Future Sustainability
Open Access Journal
ISSN 2995-0473

February 2025| Volume 03 | Issue 01 | Pages 49-58

Journal homepage: https://fupubco.com/fusus

https://doi.org/10.55670/fpll.fusus.3.1.5

Future Publishing LLC

Article

Evaluating the economic impact of solar energy on local industries in Semnan, Iran

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ARTICLE INFO

Article history:
Received 20 December 2024
Received in revised form
23 January 2025
Accepted 31 January 2025

Keywords:
Energy economics, Energy policy,
Solar power, Renewable energy,
Economic feasibility, Environmental impact

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DOI: 10.55670/fpll.fusus.3.1.5

ABSTRACT

This study provides a comprehensive technical, economic, and environmental analysis for the implementation of a 10 MW solar power plant in Semnan Industrial Park. With increasing global energy demand, the transition from fossil fuels to renewable energy sources is essential to mitigate environmental impacts and reduce greenhouse gas emissions. This research highlights innovative developments in photovoltaic systems and energy storage solutions, demonstrating their potential for increased efficiency and reliability. From an economic perspective, the analysis shows that solar energy can achieve competitive energy production costs estimated at around $0.05/kWh, especially in semi-arid and solar resource-rich regions. Furthermore, the study emphasizes the importance of supportive government policies and incentives to facilitate investment in solar technologies. The results show that adopting solar energy solutions not only addresses environmental concerns but also offers significant economic benefits, including a 7-10 year payback period for the proposed power plant. Overall, this research highlights the vital role of solar energy in fostering sustainable industrial development while contributing to climate change mitigation efforts.

1. Introduction

Projections indicate that by 2050, global energy demand will experience an unprecedented increase of 1.5 to 3 times due to rapid population growth, accelerated economic development, and improvements in living standards [1]. The rising consumption of fossil fuels, as the conventional solution for addressing the energy needs driven by urbanization and industrialization, has become one of the most significant global challenges [2]. Currently, fossil fuels account for approximately 85% of the world's energy consumption and are responsible for over 56.6% of global greenhouse gas emissions [3]. The transition to renewable energy is not solely driven by environmental considerations but also by the pursuit of cost-effective electricity production. Efficient solar energy generation depends on factors such as economic conditions, electricity tariffs, taxation policies, supportive regulations, photovoltaic (PV) system efficiency, technological advancements, and solar irradiation [4, 5]. Estimates suggest that converting just 0.1% of the solar energy received by the Earth into electricity at a 10% efficiency rate could generate approximately 3,000 GW of power, nearly four times the world's annual energy consumption [6, 7]. Photovoltaic (PV) systems are broadly classified into grid-connected and off-grid systems. Grid-connected systems supply electricity directly to the grid without requiring battery storage, while off-grid systems deliver energy directly to the load, utilizing batteries as needed [8]. In recent years, solar electricity generation has experienced remarkable growth, with the current global installed capacity exceeding 22 GW peak. Projections suggest that this capacity will grow at an average annual rate of 40% [9]. The energy output of a PV module is significantly influenced by the PV material and the level of solar irradiation it receives [10]. Over time, the efficiency of solar modules decreases due to internal factors such as corrosion and cracking, as well as external environmental factors like dust accumulation. However, regular maintenance, including cleaning, can restore their performance to near-original levels [11, 12]. Semnan Province, located south of the Alborz Mountain range, covers an area of 97,000 square kilometers, making it the sixth-largest province in Iran [13]. Characterized by low rainfall and high temperatures, Semnan is one of the driest and warmest regions in the country. Concentrated Solar Power (CSP) systems, which convert solar energy into heat, enable its use as a source for conventional power plants. By incorporating Thermal Energy Storage (TES), CSP systems ensure a stable energy supply even during periods of reduced solar irradiation [14]. In solar power plants, sunlight is converted into direct current (DC) electricity through solar panels, which is subsequently transformed into alternating current (AC) electricity by inverters for integration into the power grid [15]. These plants operate exclusively on solar energy without reliance on fossil fuels and achieve zero greenhouse gas emissions. Adopting such clean energy solutions is critical in mitigating global warming and advancing environmental sustainability [16]. This paper presents a comprehensive feasibility study of implementing a 10 MW solar power plant in Semnan Industrial Park, considering technical, economic, and environmental aspects. It highlights innovative technologies such as advanced photovoltaic systems and energy storage solutions, which increase efficiency and reliability. Furthermore, it emphasizes the importance of supportive policies and economic incentives to facilitate the transition to renewable energies, ultimately contributing to sustainable industrial development while reducing carbon emissions.

2. Literature review

The technical feasibility of solar power plants has been extensively studied in recent years, particularly focusing on 10 MW installations that cater to industrial applications. These studies highlight the advancements in photovoltaic (PV) and concentrated solar power (CSP) systems and their role in addressing energy challenges globally. One significant area of exploration is the performance of concentrated solar power systems in challenging climates. C. Vennila et al. [17] demonstrated the adaptability of CSP technology to high direct normal irradiance (DNI) regions, particularly in cold and arid conditions. Their study focused on a 10 MW solar thermal power plant, showcasing its efficiency and sustainability, even under extreme climatic variations. The plant achieved a conversion efficiency of 45%, making it a reliable energy source in arid regions. Energy storage integration is another pivotal aspect. G. Castilla et al. [18] provided a techno-economic analysis of high-temperature thermochemical storage systems designed for large-scale solar installations. Their findings underline the importance of these systems in ensuring reliability and scalability, particularly for continuous energy supply during periods of low solar irradiance. The study demonstrated a 25% cost reduction in energy storage per MW compared to conventional methods. Meanwhile, S. Hoseinzadeh and F. Pourfayaz [19] presented a study on Iran's technical and economic feasibility of a grid-connected PV system. They concluded that 10 MW solar power plants using modern PV technologies have technical and economic feasibility, especially in semi-arid areas rich in solar resources. They have also pointed out that selecting the best site and high PV module efficiency is crucial to successfully implementing such projects. Their calculated energy generation cost was \$0.05/kWh, which makes it competitive with fossil fuels. The application of predictive technologies, particularly machine learning, has garnered significant attention in enhancing energy system performance. Liu [20] investigated the use of machine learning algorithms to improve the predictability and operational efficiency of 10 MW solar systems. By leveraging climatic data, these algorithms effectively forecast energy output, addressing the challenges associated with variability. The study reported a prediction accuracy of 93%, demonstrating a substantial improvement in energy management and operational reliability. Floating photovoltaic (FPV) systems have emerged as a promising solution to land-use constraints.

A. Mumtaz et al. [21] evaluated mega-scale FPV plants, showcasing their adaptability across diverse climatic zones. Their research highlights the technical feasibility and environmental benefits of such systems, particularly for projects exceeding 10 MW capacities. They observed a 20% increase in efficiency due to reduced module temperatures. The integration of hydrogen storage systems as auxiliary components for solar power plants has also been explored. Raimondi and Spazzafumo [22] investigated the potential of hydrogen as a reliable medium for long-term energy storage. Their findings highlight its ability to enhance grid reliability, particularly in large-scale solar installations. The hydrogen-based system achieved a storage efficiency of 80%, enabling extended-duration energy dispatch and addressing the intermittent challenges of solar energy. Battery technology advancements have also been pivotal in supporting the technical feasibility of solar power plants. S. Atatreh et al. [23] explored redox flow batteries as a cost-effective alternative to traditional lithium-ion solutions. For capacities exceeding 10 MW, these batteries offer enhanced reliability and long-duration storage, essential for balancing energy supply and demand. The batteries achieved a lifecycle of 10,000 charge-discharge cycles, doubling that of lithium-ion systems. Complementary technologies, like thermal desalination and ocean thermal energy conversion, have been compared with each other by V. Raphael et al. [24]. Their study showed the synergies of these technologies with solar power systems, especially for resource-efficient coastal industrial zones. This resulted in a 15% boost in overall energy efficiency from the integration. Economic considerations are central to the implementation of 10 MW solar power plants. Several studies have analyzed cost structures, financial returns, and overall economic viability in various contexts.

Panahi et al. [25] analyzed the impact of environmental cost internalization on the economic performance of solar power plants. Their findings indicate that while the initial capital expenditure for solar projects is relatively high, incorporating environmental cost savings can enhance their economic appeal. Specifically, the study concluded that internalizing environmental costs can reduce overall lifetime expenses by up to 25%, underscoring the economic advantage of transitioning to solar energy. F. Ahmad et al. [26] conducted research into hybrid solar-assisted systems and their respective economic advantages. They showed that the original integration of technologies lowers the cost while increasing energy efficiency in large-scale installations. In fact, the hybrid system achieved a 20% reduction in operational costs. J. Li et al. [27] assessed the feasibility of integrating hydrogen-fuelled reciprocating engines with PV power plants. The study emphasized the role of hydrogen storage in reducing operational costs and increasing economic sustainability. Their system achieved an energy cost of $0.08/kWh with 60% operational efficiency. Stevenson et al. [28] investigated data-driven optimization strategies for campus battery energy systems, demonstrating the potential of predictive analytics to improve the financial performance of solar energy projects. Their optimized system achieved a 25% reduction in operational costs, showcasing the value of integrating advanced analytical tools into energy management.

G. Raimondi and G. Spazzafumo [22] analyzed the economic implications of renewable hydrogen in energy communities. Their results showed that hydrogen-based systems can improve cost-effectiveness in large-scale solar installations. The hydrogen integration reduced operational costs by 15%. M. Karrabi et al. [29] presented a thermo-economic modeling of solar energy-driven multi-generation systems. The results showed huge savings in cost due to the integrated solution of energies. The model resulted in a 20% improvement in overall cost-effectiveness. Mahmoudi et al. [30] evaluated the return on investment (ROI) and payback periods for solar energy projects in industrial zones. Their research revealed that a 10 MW solar plant could achieve a payback period of 7–10 years, depending on market conditions and the cost of imported photovoltaic components. Importantly, they noted that local production of solar panels could significantly shorten the payback period, making the projects even more attractive to investors. Economic policies and subsidies play a crucial role in determining the financial viability of solar power plants. Islam and Sokhansefat [31] emphasized the importance of government incentives such as subsidies covering 30% of installation costs and low-interest loans for project financing. They further highlighted that net metering policies could reduce energy costs for industrial users by up to 20% annually, providing additional motivation for adopting solar energy solutions. Rahmani and Goli [32] performed a comprehensive cost-benefit analysis of solar power plants, focusing on long-term financial benefits. Their study estimated that a 10 MW solar plant could save up to $1 million over 20 years under optimal maintenance conditions. This significant cost saving demonstrates the strong economic potential of solar power, especially when combined with consistent operational efficiency. Market stability and energy pricing were investigated by Farsad et al. [33], who highlighted the challenges posed by fluctuating energy prices and unstable policy frameworks. Their research suggested that stabilizing renewable energy tariffs could increase investor confidence by 15%, thereby facilitating greater adoption of solar energy technologies. Environmental feasibility is a critical consideration for deploying 10 MW solar power plants, given their potential to reduce greenhouse gas emissions and their minimal ecological footprint compared to traditional energy systems. F. Ahmad et al. [26] discussed the environmental advantages of hybrid solar systems, pointing to the fact that they can further reduce emissions and enhance resource use efficiency. The system resulted in a 25% reduction in water consumption. On the other hand, C. Liu et al. [34] analyzed innovative systems for space solar power stations. They found in terrestrial green energy receiving systems the model that could reduce the environmental footprint. The system showed 40% improved energy efficiency over traditional terrestrial-only systems. F. Dayi et al. [35] reviewed sustainable investments in renewable energy, emphasizing the environmental advantages of integrating solar energy systems into industrial infrastructure. The integration resulted in a 10% reduction in operational energy waste. P. Asadbagi et al. [36, 37] proposed an eco-friendly power plant model integrating solar and hydrogen, offering zero-carbon energy [38] solutions for large-scale applications. The model achieved a 95% reduction in carbon emissions. Tahir et al. [39] employed deep learning techniques to optimize solar PV projects, addressing energy wastage and the environmental degradation typically associated with conventional energy systems. Their approach resulted in a 20% improvement in energy efficiency, demonstrating the potential of advanced computational tools in enhancing the performance and sustainability of solar energy projects. Hajinezhad et al. [40] explored integrating solar power plants with CO_2 capture systems. Their multi-objective optimization revealed that such hybrid systems could significantly reduce carbon emissions while providing reliable energy. The study concluded that solar plants with CO_2 capture technologies [41] achieve up to a 30% reduction in overall emissions compared to standalone solar plants, making them a strong candidate for environmentally sustainable energy systems. Kiehbadroudinezhad and Merabet [42] evaluated the environmental performance of renewable energy-based microgrids, focusing on human health, ecosystem quality, and resource use. The findings highlighted that solar-powered microgrids outperform wind-based systems in minimizing environmental impacts. Specifically, deploying solar microgrids reduced ecosystem degradation by 40%, demonstrating the ecological advantage of integrating solar technology into energy systems. Opoku and Song [43] assessed a hybridized renewable energy system combining solar, lithium battery storage, and solid oxide fuel cells. Their results indicated that such systems not only provide stable power generation but also significantly lower environmental footprints. The study emphasized the importance of integrating solar energy with storage solutions to enhance sustainability, estimating an 18% improvement in energy efficiency and a proportional reduction in environmental impacts.

3. Methodology

The establishment of a solar power plant can have significant positive impacts on air quality in the Semnan Industrial Park. Below are several reasons highlighting these positive effects:

- **Reduction of greenhouse gas emissions**

Solar power plants, as a clean energy source, do not emit greenhouse gases such as carbon dioxide (CO_2) or nitrogen dioxide (NO_2). By replacing fossil fuels with solar energy, the levels of these gases in the atmosphere decrease, which can lead to improved air quality [44]. Figure 1 serves as a visual representation of essential concepts related to the processes of powering an industrial estate by a solar power plant in Semnan, Iran.

- **Reduction in air pollution**

Fossil fuel energy sources are typically associated with releasing particulate matter and other pollutants that harm air quality. Utilizing solar energy can help mitigate this type of pollution, providing cleaner air for residents and workers in the industrial park.

- **Impact on public health**

Improved air quality resulting from reduced pollution can contribute to a decrease in respiratory and cardiovascular diseases. This not only enhances public health but can also reduce healthcare costs and absenteeism from work.

- **Sustainability and sustainable development**

The use of solar energy as a sustainable source can aid in the economic and social development of the region. By creating jobs in the renewable energy sector and reducing energy costs, the Semnan Industrial Park can move towards sustainable development. Overall, the presence of a solar power plant in the Semnan Industrial Park will not only have positive effects on air quality but can also enhance living and working conditions in the area [45].

- **Conservation of water resources**

Solar power plants generally require less water compared to thermal power plants, which need water for cooling. This can alleviate pressure on local water resources and help preserve aquatic ecosystems.

- **Optimal land use**

Solar power plants can be installed on non-arable land or alongside industrial activities without necessitating the destruction of natural environments. This type of land use can contribute to the preservation of agricultural and natural areas. The implementation of a 10-megawatt solar power plant can significantly reduce energy costs in industrial parks for several reasons:

- **Reduction in electricity costs**

Solar power plants, as renewable energy sources, lower electricity production costs. By generating electricity from solar resources, industrial parks can decrease their reliance on the grid and its fluctuating prices. This can result in substantial savings, especially during periods of high electricity prices [46].

- **Cost stability**

Utilizing solar energy helps industrial parks shield themselves from fluctuations in fossil fuel prices. Solar energy costs are generally more stable and predictable, aiding better financial planning [47].

- **Reduction in operational costs**

Solar power plants typically incur lower operational costs compared to fossil fuel plants. After installation, maintenance and repair expenses for these systems are relatively low, and they do not require fuel [48].

- **Utilization of incentives and subsidies**

Many countries and governments offer incentives and subsidies to support renewable energy projects. These incentives can reduce initial investment costs and accelerate return on investment.

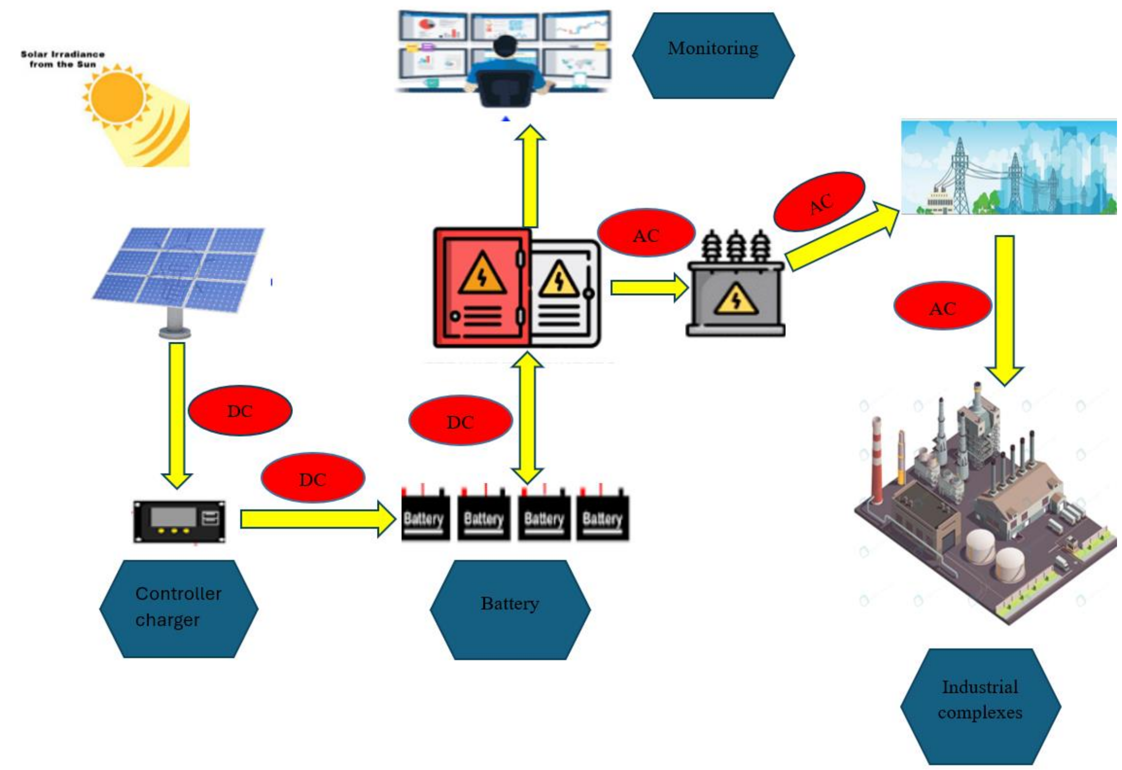


Figure 1. Solar energy supply trend in residential complexes

3.1 Software introduction

In this study, we will utilize RET Screen software for technical, economic, and environmental analysis. This software provides comprehensive tools for evaluating the feasibility of renewable energy projects, allowing for informed decision-making regarding solar power plant implementation in the Semnan Industrial Park. Figure 2 shows a view of the Semnan industrial area, which aims to supply electricity to this industrial zone.

Figure 2. A view of Semnan industrial town

According to Figure 3, Semnan City, with its suitable climate and area, benefits from many sunny days throughout the year due to its geographical conditions. It also has a favorable investment capacity, making it one of the best regions in the country for the development of solar energy. Statistics indicate that Semnan province enjoys sunny weather for about 325 days out of the 365 days a year, translating to approximately 3,000 kilowatt-hours per square meter annually from solar radiation, indicating a suitable capacity for solar energy development. Recent reports highlight that solar power plants in Semnan have seen an increase in capacity. Over 354 solar power plants have been installed, generating a total of 14 megawatts. Additionally, a new solar power project with a capacity of 6 megawatts was inaugurated during the second round of the presidential visit to Semnan province. According to Figure 4, the average hourly direct solar radiation in the region peaks at 758 watts per hour during September between 11 AM and 12 PM. September, August, and June exhibit the highest radiation levels during the hours of 11 AM to 1 PM. Conversely, in December and January, the lowest radiation values occur between 8 AM and 9 AM. Overall, Semnan province demonstrates a strong solar potential, making it suitable for establishing a solar power plant. According to Figure 5, the solar radiation in Semnan city is significant, with estimates of solar radiation in Iran ranging from 1,800 to 2,200 kilowatt-hours per square meter annually. This level is higher than the global average, and the country reports an average of over 280 sunny days yearly. Based on this data, Semnan province stands out as one of the best regions in the country for solar energy production. The development of renewable energies, such as solar energy, is considered a crucial indicator of economic development. However, experts indicate that challenges related to pricing and efficiency hinder the growth and utilization of solar energy in the country. In Semnan province, with approximately 325 sunny days out of 365 annually, there exists a substantial potential for harnessing solar energy. The region's conditions are conducive for solar power generation, making it an ideal location for investment in this sector.

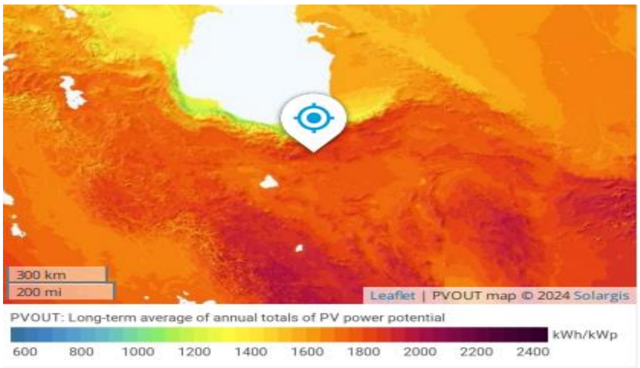
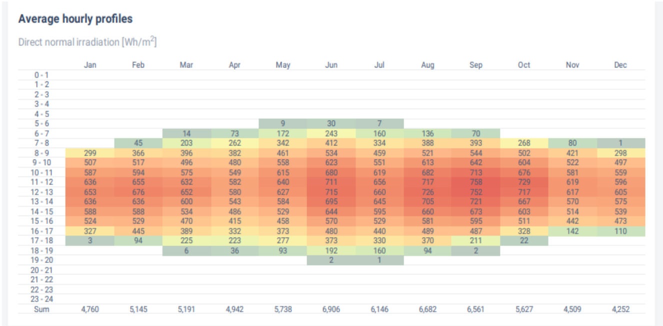


Figure 3. The situation of solar energy in Semnan industrial town



Average hourly profiles

Direct normal irradiation [Wh/m²]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6					9	30	7					
6 - 7			14	73	172	243	160	136	70			
7 - 8		45	203	262	342	412	334	388	393	268	80	1
8 - 9	299	366	396	382	461	534	459	521	544	502	421	298
9 - 10	507	517	496	480	558	623	551	613	642	604	522	497
10 - 11	587	594	575	549	615	680	619	682	713	676	581	559
11 - 12	636	655	632	582	640	711	656	717	758	729	619	596
12 - 13	653	676	652	580	627	715	660	726	752	717	617	605
13 - 14	636	636	600	543	584	695	645	705	721	667	570	575
14 - 15	588	588	534	486	529	644	595	660	673	603	514	539
15 - 16	524	529	470	415	458	570	529	581	595	511	442	473
16 - 17	327	445	389	332	373	480	440	489	487	328	142	110
17 - 18	3	94	225	223	277	373	330	370	211	22		
18 - 19			6	36	93	192	160	94	2			
19 - 20						2	1					
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	4,760	5,145	5,191	4,942	5,738	6,906	6,146	6,682	6,561	5,627	4,509	4,252

Figure 4. Average hourly solar energy in Semnan industrial town

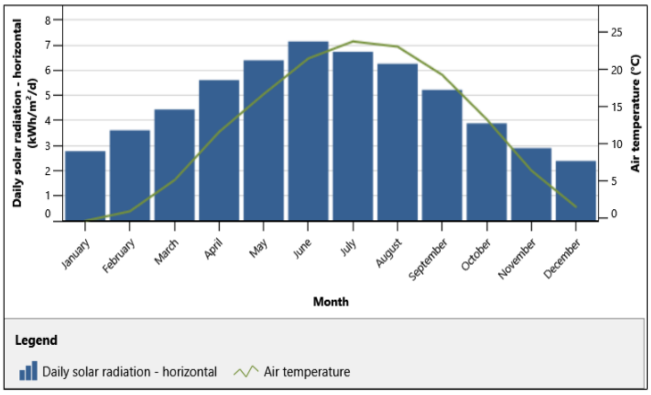


Figure5. Climate data

According to Figure 6, Semnan province experiences approximately 310 to 320 sunny days annually, making it one of the most suitable locations for implementing solar energy projects. The region's climate, characterized by a high number of sunny days, provides an excellent opportunity for harnessing solar energy effectively. The potential for solar energy development in Semnan is significant, as the province benefits from favorable weather conditions that support solar power generation. This unique advantage positions Semnan as a prime candidate for investment in solar energy initiatives, which could contribute to the overall energy needs of the country and promote sustainable development.

According to Figure 7, solar energy has two significant advantages over fossil fuels (coal, oil, and natural gas). First, while fossil fuels can still be utilized despite their limited resources, there is an endless supply of sunlight, which serves as a source of solar energy. The second advantage of solar energy is that it does not produce pollution like burning fossil fuels. However, it is important to note that the equipment required to capture and utilize solar energy can be expensive, and the high costs associated with solar energy have limited its widespread adoption. Despite these challenges, the benefits of solar energy, such as its sustainability and environmental friendliness, make it a compelling alternative to fossil fuels in the pursuit of cleaner energy solutions.

Heating design temperature	3/3-
Cooling design temperature	32/3
Earth temperature amplitude	24/9

Month	Air temperature	Relative humidity	Precipitation	Daily solar - radiation horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	C°	%	mm	kWh/m²/d	kPa	m/s	C°	C-d°	C-d°
January	0/4-	%62/3	25/73	2/78	83/0	2/4	1/8-	570	0
February	0/9	%58/9	24/64	3/61	82/9	2/7	0/3	479	0
March	5/1	%53/9	24/49	4/44	82/9	2/8	5/2	400	0
April	11/6	%47/4	16/20	5/61	83/0	2/7	12/3	192	48
May	16/7	%41/0	10/54	6/40	83/1	2/7	18/3	40	208
June	21/5	%34/7	6/60	7/15	82/9	3/4	23/8	0	345
July	23/8	%35/5	6/82	6/74	82/9	3/8	26/2	0	428
August	23/1	%36/3	8/06	6/26	83/0	3/3	25/3	0	406
September	19/3	%38/2	11/10	5/22	83/2	2/7	20/5	0	279
October	13/3	%46/0	18/91	3/89	83/4	2/4	13/3	146	102
November	6/4	%56/7	24/90	2/90	83/3	2/3	5/4	348	0
December	1/5	%62/0	22/94	2/39	83/2	2/3	0/1-	512	0
Annual	12/0	%47/7	200/93	4/79	83/1	2/8	12/5	2,687	1,816

Figure 6. Weather conditions and factors affecting solar power plants

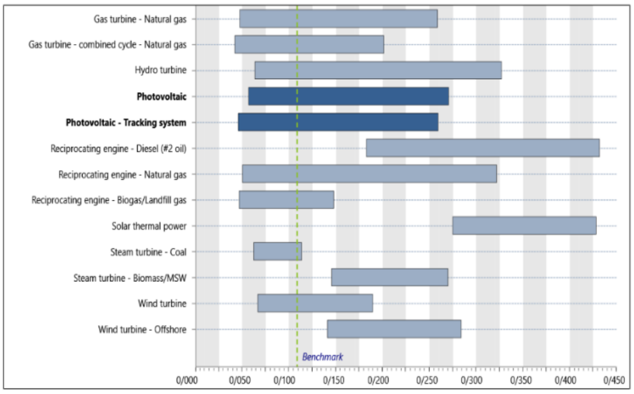


Figure 7. Energy production cost - Central-grid - Range ($/kWh)

4. Results

The data shows significant solar radiation patterns throughout the year, especially during peak months, and demonstrates the economic viability of solar energy investments in the region. In addition, the environmental benefits of switching to solar energy are highlighted, demonstrating its role in reducing greenhouse gas emissions and promoting ecological sustainability.

4.1 Economic analysis

Figure 8 represents the pre-tax cash flow over 20 years for a solar energy project intended to supply power to an industrial zone in Semnan. Here's an analysis of the graph from an energy economics perspective:

The significant negative cash flow in Year 0 indicates a substantial upfront capital investment. This includes costs for purchasing and installing solar panels, inverters, and other equipment, as well as potential grid integration costs and land acquisition. From Year 1, the project generates positive pre-tax cash flows, suggesting that operational revenues from selling electricity or cost savings from avoided grid energy purchases surpass the annual operation and maintenance costs. This phase represents the payback period, where the investment begins to recover costs. The sharp decline in cash flow during Year 13 likely points to significant maintenance or replacement costs, such as replacing aging components like inverters or repairing damaged systems.

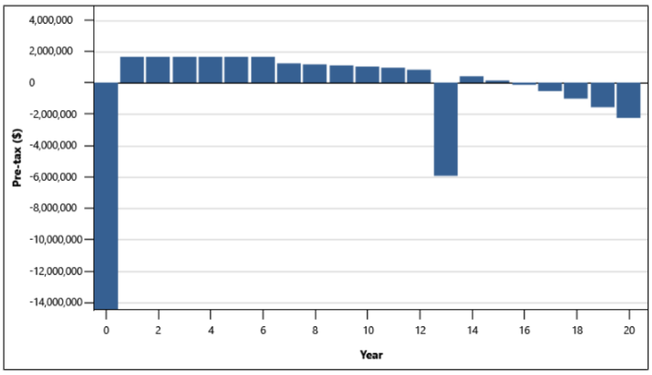


Figure 8. The pre-tax cash flow over 20 years

Figure 9 shows the sensitivity of different parameters to the net present value (NPV) of a project, in terms of economic implications. The relative impact of each parameter is measured in terms of standard deviation, both positive and negative, and the parameters are ordered according to their importance to the NPV. The largest negative impact on the NPV comes from the upfront costs, which strongly suggests that capital-intensive projects significantly reduce profitability. This emphasizes the importance of minimizing upfront costs or obtaining low-interest financing to improve project feasibility. Electricity exported to the grid has a significant positive impact on the NPV. This indicates the economic advantage of using surplus energy in grid-connected systems, as it generates additional revenue streams and offsets the upfront costs. Electricity export rates that are strongly linked to electricity exports (e.g., feed-in tariffs or market electricity prices) also significantly affect the NPV. Higher export rates directly increase economic returns, underscoring the importance of favorable pricing policies or market mechanisms to support renewable energy projects. While less influential than the above parameters, O&M costs still have a negative impact on NPV. This highlights the need for efficient, low-maintenance technologies to reduce long-term costs and improve profitability. The credit rate for avoided carbon emissions (CE) has a small positive impact on NPV, reflecting the economic benefits of carbon credit systems. Expanding carbon markets or increasing credit value could provide further incentives for environmentally friendly investments. Similarly, the credit rate for greenhouse gas reductions contributes only marginally to improving NPV, suggesting that current carbon pricing or incentives have limited economic impact. Strengthening these mechanisms could increase their impact. Overall greenhouse gas reductions have the least impact on NPV, suggesting that the environmental benefits of the project are currently undervalued in financial terms. Policymakers may consider incorporating stronger economic incentives for greenhouse gas reductions to align financial outcomes with environmental goals. Figure 10 highlights the dominant role of upfront costs and electricity export dynamics in determining project viability. From an economic perspective, reducing capital costs through subsidies, tax credits, or technological innovations, along with policies that ensure fair compensation for exported electricity, are crucial to improving NPV. In addition, strengthening carbon pricing mechanisms can increase the financial attractiveness of sustainable projects while achieving environmental goals.

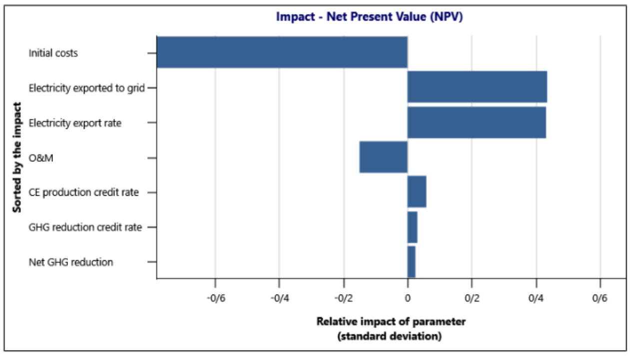


Figure 9. Impact risk solar power plant

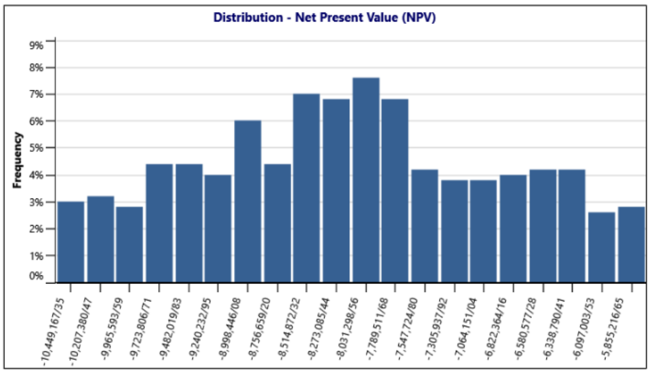


Figure10. Net Present Value (NPV) Frequency Distribution

As shown in Figure 10, the distribution exhibits a negative curve shape, with the highest frequencies concentrated around the mid-range NPV values of approximately -8.31 to -7.10 units. This indicates that most scenarios present moderately negative NPVs. The modal class, corresponding to the highest frequency, lies in the range of approximately -8.21 to -7.89 units. This range accounts for the most likely outcome in the simulation. The left tail is significantly more extended, with NPVs as high as -10.49, reflecting a low probability of extreme negative outcomes. The right tail, while shorter, indicates that there are no positive NPV outcomes in this analysis. The overall negative NPV values indicate that in most scenarios, the investment is not financially viable.

4.2 Environmental analysis

Figure 11 presents a comparison between the Base Case and the Proposed Case in terms of greenhouse gas (GHG) emissions. The vertical axis shows the amount of greenhouse gas emissions (tCO_2), and the horizontal axis compares the two different scenarios. The amount of greenhouse gas emissions, in this case, is close to 4,000 tons of CO_2 per year. This case represents the current situation without any improvements or changes to the system. Given the green color, it seems that approximately a 93% reduction in greenhouse gas emissions has been achieved. This graph effectively shows the importance of adopting greenhouse gas reduction strategies to reduce environmental impacts. Such analyses can be useful for policymakers and researchers to develop carbon reduction policies and promote sustainable technologies.

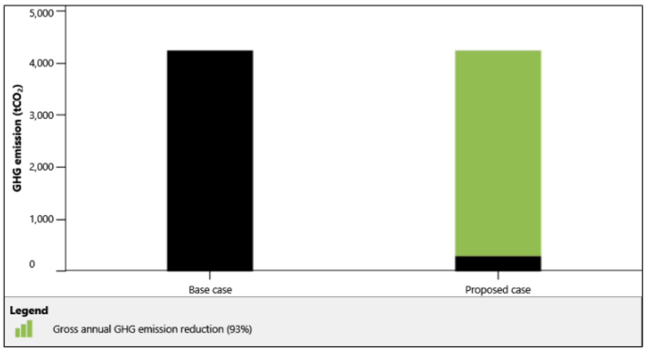
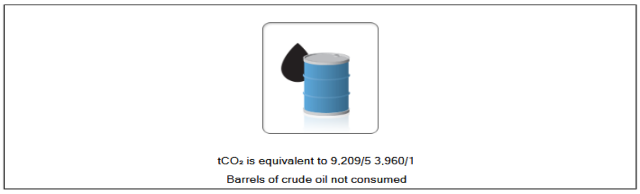


Figure 11.GHG emission solar power plant

Figure 12 shows that at the top of the figure, it is noted that tCO_2 is equivalent to 9.209.5 or 1.3960 barrels of unconsumed crude oil. This equivalence provides a measure for better understanding the reduction in greenhouse gas emissions due to fossil fuel savings. This method is useful for connecting audiences with the concept of carbon reduction and its positive effects in reducing the consumption of natural resources. Annual emissions are equivalent to 4,258.2 tCO_2. This value represents greenhouse gas emissions in the current scenario or without intervention. Annual emissions are equivalent to 298.1 tCO_2. This value represents the number of emissions if an optimal solution or new technology is implemented.: Emission reduction of 3,960.1 tCO_2 represents the difference between the baseline and the proposed scenario. This value has a significant impact on emission reduction and indicates the high potential of the proposed scenario to improve the environmental situation.



GHG emission		
Base case	4,258/2	tCO_2
Proposed case	298/1	tCO_2
Gross annual GHG emission reduction	3,960/1	tCO_2

Figure12. GHG equivalence solar power plant

5. Conclusions

Implementing a 10 MW solar power plant in Semnan Industrial Park is a significant step towards sustainable energy solutions in the region. The study has shown that solar energy is technically feasible and economically viable, with a competitive cost of $0.05/kWh and a payback period of 7-10 years. Integrating advanced photovoltaic technologies and energy storage solutions increases the efficiency and reliability of operations. In addition, the environmental benefits are significant, as the proposed solar power plant operates with zero greenhouse gas emissions and contributes to climate change mitigation efforts. Future studies should investigate the long-term effects of integrating hydrogen storage systems with solar power plants to address intermittent issues and increase grid reliability. In addition, investigating the economic implications of local production of photovoltaic components could further reduce costs and improve project feasibility. Research should also focus on the socio-economic impacts of adopting solar energy in industrial estates and assess how such projects can contribute to local job creation and economic development. Finally, comparative studies on the performance of hybrid renewable energy systems that combine solar energy with other renewable sources can provide valuable insights into optimizing energy production and sustainability under diverse climate conditions.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the authors.

Conflict of interest

The authors declare no potential conflict of interest.

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