an economic and design analysis of an on-grid solar rooftop PV system based on PVsyst software. According to the data obtained through this study, it could be seen that the provided designed on-grid solar rooftop PV system possesses some solar PV capacity of 10 kilowatts along with an attainable estimated annual energy yield of 19323 kilowatt-hours. The financial analysis indicates that the initial capital required to install the solar system is US\$ 5213, with a payback period of 6.3 years and an estimated return on investment of 457 %. For this study, we conducted a detailed design and economic analysis of an on-grid solar rooftop PV system with the PVsyst software. This was for determining the viability and financial viability of having such a system installed. Design comprised assessing the potential of the rooftop solar, determining the optimal tilt and direction of panels, and component sizing of the system. With the help of the PVsyst software, we could simulate the system performance well, considering shading, temperature, and panel efficiency. This enabled us to design a proper and optimized system that could harness the maximum solar power. An economic analysis was done to determine the cost-effectiveness of the project. We considered the initial investment, that is, the cost of purchasing and installing solar panels, inverters, and other necessary equipment. We also considered maintenance and operational expenses in the long term, such as cleaning, monitoring, and even repairs.

Pourasl et al. [8] highlight the global growth of solar energy, especially in PV and concentrated solar power technologies. While solar only accounts for 3.6% of global electricity, it makes up 31% of the world's renewable capacity.

Nikolaidis [9] describes solar energy as a clean and practical alternative to fossil fuel-based systems. The study thoroughly examines solar energy conversion technologies, focusing on both direct (PV) and indirect (thermal) methods to improve efficiency and promote fair energy distribution.

Maka and Alibad [10] found that each 1 GW of installed solar capacity creates 8,200 direct jobs and reduces sector emissions by 2.8 million tons each year.

The transportation-energy interface has become an important area of study. Ulinuha et al. [11] developed modular microgrid solutions for electric mobility, achieving 98.5% charging reliability in off-grid operations with their proprietary bidirectional power management system.

The International Energy Agency's recent scenarios report by Birol [12] includes updated learning curves, predicting that solar PV will contribute 38% of global generation by 2040.

New modeling methods are changing how policies are made. Naseem et al. [13] conducted a longitudinal econometric analysis of G20 nations and found a threshold effect. When renewable energy penetration exceeds 32%, economic growth becomes separate from emissions.

Gyani and Chandel [14] have developed a strong methodological framework to measure global progress toward Sustainable Development Goal 7, which aims for universal access to reliable, affordable, and sustainable energy. The study highlights three key factors crucial for energy transition efforts: technological optimization, policy integration, and financial mechanisms.

Recent work in building science by Reddy et al. [15] has created effective methods for reducing carbon in the building sector. This study introduced a systematic approach to evaluate low-carbon options for urban infrastructure.

Bakhsh et al. [16] conducted a recent empirical study on what makes energy transitions successful in industrialized economies. In their study, they used advanced econometric techniques, and they analyzed socioeconomic and environmental data from the past 30 years (1990–2021).

Urban integration challenges have been tackled by Etukudoh et al. [17], using architecture optimization codes to achieve 55% greater PV penetration in dense urban settings.

In institutional decarbonization, Altassan [18] has planned educational campuses to achieve net-positive energy. This includes adaptive PV façades, AI-optimized resource recovery systems, and nudging designs that reduced energy consumption by 31%.

Kabeyi and Olanrewaju [19] introduced a new framework for achieving deep decarbonization in the power sector. The framework of work is built on three interdependent pillars: demand-side transformation, supply-side optimization, and system-wide Modernization.

Research by Victoria et al. [20] highlights the essential role of PV technology in global CO₂ reduction efforts. Their findings indicate that current decarbonization models often underestimate their economic and environmental contributions by 15–20%.

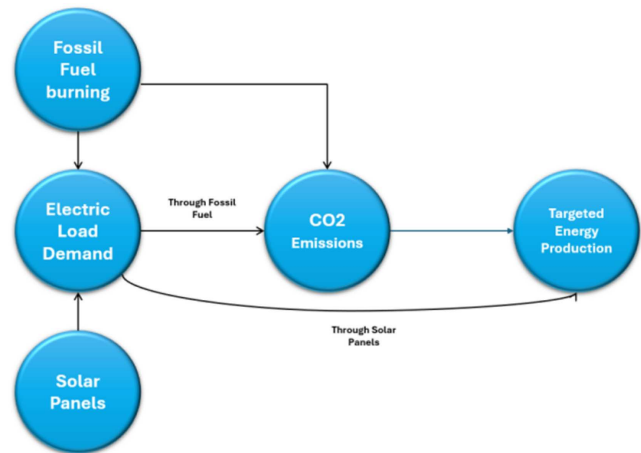
Nazarko et al. [21] conducted a sectoral analysis comparing energy consumption trends among EU countries with their emission targets under the European Green Deal. The article emphasizes the need for coherent policy measures to align 2030 decarbonization goals with ongoing economic growth.

Regional studies such as Misconel's [22] on German abatement cost optimization demonstrate how staged investment can speed up transitions and support grid stability.

3. Foundational Theoretical Structure

The worldwide demand for electricity creates serious energy security challenges, primarily due to continued dependence on carbon-based methods of power production. Electricity from fossil fuels remains the source of almost two-thirds of energy-related CO₂ emissions, perpetuating both economic and environmental vulnerability. Traditional thermal power generation facilities are faced with two fundamental constraints: (1) high natural gas requirements (2.8–3.2 m³ per unit of kWh produced) and (2) complex global

Figure 1
Theoretical framework illustrating fossil fuel combustion and solar photovoltaic systems



supply networks that increase vulnerability to geopolitical uncertainty and transportation limitations. The facilities have high price responsiveness to fuels, with econometric projections revealing high sensitivity of the price of gas and end-user electricity prices ($\beta = 0.72, p < 0.01$).

The developed analytical framework (Figure 1) presents a multidimensional contrast between conventional thermal generation and solar PV technologies on the basis of assessing:

- 1) Climate impact (lifecycle emissions)
- 2) Economic resilience (price volatility resistance)
- 3) Infrastructure security (supply chain localization potential)

This configuration's setup offers practical options for reducing carbon emissions. It balances the integration of renewable energy with the requirement for a reliable power supply.

4. Highlight on the Research Study

Thermoelectric power generation is the dominant source of human-generated CO₂ emissions, and most electricity-related carbon emissions arise from the burning of fossil fuels. This paper employs the country's unique energy profile – hydrocarbon dominant but with phenomenal solar resource endowment ($\geq 2,200$ kWh/m²/year irradiation) – as a case study to examine renewable transition potential for petro-economies. Our research shows grid-scale PV systems to be technically feasible and economically on par with carbon-free performance and with much reduced lifecycle environmental impacts compared to traditional thermal power production.

For constructing robust decarbonization metrics, this study employs:

- Installed power plant capacity
- Required solar panel output
- CO₂ emissions
- Target energy production

Polynomial regression equations (quartic) were derived from CO₂ emission production data. Estimation models for installed capacity, energy production, and CO₂ emissions were also developed for Bahrain. Solar energy systems can reduce reliance on fossil fuels, are low-maintenance, and offer cost and energy savings. Additionally, solar systems can generate electricity in any climate.

The present research tests dynamic power production, CO₂ emissions, and decarbonization of the adoption of solar energy. As increasing global ecological concerns – most notably climate change and global warming – carbon emission reduction has become a matter of extreme urgency. Through examination of modern energy systems, the current research finds necessary strategies for a transition toward the future low-carbon and sustainable energy.

Two comparative scenarios have been set, with comparative analysis determining that the second scenario is a more probable pathway to net-zero CO₂ emissions. The findings underscore the importance of incorporating renewable energy in attaining environmental resilience and long-term sustainability.

5. Results and Discussion

The continuous expansion of global electricity generation capacity has been marked by the rising application of natural gas-fired power generation in meeting increasing energy requirements. Empirical research shows that weather, high temperatures, and increased humidity levels during the summer months make significant contributions to peak electricity demand. Seasonal peaks put intense operating stress on power infrastructure, calling for flexible and responsive generation capacity. The growing dependence on natural gas in this direction is examined here, and its effects on grid stability and energy sustainability are evaluated.

Annual installed capacity estimates for the period 1980–2060 were analyzed using historical data and quartic polynomial regression models. Curve-fitting techniques were applied to project future capacity trends based on historical data, incorporating mathematical modeling to forecast future trends. This required compiling historical data on installed electricity generation capacity, with projections extended to 2060.

World energy markets are coming under growing pressure from increasing electricity demand, while fossil fuels – most particularly natural gas – remain a substantial source of supply. Climatic influences, including summer heat and humidity, add further to peak demand, stressing power grids. In this analysis, the considered country's expansion in electricity load and associated CO₂ emissions between 1980 and up to 2060 are modeled, employing quadratic regression for trend estimation and implications on the environment.

The considered electricity demand has grown steadily since 1980, and continued growth is planned, propelled by economic

and demographic pressures. Fossil fuel dominates generation, and resulting CO₂ emissions are rising.

Quadratic regression reveals a nonlinear increase in CO₂, consistent with the combustion of fossil fuels for electricity production. Emissions intensity is determined by fuel content and technological efficiency.

Growing per capita CO₂ emissions are a consequence of population growth and growing energy consumption, peaking by 2060 along business-as-usual trends.

The findings highlight the importance of diversification of the energy mix, as well as the employment of low-carbon technology to minimize emissions. Proper demand and emission estimation, as evidenced here, is essential in the establishment of sustainable energy policy aligned with climate goals.

The study utilizes nonlinear regression techniques to account for outliers in the data and time-varying trends to enhance precision in long-term energy and emissions projections.

To estimate future electricity demand, a quadratic regression model was applied to historical load data spanning the years 1980–2060. This model, as shown in Figure 2, expresses the electric load as a second-degree polynomial function of time. Curve-fitting techniques were employed to minimize the deviation between predicted and actual values, thereby improving the model's predictive accuracy. Meanwhile, future and improved electric loads are calculated according to the provided data from 1980 to 2023. The estimated future electric load is acquired up to 2060 years, where the data model is derived through a curve-fitting technique and is provided using Equation (1). Always, the predicted future values should be compared against actual past data, and observe that the process requires careful consideration as to what kind of curve is appropriate. In addition, the regression coefficients were calculated with high numerical precision to reduce the influence of outliers, which can significantly distort results in nonlinear modeling. The model of the data using quadratic regression becomes:

$$y = 15476026 - 15581x + 3.9x^2 \quad (1)$$

where:

- x represents year.
- y represents the annual maximum electric load and its estimated annual maximum electric load.

Figure 2
Electric load versus year

Polynomial Quadratic Regression

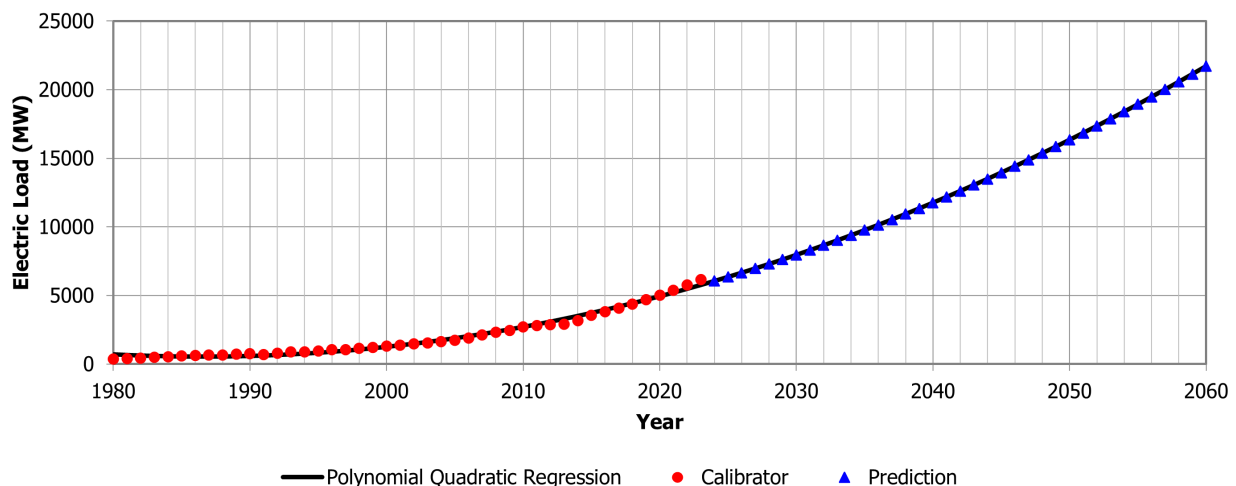
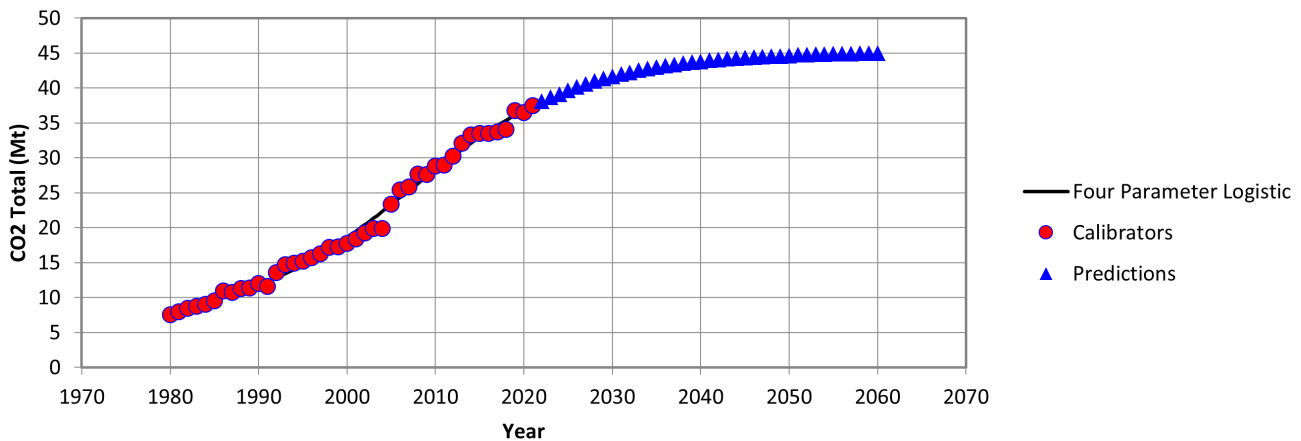


Figure 3
CO₂ total emission versus year



The study applied the same strategy of approach to analyze CO₂ emission trends during the same study duration. The rise in atmospheric concentration of CO₂, as reported, is largely due to burning hydrocarbons in electric power generation. As an absorbing radiation greenhouse agent, CO₂ molecules trap and re-radiate heat energy, raising the Earth's greenhouse effect and accelerating man-induced climatic development.

The temporal trend of past and future aggregate CO₂ emissions, showing the relationship between CO₂ emission and the years, was plotted, as illustrated in Figure 3. The forecast of future values of CO₂ emissions is centered on the basis of the past data from 1980 to 2021. Thus, the future CO₂ emission forecasted up to the year 2060, where the model of the data is obtained by calculating it on the basis of the curve-fitting technique and explained through Equation (2). At every point in time, the projected future CO₂ emission values must be compared to historical actual values. As one of the things to be considered, it should be noted that the technique used must identify well the right kind of curve. The projections were created by employing advanced mathematical modeling techniques. Second-order polynomial regression analysis was used specifically to ascertain the chronological correlation between annual amounts of emissions and temporal trends. This analysis technique provides better forecasting accuracy corresponding to anticipated trends in power generation capacity as well as consumption patterns.

CO₂ emissions per kilowatt-hour (kWh) of electricity generated vary according to the fuel mix used in power plants. Consequently, annual CO₂ emissions are expected to fluctuate depending on changes in energy sources integrated into the national grid. Additionally, natural gas consumption in power generation is directly correlated with CO₂ output. However, emissions from land-use changes and non-electricity-related sources have been excluded from this analysis.

This longitudinal analysis of electricity consumption trends and their corresponding carbon emission pathways in the current study provides useful empirical evidence for the examination of the sustainability challenges faced energy sector. Models built in this study have high forecasting capacity and can be utilized to:

- 1) provide estimates of the environmental consequences of current energy consumption trends,
- 2) project future emission trajectories under business-as-usual scenarios, and
- 3) determine the probable impact of alternative courses on energy.

These findings form a good evidence base for building targeted interventions that reconcile energy security and climate mitigation objectives.

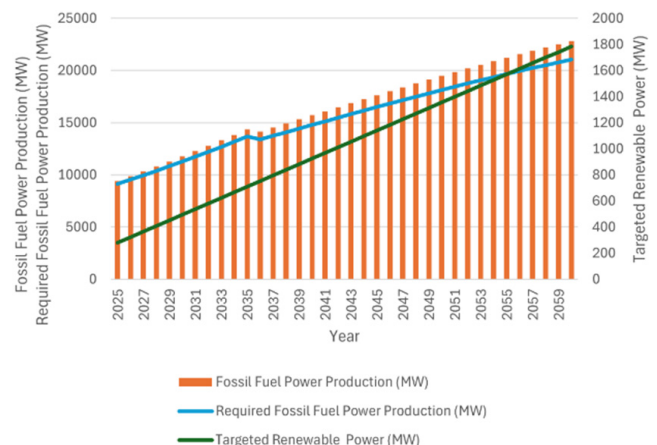
$$y = -2775 + 2.05x - 0.0004x^2 \quad (2)$$

where:

- x represents the year.
- y represents CO₂ emissions.

On the basis of the empirical evidence, two decarbonization routes (two scenarios) are constructed in this research, strategically detailed to concur with the national development aspirations and meet climate commitments. The incremental transition route is the first scenario, and the accelerated transformation plan is the second scenario. Both constructs were suitably traced against the country's Economic Vision 2030 and other countries' national development plans, finding them to be practically applicable for energy industry stakeholders.

Figure 4
Fossil fuel production, required fossil fuel power production, and targeted renewable power generation versus the years



5.1. Scenario 1: Bahrain Vision 2030

The Vision 2030 puts environmental sustainability first through policies protecting ecosystems, adapting to the impacts of climate, and transitioning toward cleaner energy systems. The Kingdom, in particular, already surpassed its energy efficiency targets ahead of schedule, realizing a 6% reduction in energy intensity by 2019 – despite the economic shocks on world economies caused by the COVID-19 pandemic. It says a lot about strategic investment in:

- 1) Planned integration of utility-scale and distributed renewables into the power system to supplant fossil fuel reliance and reduce sectoral emissions.
- 2) Diversifying energy sources (solar, wind, waste-to-energy).
- 3) Policy frameworks that reconcile growing energy demand and environmental preservation to enable low-carbon, long-term growth.

These measures demonstrate the commitment to reconciling economic growth with climate resilience and offer a blueprint for hydrocarbon-based economies in transition toward energy.

The energy master plan intends ambitious capacity targets, 280 MW of renewable capacity by 2025, going up to 710 MW by 2035. A tipping point can be observed around 2055, wherein conventional energy requirement (estimated at 19.25 GW) intersects with renewable capacity (estimated at 1.785 GW). This transition pathway scenario, as depicted in Figure 4, shows the high potential for decarbonization, with estimated emissions savings of 5–6 metric tons of CO₂ equivalent annually. These mitigation levels would be significant in underpinning the Kingdom's Nationally Determined Contributions under the Paris Agreement. Besides, there is CO₂ reduction emphasis that is a target achievement of the renewable energy ambitions. This is seen from both visions in this study. The results of this study project two scenarios of both Vision 2030 and 2050, where this focus needs to be pushed toward the timely adoption of renewable energy sources, ramping up grid capacity for facilitating variable renewable energy inputs and accelerating local learning.

5.2. Scenario 2: Bahrain Vision 2050

The oil and gas industry revolution was at a fresh level with the February 2024 rollout of Vision 2050, the master plan for developing sustainable energy. The plan for the nation envisions the launch of the kingdom's largest utility-scale renewable to date, a 72 MW Sakhir solar power facility. Two of the national climate goals are aided by the project: a 30% reduction in greenhouse gas emissions by 2035 and carbon neutrality by 2060.

Recent figures reveal that the targeted renewable energy sector remains in its early stages, installing a mere 12 MW (0.1% of installed capacity) in 2021. The Sakhir project alone will contribute 28% of the intended 250 MW of new renewable capacity by 2025. Expansion is particularly relevant given the country has a record global per capita carbon footprint (26.7 tCO₂/person).

Also comprising complementary sustainability endeavors are ALBA's innovative solar-powered charging infrastructure for EVs, which will:

- Conserve 110 MWh of grid electricity annually
- Avoid 42 metric tons of CO₂ emissions each year

As can be seen in Figure 5, the overall projects are estimated to decrease the reliance on fossil fuels by an estimated 30%. The shift has triple dividends:

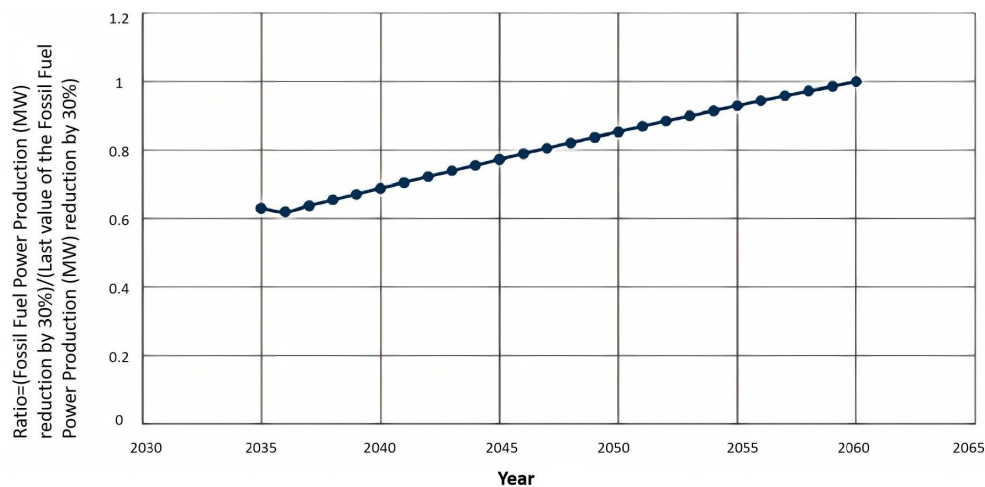
- Environmental improvements through emission reductions
- Economic diversification opportunities
- Enhanced energy security through domestic renewable resources

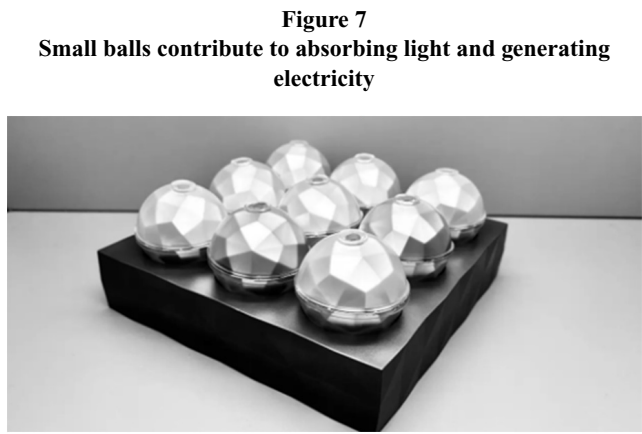
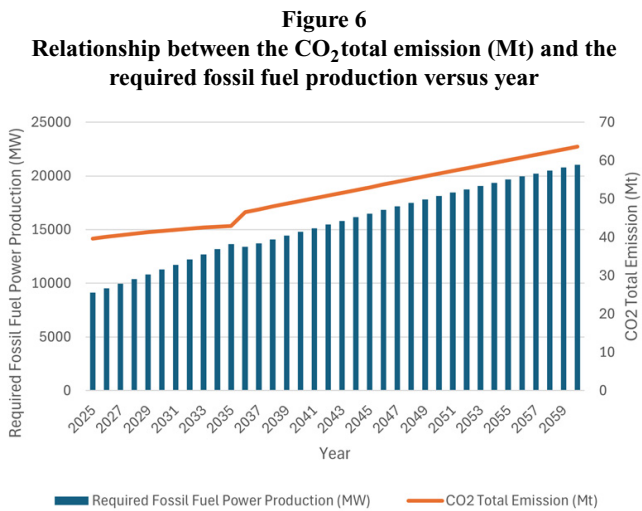
This forward-thinking strategy places the country at the forefront as a new champion of sustainable energy transition among hydrocarbon economies.

The ratio of fossil fuel power production (MW) to last value of the fossil fuel power production (MW) versus year is illustrated in Figure 5.

The projected evolution of the energy mix and associated emissions is revealed in Figure 6, demonstrating the central

Figure 5
Ratio of fossil fuel power production (MW) to last value of the fossil fuel power production (MW) versus year





interdependence between fossil fuel utilization and cumulative CO₂ production (given in metric megatons). Relying on our calculations, conventional generation capacity will amount to close to 23 GW in 2060, assuming current demand estimates. In order for any country

to successfully decarbonize and catch up with rising energy needs, it must adopt an ambitious plan of renewable deployment:

- Initial Phase (2025): Establish 250 MW baseline renewable capacity
- Scaling Period (2025–2060): Implement annual increments of 650 MW
- Target Achievement: Attain 23 GW of renewable generation capacity by 2060

This coordinated transition route, if implemented, would enable substitution of fossil fuel dependency at no loss in grid stability – a critical requirement in the attainment of carbon neutrality in the vision timeline.

Strategic ramping of clean energy infrastructure is a viable way to reconcile energy security and climate imperatives and one that other hydrocarbon-dependent economies can take note of.

6. Conclusion

This research offers two decarbonization scenarios for Bahrain on the basis of the implementation of historical analysis (1980–2021) and forward modeling (2022–2060). The method integrates three key indicators: (1) cumulative CO₂ production (MtCO₂), (2) power capacity additions (MW), and (3) per capita emission intensity (tCO₂/person). Comparative policy option analysis and related environmental and energy system considerations are provided by the models.

Traditional dominance scenario projects continued fossil fuel reliance (91.5% penetration), with little renewables integration (8.5%), as far out as 2060, based on the policy status quo, while complete transition scenario demonstrates the technical feasibility of complete power sector decarbonization through strategic use of renewables, with near-zero hydrocarbon-based power generation.

Besides, the study suggests an innovative design of the model that:

- Quantifies emission trajectories under alternative policy regimes
- Evaluates infrastructure requirements for energy transitions
- Provides decision support for climate policy formulation

Table 1
Comparison between flat solar panel and Sphelar module

Aspect/Term	Flat Conventional Solar Panel	Sphelar Module
Integration with Other Materials	It helps in high engineering alterations for seamless incorporation into the current infrastructure.	Ideal mass design, reduced integration protocol, and improved cost-performance ratio.
Hydrogen Production	Catalytic processing of hydrocarbons from fossil fuels.	Renewable hydrogen can be synthesized through solar-driven processes.
Current and Voltage	Requires a large space to achieve high voltage.	Can be freely connected in series and parallel; high voltage can be achieved in small areas.
Power Transmission	Two key areas of infrastructure: grid integration requirements and natural hazard vulnerability.	Building material integration of the technology eliminates the need for additional transmission infrastructure.
Low Power Generation in Cloudy Weather	Significant drop in power generation under diffused light on cloudy days.	No light directivity; easily absorbs diffused or scattered light with minimal power loss.
Light Damage	Reflected light causes glare and light pollution in natural environments.	No glare or light pollution due to minimal light reflection.
Production Method	High energy consumption and large raw material loss during manufacturing.	Simple manufacturing process that saves energy and raw materials.

The complete transition scenario establishes the country's potential to:

- Emerge as a Gulf Cooperation Council leader in clean energy innovation
- Align national development with international climate commitments
- Develop future-proof energy infrastructure
- Catalyze sustainable economic transformation

The research provides empirical rationale for the rapid deployment of renewables as both a green imperative and an economic strategic imperative for hydrocarbon-abundant nations in the energy transition process.

7. Future Vision Statement and Research

New breakthroughs are miniature versions of solar panels, that is, minuscule photo-absorbing balls (Figure 7). These balls (1–4 inches in diameter) [23] are 30 times smaller than a panel but generate 7.5 times more power. WAVJA (New York) created these “photon energy systems,” which are multilayered advanced materials that absorb sunlight and artificial light, 200 times better than solar panels.

Comparison of flat solar panel: Sphehar module [24] is given in Table 1. Table 1 contrasts and displays two applications of solar energy. Although a proposal for the future deployment of a new innovation has been made, the second application which is the Sphehar Module is yet to be deployed in Bahrain. The proposed plan aims to improve the current use by adding and applying this new concept utilized in other countries. In terms of vision for the future, the idea is to utilize the idea in Sphehar Power [24] that is yet to be used and help reduce the area/space usage to the barest minimum.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data are available from the corresponding author upon reasonable request.

Author Contribution Statement

Isa S. Qamber: Conceptualization, Methodology, Validation, Formal analysis, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Salwa Baserrah:** Writing – review & editing, Visualization, Supervision, Project administration.

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