



Towards hybrid grid-connected solar power plants: A case study of IAUN Science and Technology Park in Iran

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ABSTRACT

The growing global demand for electricity has intensified the need for efficient and sustainable energy production. While a variety of technologies — ranging from fossil fuels to hydropower, nuclear, and renewables — are utilized for electricity generation, fossil fuel power plants remain predominant. However, the environmental consequences of fossil fuel use, including pollution and global warming, as well as the finite nature of these resources, present significant challenges. In response, there has been a growing focus on alternative energy sources, particularly renewable technologies. Among these, solar photovoltaic (PV) systems have garnered increasing attention due to their availability, low installation and maintenance costs, and low environmental impact. Iran, facing high establishment costs for other types of power plants, is turning to solar energy as a key solution. This article evaluates the feasibility of installing a 100 kW PV power plant at the Science and Technology Park of Islamic Azad University of Najafabad (IAUN) in Iran. The system incorporates both rooftop and floating PV installations. Technical analysis is conducted using PVsyst software, while economic and environmental assessments are carried out with RETScreen software. The results indicate a payback period of 3.4 years, with the system expected to mitigate 109 tons of CO₂ emissions annually.

1. Introduction

The remarkable advancements achieved by humanity over the past two centuries can be attributed to numerous factors, with the electricity industry standing out as one of the most transformative contributors to this progress. However, despite the undeniable benefits of widespread electricity use, its generation has introduced significant environmental challenges. Since the majority of today's electricity is generated from fossil fuels, the environmental impact of this energy generation technology is profound. The excessive reliance on fossil fuels has resulted in severe pollution, with electricity generation playing a substantial role in the global environmental crisis. Greenhouse gas (GHG) emissions from fossil fuel-based power plants, primarily carbon dioxide, methane, and nitrogen dioxide, are key contributors to this pollution. According to the latest International Energy Agency (IEA) reports, the global energy system accounts for approximately 75% of total GHG emissions, making it the primary contributor to climate change. Despite the rapid growth of clean energy technologies such as solar photovoltaic (PV), electric vehicles, and battery storage in recent years, achieving the 1.5 °C climate target still requires much faster and broader deployment of renewable and low-carbon technologies by 2030 [1]. Given the significant environmental consequences of such vast energy-related

emissions, it is imperative to implement fundamental changes in how electricity is generated. Since modern society is deeply intertwined with electricity consumption, reducing energy generation is not a viable solution, and alternative approaches must be pursued to address this pressing issue.

Renewable energy has emerged as a viable solution for reducing GHG emissions while meeting the growing global demand for electricity [2]. This is primarily due to the fact that renewable energy sources produce little to no GHG emissions during electricity generation. Significant progress has been made globally in expanding renewable energy capacity. According to the latest IEA World Energy Investment 2025 report, global energy investment is projected to reach USD 3.3 trillion in 2025, of which USD 2.2 trillion is directed toward clean energy technologies — including renewables, grids, storage, and electrification — representing twice the investment in fossil fuels [3]. Among these technologies, solar PV remains the dominant driver of growth, with global investment in PV systems (both utility-scale and rooftop) expected to reach USD 450 billion in 2025, making it the single largest item in global clean energy investment. China continues to lead this transition, significantly expanding its renewable capacity and strengthening its dominant position in global PV manufacturing and deployment, with

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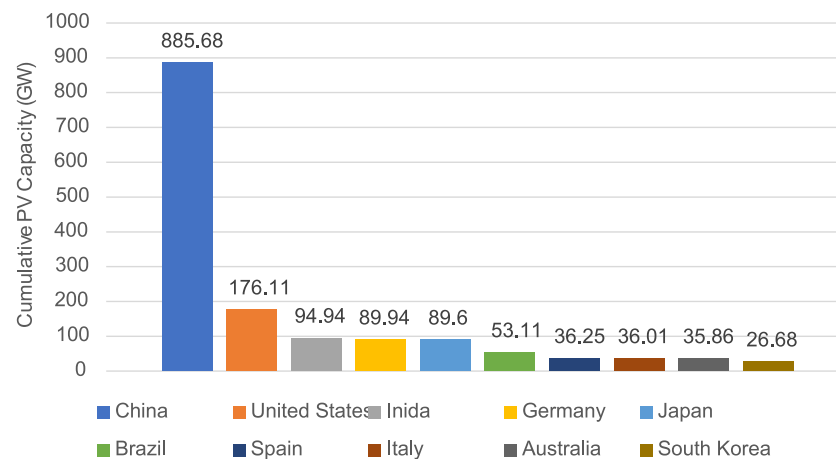


Fig. 1. Cumulative solar PV capacity by country as of 2024 [8].

its renewable electricity capacity expected to increase by more than 2000 GW between 2023 and 2028 [4]. This highlights the critical role of renewable energy in both mitigating environmental damage and addressing the increasing need for sustainable power generation.

Among the various types of renewable power plants, solar power plants have emerged as one of the most widely adopted technologies. Their growing popularity can be attributed to several advantages, including advances in PV modules, relatively low installation costs, government incentives, the absence of fossil fuel requirements for electricity generation, accessibility, significantly lower maintenance costs compared to other power plants, and the flexibility to be installed on rooftops and lakes [5]. These systems generate electricity through solar panels, which harness energy from sunlight. The origins of solar electricity date back to the 19th century when a young French scientist first discovered the PV effect. Throughout the 20th century, advancements in physics led to significant improvements in solar cell technology, culminating in the 1958 launch of the first satellite powered by solar panels. In the 1970s, Solarex developed highly efficient silicon solar cells, bringing this technology closer to widespread use. The last decades of the 20th century saw substantial progress in solar power systems. In the 21st century, due to the growing concern over climate change and GHG emissions, solar energy has received renewed attention. In 2002, solar power plants generated 277 MW of electricity, with a market value of \$1 billion [6]. In 2022, solar PV generation increased by a record 270 TWh (26%), surpassing wind for the first time and reaching nearly 1300 TWh [7]. Fig. 1 shows the cumulative solar PV capacity by country as of 2024, highlighting that China's total solar PV capacity reached 885 GW [8]. Projections suggest that this capacity will grow to 1 TW between 2025 and 2028 [9]. This growth mirrors the pace needed to meet the Net Zero Emissions by 2050 Scenario [10]. To maintain a growth rate in line with the Net Zero scenario, annual capacity additions will need to triple by 2030.

Iran is not exempt from the growing need to develop solar power plants and has made notable progress in this area. The country's vast land area and abundant sunshine provide an ideal foundation for large-scale solar energy generation. Utilizing just 1% of Iran's landmass for solar power plants, with panels operating at 10% efficiency, could generate over 9 million MWh of electricity per day [9]. It is important to note that Iran provides substantial subsidies for fossil fuels, amounting to \$30 billion in 2022 alone, specifically for electricity production. This makes Iran the second-largest provider of fossil fuel subsidies in the world, following Russia, with these subsidies accounting for approximately 8.5% of the country's total GDP [11]. The installation of PV power plants can significantly reduce these high energy costs in Iran. Recognizing this potential, Iran has made significant strides in solar energy development. By 2021, the country's total solar electricity

capacity had reached 365 MW [9], and by 2025, this capacity had increased to over 1400 MW.

The purpose of this article is to evaluate the possibility of using a hybrid solar power plant to provide electrical energy for Islamic Azad University of Najafabad (IAUN) Science and Technology Park. For this purpose, the required energy of this building is calculated in Section 2. The desired PV system is designed in Section 3 and is evaluated in Section 4 from technical point of view. Then, this hybrid system is evaluated from the economic and environmental perspectives in Section 5. Finally, Section 6 concludes the article.

2. Electrical system of IAUN science and technology park

Islamic Azad University of Najafabad, one of the largest higher education institutions in central Iran, spans over 1270 hectares and serves more than 30,000 students. The IAUN Science and Technology Park, a three-year old building with an area of over 21,000 square meters, is located in the southeast part of the campus with the approval of the Iran Ministry of Science, Research, and Technology. This facility hosts companies established by university faculty, students, and other researchers working in various technological fields. Each floor houses several offices, connected by corridors, along with restrooms. The building's electricity consumption is primarily attributed to lighting, air conditioning systems, office outlets, and other minor loads. The air conditioning system is the largest consumer of electricity, driven by the city's climatic conditions, which feature hot summers and relatively cold winters. Effective air conditioning is essential to ensure adequate ventilation and climate control throughout the building. The system includes both air conditioners and split cooling units, with higher electricity consumption during cooling mode compared to heating mode. In addition to air conditioning, each office is equipped with multiple outlets for devices such as computers and tea makers, which are categorized as separate loads for each room. The lighting system also plays a significant role in the building's energy consumption. Due to the north-south orientation of the offices, natural sunlight is insufficient, necessitating extensive use of artificial lighting to meet the building's needs.

Given that not all offices are occupied simultaneously throughout the day, it is important to apply a diversity (simultaneity) factor to accurately assess the building's energy use. The detailed consumption data for the IAUN Science and Technology Park are provided in Table 1, considering the diversity factors based on Schneider Electric guide [12]. By considering the diversity factor of 0.6 for 10 or more distribution circuits, the total energy consumption is equal to $175.8 \times 0.6 = 105.5$ kW.

Table 1
Electric Power Consumption of IAUN Science and Technology Park Building.

Load	Power (W)	Quantity	Diversity factor	Efficiency (%)	Total power (W)
Round ceiling lamp 1	7	132	1	–	924
Round ceiling lamp 2	9	78	1	–	702
Linear bracket lamp	20	254	1	–	5080
Ceiling lighting panel 40 × 40	100	57	1	–	5700
Ceiling lighting panel 20 × 20	30	7	1	–	210
Air conditioner	1100	61	1	84	67,100
Ground fan coil	37	6	0.8	–	177.6
Split cooling unit	1300	61	0.8	84	63,440
CCTV camera	5	7	1	–	35
Sockets	5000	65	0.1	–	32,500

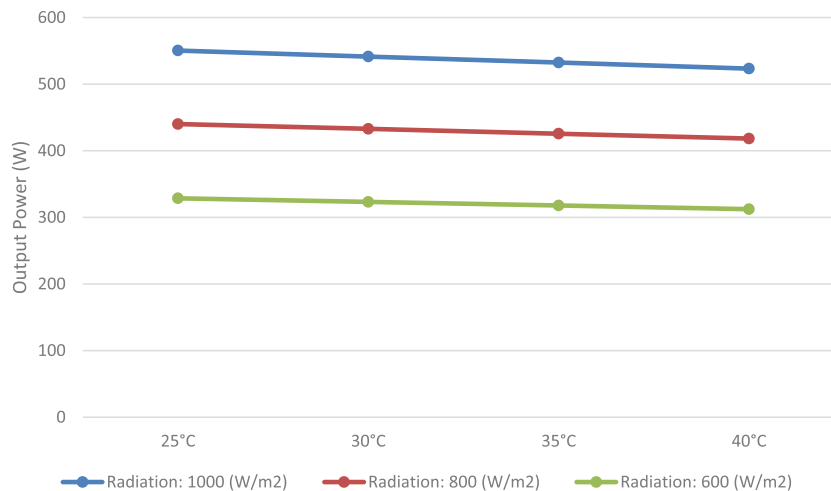


Fig. 2. Output power of project solar panels in terms of temperature.

3. Design of grid-connected hybrid solar power plant

The design of solar power plants is tailored to the specific location and operational requirements of the installation. Key factors to consider during the design process include selecting an appropriate installation site, evaluating potential shading on the panels, and determining the system's distance from the utility power grid if it will be grid-connected. The first and most critical step is identifying an optimal location for installation, which requires favorable sunlight conditions, appropriate temperatures, and the solar spectrum. Fig. 2 shows the output power of the solar panels used in this project at various temperatures and solar radiation levels.

To maximize the efficiency of the solar power plant, the installation site must be carefully selected based on the specific conditions of the IAUN Science and Technology Park campus and its surrounding environment. The campus building is surrounded by several trees, making the area around the building unsuitable for solar panel installation due to shading. Therefore, the building's roof, which is free from tree shadows, is an ideal location for installing the solar panels. Additionally, to further optimize performance, the water storage pool located on the eastern side of the building, which receives ample sunlight, will also be used for panel installation. Fig. 3 presents the system's location by using the Google Earth map.

Based on the electrical energy consumption of the IAUN Science and Technology Park campus building, as well as the available installation space on the building's roof and the adjacent water storage pool, the rating of the installed solar power plant is set at 106 kW.

3.1. Floating solar power plant

Floating solar power plants, developed over the past two decades, represent a new and innovative approach for PV energy generation.

The concept of floating power plants dates back to the early 20th century when the UK converted a warship into a floating power station. However, the development of floating solar systems began in the early 21st century, with two Japanese companies patenting the technology. Floating solar systems offer distinctive advantages that have garnered significant attention from engineers and investors worldwide. One of the primary benefits is that these systems do not require land for installation, avoiding the need to occupy wasteland. This feature is particularly valuable given the growing global population and the increasing demand for agricultural land to meet food production needs. Another key advantage is the improved efficiency of floating solar power plants, which can achieve up to 15% higher output compared to land-based systems. This efficiency boost is due to the cooling effect from water evaporation and enhanced wind circulation in coastal areas [14]. Additionally, floating solar panels reduce water evaporation at the installation site by blocking direct sunlight from the water surface, a benefit that can decrease evaporation by as much as 28% [15, 16]. Additionally, water reservoirs typically have minimal shading from structures like tall buildings, which reduces system losses. Furthermore, floating PV power plants benefit from less dust and dirt accumulation, resulting in lower soiling losses. These advantages explain the growing popularity of floating PV systems over time. It is projected that this technology will expand by 22% annually through 2024 [17]. Notably, the Levelized Cost of Energy (LCOE) for floating PV systems can be over 20% lower compared to land-based PV plants [15].

Japan pioneered this field by constructing the first floating solar power system with a capacity of 20 kW [15,18]. In 2008, the United States followed suit, building a 175 kW floating solar plant. In 2018, the total installed capacity of floating solar systems had grown to 1 GW globally [18]. Continued advancements in this technology led to a worldwide capacity of over 3 GW by 2021 [15]. Table 2 presents examples of floating solar installations around the world [19].



Fig. 3. The location of the solar power plant in the IAUN Science and Technology Park campus building using the Google Earth map [13].

Table 2

Some Solar Floating Systems Around the World [19].

Location, Country	Dimensions of the floating system (km ²)	Capacity (MW)
Huinan, China	8	40
Huinan, China	0.45	150
Watton-on-Thames, UK	0.057	6.3
Zwolle, Netherlands	0.18	14.5
Ichihara, Chiba Prefecture, Japan	0.18	13.7
Khandwa, India	100	600
California, USA	0.0607	4.8
Johor Strait, Singapore	0.05	5

Despite these benefits, floating PV systems face certain challenges. One of the primary issues is the fluctuation in water levels. In projects where water levels vary significantly, especially during hot seasons when surfaces may dry out, additional measures are required to adjust the system, leading to increased project costs [17]. Another challenge is that wave movements can affect the positioning of PV modules, causing them to experience changes in orientation, which can impact performance [20].

The installation of floating solar power plants requires specific infrastructure. The main components include floating platforms to support the solar structure, anchors to secure the floats to the bottom of the reservoir, the solar mounting structure, solar panels, inverters, and other electrical equipment such as cables. The floating platforms are typically made from high-density polyethylene (HDPE), which is both fire-resistant and UV-resistant [14]. These platforms are installed in two primary configurations: suspension bridge mode, which is further divided into three subcategories, and surface installation mode, which has two subcategories [12]. Figs. 4(a) and 4b show the various floating structures used in floating solar systems. The anchoring system for floating solar power plants typically consists of chains made from fiber

or elastic rubber. In more demanding environments, such as floating solar installations on seas, steel chains are used for enhanced durability and stability [20].

3.2. Simulation of the hybrid solar power plant

The simulation of a solar power plant is a critical phase in its design and analysis, which involves modeling the system using technical simulation software. In this study, PVsyst software is used for the design and simulation of the solar system. A key feature of the designed PV system is the use of bifacial panels, meaning both sides of each panel can generate electricity. While these panels are more expensive than traditional monofacial types, their use in a floating solar system significantly enhances efficiency by capturing light reflected from the water surface, thereby increasing energy production.

The geographical data for the installation site is sourced from Meteororm database. The initial step in the design process involves selecting the installation location and method. Given the location at IAUN and the fact that Iran is in the northern hemisphere, the solar panels should face south for optimal performance. To ensure correct

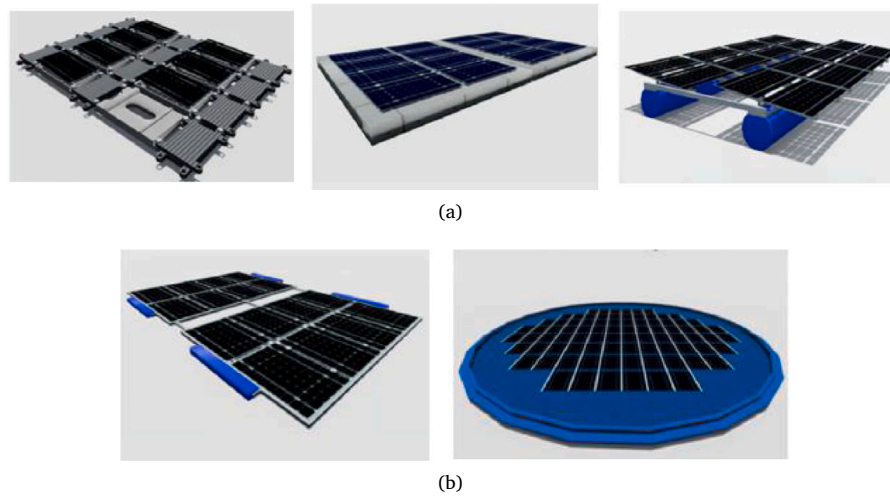


Fig. 4. Floating PV system. (a) Suspension bridge and (b) Surface floating [12,20].

Table 3
JAM72D30550/MB Solar Panel Specifications.

Parameter	Value
Maximum power	550 W
Open-circuit voltage	49.9 V
Maximum power point voltage	41.96 V
Short-circuit current	14 A
Maximum power point current	13.11 A
Panel efficiency	21.3%

Table 4
Blueplanet 50.0 TL3-INT BASIC Inverter Specifications.

Parameter	Value
Maximum recommended PV generator power	70 kW
Maximum power point range	580–900 V
Maximum no-load voltage	1100 V
Maximum input current	90 A
Maximum short-circuit current $I_{sc,max}$	190 A
Rated output	50 kVA
Number of grid phases	3
Rated frequency	50/60 Hz
Protection class	IP 65
Maximum efficiency	98.5%

alignment, the panels are oriented to the zero-degree (true south) direction. Additionally, based on the geographical location of Najafabad city, the panels are installed at a 33-degree tilt angle to increase efficiency.

The system is designed to fully utilize the available space, with a nominal capacity of 106 kW, comprising 36 kW for the floating installation and 70 kW for the rooftop installation. To achieve proper efficiency, the appropriate arrays and inverters are selected. The design utilizes JA Solar panels and KACO inverters, specifically 192 panels with a capacity of 550 W and two inverters rated at 50 kW. Detailed specifications of the panels are provided in Table 3 for the standard Test Conditions (STC) with a temperature of 25 °C, solar irradiance of 1000 W per square meter, and an air mass of 1.5. Table 4 presents the specifications of the selected inverter.

One of the key considerations in the design and installation of solar systems is maintaining the appropriate DC-to-AC power ratio. A DC/AC ratio greater than one allows for increased energy output without raising inverter costs. In this study, the DC/AC ratio is set at 1.06, meaning the total inverter capacity is 100 kW, while the nominal output power of the solar panels is 106 kW. This approach enhances economic efficiency by optimizing the system's energy output.

The design outcome is depicted in Fig. 5, where the floating solar array, located on the right side of the figure, consists of 64 panels generating a total of 36 kW, while the rooftop installation, comprising 128 panels, produces 70 kW.

3.3. Simulation assumptions for land and floating PV

To accurately represent the operating conditions of both the land-based and floating PV sections of the project, the performance of the systems was modeled in PVsyst using detailed assumptions related to thermal behavior, soiling effects, and module degradation mechanisms. These factors are known to significantly influence long-term energy yield and therefore were incorporated into the simulation framework for both configurations.

3.3.1. Temperature effects

Floating PV installations generally exhibit lower operating temperatures due to the cooling influence of the water surface. Based on the experimental results reported in [21], the floating PV modules were assumed to operate at an average temperature that is approximately 7.5 °C lower than the rooftop modules. This adjustment resulted in a thermal loss of 3.9% for the floating PV system, compared to 5.11% for the land-based system as calculated by PVsyst.

3.3.2. Soiling losses

Differences in dust accumulation between the two systems were also incorporated. In accordance with [17], soiling losses for the land-based installation were set to 5%, which is typical for industrial regions as IAUN is located in an industrial city. For the floating PV system, a lower soiling loss of 3% was adopted, consistent with reported trends in floating PV performance, where distance from ground-level dust sources generally reduces particle deposition on module surfaces.

3.3.3. Degradation and reliability factors

Multiple degradation mechanisms were considered in the simulation:

- **Light-Induced Degradation (LID):** A value of 2% was applied to both systems (default assumptions of PVsyst, as the module datasheets did not specify LID behavior).
- **Potential-Induced Degradation (PID):** PID was mitigated by grounding the negative pole of the array, which prevents voltage-induced leakage currents. Thus, PID-related losses were considered negligible for the designed system.

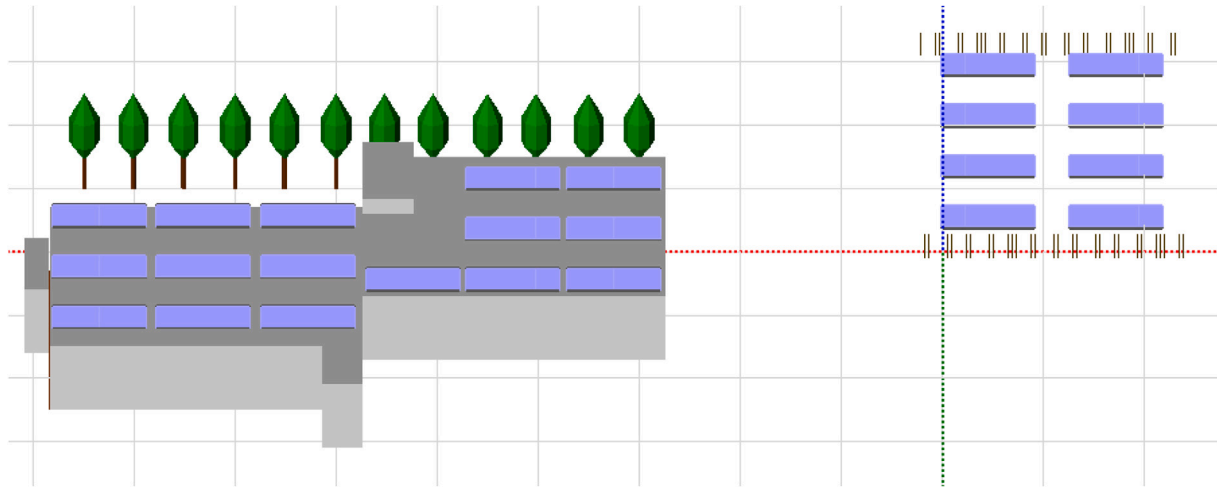


Fig. 5. Top view of the designed solar power plant.

Table 5
Generated Electrical Energy of the Designed Solar Power Plant.

Month	Energy of arrays (MWh)	Injected energy into the grid (MWh)
January	18	16
February	17.7	17.1
March	18	16
April	17.7	16.1
May	18.1	17.7
June	18.3	17.7
July	18.4	17.8
August	19.2	18.7
September	19.4	18.8
October	19.6	18.1
November	17	15.9
December	17	16.5

- Long-term Module Degradation/Corrosion: PVsyst's aging factor was used to model long-term degradation and corrosion effects, resulting in an expected lifetime degradation loss of 3.8% for both land-based and floating systems.

All simulation results, including energy yield, performance ratios, and financial indicators presented in this study, reflect these modeled conditions for both the rooftop and floating PV installations.

4. Technical performance evaluation

Table 5 presents the energy production and the monthly performance ratio of the designed solar power plant. The amount of electricity generated by the solar system varies across different months of the year, influenced by radiation and temperature conditions, snowfall, rainfall, and dust accumulation in the area. From May to September, when sunlight duration is longer and precipitation decreases, the system achieves its peak energy production. According to the results, September records the highest energy output, while November and December show the lowest production levels. This reduced output during winter months is primarily due to increased rainfall and the shorter duration of sunlight.

Table 6 presents a summary of system losses and energy production. Losses in solar power systems arise from several factors, each detailed in this table. The most significant loss during the energy generation process occurs due to temperature effects on the solar panels. Additionally, after energy is generated and transferred to the inverter, the highest energy loss is attributed to the inefficiencies of the inverter itself. Taking into account all system losses, the total annual energy production is 235 MWh, of which 230 MWh will be delivered to the utility power grid.

Table 6
Generated Energy and System Losses.

Parameter	Value
Global horizontal irradiation	2235 kWh/m ²
Global incident	+15.8%
Near Shadings: irradiance loss	-1.46%
Nominal energy of the arrays (kWh per year)	218,000
Temperature losses	-4.7%
Mismatch losses, modules and strings	-3.43%
Ohmic losses of wiring	-1.3%
Operation loss of the inverter	-2.2%
Inverter threshold voltage loss	0%
Energy injected into the grid (kWh per year)	209,000

5. Economic and environmental assessment

5.1. Economic assessment

The economic aspects and profitability of solar power plants are undoubtedly the most attractive factors for investors, which is why an economic analysis has been conducted for this project. The primary cost associated with solar power plants is their initial setup, while their maintenance costs are minimal. Due to the continuous advancement of technology and significant improvements in this field, the cost of installing solar systems is steadily decreasing. For the study system, equipment available in the Iranian solar energy market has been utilized, and the total cost has been estimated based on prices as of August 2024. Considering both the floating and rooftop components of the system, and acknowledging that the cost of floating systems is higher due to the need for a floating structure, the average cost per kilowatt for this project is approximately \$470. Thus, the total cost for constructing the entire 106 kW system is estimated to be about \$50,000.

The return on investment (ROI) for solar energy projects in Iran is calculated based on the electricity purchase price set by the Iran Ministry of Energy. This price varies depending on the rating of the power plant, with larger plants receiving a lower rate. For this particular project, the Ministry of Energy's purchase rate is \$0.05 per kilowatt-hour. Taking into account the construction costs, maintenance expenses, projected increases in the renewable energy purchase price, tax exemptions for renewable energy projects, and the gradual reduction in solar plant efficiency over time, a detailed economic analysis is conducted using RETScreen software. The annual maintenance cost for each kilowatt of the system is estimated at \$4. The results of this economic analysis are summarized in Table 7.

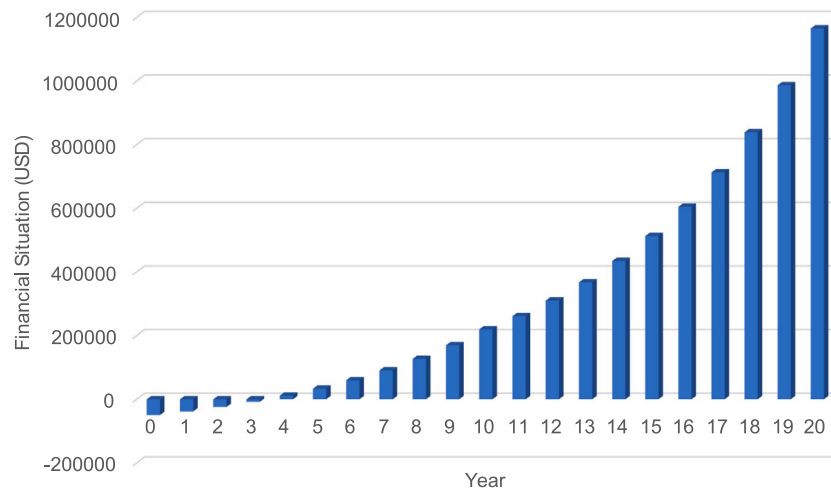


Fig. 6. Financial Cash Flow of the Project.

Table 7

Economic Analysis of the Study Hybrid Solar Power Plant.

Financial estimates	Value
Construction cost per kilowatt of capacity	\$470
Cost of maintenance and repairs per kilowatt in a year	\$4
Carbon reduction rate per ton	\$0.008
Electricity purchase rate per kilowatt-hour	\$0.05

In Iran, the Ministry of Energy offers a guaranteed electricity purchase agreement to solar power plant investors for a period of twenty years. Accordingly, the economic simulation for this project is conducted over the same timeframe. Fig. 6 shows the financial status of the system throughout the twenty-year operational period. According to the calculations and considering both the initial setup costs and ongoing maintenance expenses, the system reaches its break-even point midway through the third year. The financial analysis based on the RETScreen data indicates that with an initial investment of \$49,000, the project will fully recover its costs within three and a half years. After this point, all subsequent income will be considered net profit. By the end of the project's twenty-year operational period, the total net profit from this investment is projected to reach \$80,000.

An additional key aspect of economic analysis is the assessment of risk and sensitivity, which is conducted using various criteria. In this study, a sensitivity analysis is performed focusing on equity payback period (EPP). The results of this analysis are presented in Fig. 7. According to the analysis, if the construction cost of the power plant is reduced by 25%, the break-even point, based on the current electricity sales price to the grid, will be reached in 2.7 years, after which the project will become profitable. Conversely, if the construction cost increases by 25%, with the current electricity purchase rate set by the Ministry of Energy, the break-even period will extend to 4.4 years—one year longer than the current estimated time of 3.4 years.

5.2. Environmental assessment

Another crucial aspect of this project is its environmental benefits, especially in light of the growing issues related to fossil fuel consumption. It is vital to consider the environmental impact of every power plant, including CO₂ emissions, pollutants, and water consumption [22], all of which deserve thorough discussion. The primary environmental concern with PV power plants arises when solar panels reach the end of their lifespan. Typically, a PV system has an average lifetime of 30 years. For instance, a plant installed in 2020 would need to be decommissioned by 2050. If the panels are not properly recycled, they

could pose a significant environmental hazard. Additionally, research suggests that under certain conditions, the expected lifespan of a PV system could be reduced to as little as 12 years [23].

Water consumption is another critical issue across various human activities. With population growth and expanding industries, water demand continues to rise. About 10% of the world's fresh water is used by the energy industry [24]. Solar PV plants, however, significantly reduce water usage while generating electricity. Furthermore, floating PV systems offer the added benefit of reducing water evaporation from reservoirs, thus contributing to water conservation.

GHG emissions from PV solar power plants are dramatically lower during operation compared to conventional fossil fuel power plants, as PV systems do not involve fuel combustion or the production of direct pollutants. It is noteworthy that energy-generating systems produced 37.4 gigatons of CO₂ in 2023 [25]. As the global energy landscape transitions toward renewable sources, CO₂ emissions per unit of electricity consumed have decreased. The Global Warming Potential (GWP) per kilowatt-hour remains substantially higher for fossil fuel-based energy technologies than for renewables, highlighting the environmental advantages of integrating PV systems into national grids. Countries with a higher share of renewable energy technologies demonstrate lower GWP footprints for their products, reflecting the positive impact of clean energy on greenhouse gas emissions. This paper analyzes the electricity mix in selected countries using data from the Ecoinvent databases, revealing trends in the shift toward cleaner energy over time. Understanding these trends is essential as the world works to limit global warming to 1.5 °C, with renewable technologies like solar PV playing a key role in achieving net-zero emissions by mid-century. As part of the study, an environmental assessment is conducted using RETScreen. The key environmental advantage of solar power plants is that they do not rely on fossil fuels like oil or coal, and thus do not emit harmful GHGs. By operating the study power plant, the emission of approximately 109 tons of carbon dioxide per year will be avoided. This reduction is equivalent to the emissions produced by burning 254 barrels of crude oil or the operation of 22 small furnaces annually, representing a substantial environmental impact.

6. Conclusion

The transition toward renewable energy sources is essential for mitigating the environmental and economic challenges associated with fossil fuel dependency. This study evaluated the technical, economic, and environmental feasibility of deploying a hybrid 106 kW solar PV system — comprising both rooftop and floating PV installations — at the IAUN Science and Technology Park in Iran. By incorporating

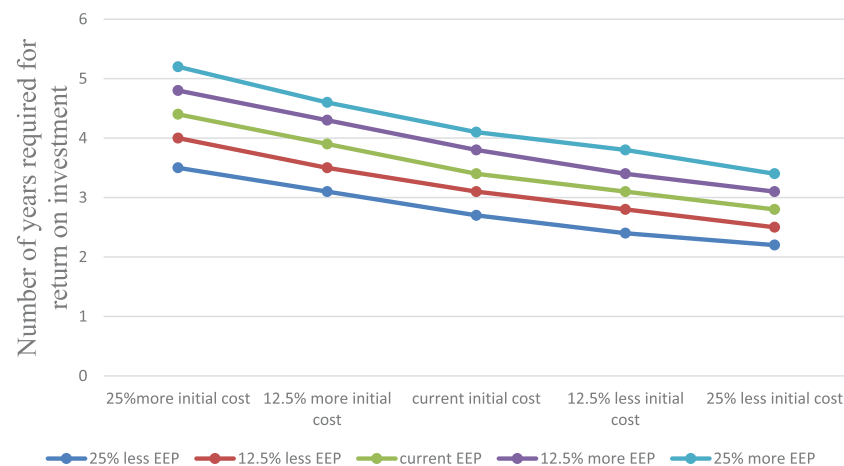


Fig. 7. Sensitivity analysis based on equity payback period.

updated and realistic parameters for temperature behavior, soiling, LID, and long-term module aging, the analysis provides a more accurate representation of system performance under local conditions. The comparative assessment between land-based and floating PV modules highlights the tangible performance benefits of floating PV systems, including lower module operating temperatures, reduced soiling accumulation, and consequently lower thermal losses. These advantages resulted in measurable improvements in annual energy yield compared to the rooftop installation. Such findings reinforce the value of floating PV technology, particularly in environments characterized by high temperatures and dust exposure. Economically, the project shows strong financial viability, with an estimated payback period of 3.4 years. Environmentally, the system is projected to mitigate approximately 109 tons of CO₂ emissions per year, supporting national and global climate targets. Overall, the results of this study not only confirm the feasibility of hybrid rooftop-floating PV systems in Iran but also demonstrate their superiority over conventional stand-alone rooftop arrays in hot and dusty climates. These insights can guide policymakers, investors, and technical planners in adopting more efficient solar deployment strategies, and highlight the need for continued innovation in floating PV design, degradation mitigation, and maintenance optimization to further enhance system reliability and long-term performance.

CRedit authorship contribution statement

Soroush Ghasemi: Writing – original draft, Visualization, Software, Investigation, Formal analysis. **Iman Sadeghkhani:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Mohammad Parhamfar:** Resources, Formal analysis.

Declaration of competing interest

There is no conflict of interest for this article.

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