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Review

Evaluating the impact of economic policies on solar energy growth in Iran

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ABSTRACT

This paper explores the techno-economic implications of Iranian policy instruments designed to promote large-scale photovoltaic (PV) power plants. As global energy demands rise and environmental concerns intensify, transitioning from conventional fossil fuels to renewable energy sources has become imperative. This study investigates the current state of Iran's electricity market and the effectiveness of its power purchase policies in facilitating PV development. Despite possessing substantial solar energy potential, Iran faces significant challenges, including financial constraints and inconsistent energy policies, which hinder the swift adoption of renewable technologies. The research utilizes a comprehensive approach to assess these barriers and proposes strategic financial solutions to enhance investor confidence and participation in the solar energy sector. Notably, this study contributes to the existing literature by providing a detailed analysis of Iran's unique socio-economic context and its impact on the implementation of renewable energy policy. The findings underscore the necessity for cohesive governmental support and innovative financing mechanisms to unlock Iran's vast solar resources, ultimately paving the way for sustainable energy solutions that align with global carbon neutrality goals.

1. Introduction

As energy consumption has risen, humanity has encountered a progressive decline in fossil fuel reserves in recent years. This has prompted the adoption of alternative and sustainable energy sources, such as wind, water, and solar power. Simultaneously, the escalating human need for energy has resulted in the excessive utilization of fossil fuel resources. Consequently, this has led to environmental degradation and damaging pollution, imposing substantial financial burdens on governments to combat ecological contamination. The depletion of fossil fuel reserves served as the primary impetus for governments to transition towards clean and renewable energy, progressively shifting their focus towards natural sources such as wind and solar power. Undoubtedly, the sun is universally recognized as the primary energy source for humans. Throughout history, humans have harnessed their heat and light for various purposes. Even in modern times, with cutting-edge technology, it is feasible to construct cost-effective solar power plants. Furthermore, it is imperative to ensure energy provision without incurring exorbitant expenses associated with the extraction and utilization of fossil fuels and the emission of detrimental gases. In the sun belt, Iran has significant potential for solar energy generation. Among these, Qazvin is a prominent province in developing and constructing solar power plants. Qazvin's favorable conditions for building a power plant and installing solar panels stem from its geographical location and high elevation, which result in a fall in air temperature at higher altitudes. The efficiency of the panels increases. However, solar radiation may be a contributing factor. In certain regions, the elevated temperature diminishes the panels' effectiveness. The expansion of trade and energy use, emerging from technological growth and changing lifestyles, are the most significant factors in global warming and environmental changes seen and reported by the researchers [1]. New investigations have revealed a higher trend in electricity demand due to industrial improvement in developing nations. This increasing trend proposes that energy consumption in developed nations will be surpassed by use in developing countries due to the enhancement of socio-economic factors [2,3]. Different methods have been developed to harness solar energy, with thermal and photovoltaic systems being the predominant ones. Both options offer several benefits, including providing pure and inexhaustible energy, which is also cost-free. Despite the vast potential, this energy usage is significantly limited [4]. The Iranian economy relies heavily on petroleum due to its abundant fossil fuel sources. The sluggish transition towards renewable energy, a key challenge, can be attributed to governmental policy and Iran's prevailing social conditions. Understanding the role of governmental policy in this transition is crucial for informed decision-making. At this point, acquiring solar energy is difficult without government support and encouragement. The feed-in tariff scheme is the most broadly approved policy instrument to promote PV [5]. The Iranian government has opted for this strategy to enhance the development of renewable energy power facilities. Extensive research has identified the optimal hybrid systems for residential applications [6].

Numerous studies have also examined the impact of government initiatives on the cost and effectiveness of solar energy supply systems and power plants. Notably, a recent study outlined a practical and straightforward method for effectively controlling the ideal scale of renewable energy systems for residential use during the conceptual phase, providing reassurance and confidence in its application [7]. Public policy substantially influences the progress of technologies in the renewable energy industry, mainly through tax incentives, production quotas, and tradable certificates [8]. Several studies have been conducted in developing countries, such as India, to evaluate policy instruments and long-term planning for photovoltaic (PV) development. The most effective instruments include various state policies, such as different Tariff fits [9, 10]. Additionally, similar research has been conducted in the US to identify the most effective policy solution for rapidly developing renewable energy [11]. Due to the different parameters in this article, the approach proposed for this optimization was based on the RET Screen software. In this paper, this policy instrument has been investigated to determine the techno-economic impact of this policy on a large-scale photovoltaic power plant. For a better understanding, the market and situation of the electricity market in Iran have been analyzed [12]. Despite the significant potential of renewable energy sources, Iran continues to rely on fossil fuel resources to meet its energy needs. The country has faced significant financial difficulties and has generated substantial greenhouse gas emissions [13-14]. Moreover, the nation has faced numerous challenges in establishing alternative renewable energy sources and formulating consistent energy policies in recent years. To examine the source of these barriers, this study initially provides a comprehensive analysis of previous energy policy initiatives in Iran. It demonstrates that sufficient commitment to long-term energy planning may have significantly mitigated these challenges. Nevertheless, past studies have shortcomings in applying individual planning tools through technical assessment.

2. The Islamic Republic of Iran's electricity context

Despite possessing the world's second-largest oil and gas reserves, Iran uses renewable energy resources in its energy mix. This decision is based on the following justifications:

- To conform to global initiatives aimed at mitigating climate change and reducing the use of fossil fuels.
- The objective is to enhance energy availability in remote and isolated areas of the country by implementing decentralized energy generation.
- To facilitate the management and mitigation of the escalating levels of urban air pollution.
- To increase the energy security of Iran's energy supply through a mix of technologies.

To sustain and guarantee the current amount of non-renewable energy exports, as of 2008, approximately 84.5% of Iran's electricity was generated by thermal power plants that utilized natural gas and heavy fuel oil as their primary fuel sources. These power plants had a combined capacity of around 53 GW. During the UN Climate Change Conference in Paris, Iran committed to reducing its greenhouse gas (GHG) emissions by twelve percent by 2030. Iran has experienced a recent upswing in its economic growth, expanding by 3% in 2015. Growth is forecast to increase to 5.8% and 6.7%, respectively, in 2016 and 2017. The share of different sources of an electric power plant and their situation should be specified to investigate the energy policy. In the next part, the electricity generation in Iran is briefly discussed [15-17].

3. Electricity generation in Iran

Electricity in Iran is generated by a combination of state-owned power plants, such as those managed by TAVANIR and affiliated Regional Electric companies, hydroelectric power plants under the control of the Deputy of Water and Sewage of the Ministry of Energy (Moe), privately-owned power plants, and the nuclear power plant managed by the Atomic Energy Organization. Privatization began with the implementation of Energy Conversion Agreements (ECAs). It progressed through the establishment of Build-Operate-Transfer (BOT) and Build Own Operate (BOO) projects in collaboration with private investors [18]. In 2013, TAVANIR conducted a competitive bidding process and sold a portion of its power plants, resulting in a 41% rise in the electricity generated from remote locations compared to the total installed capacity. This information is supported by the studies conducted by Zandi et al. [5], Aryanpur et al. [19], and Tabasi et al. [20]. Within every Regional Electric business exists a department known as the "Deputy of Power Transmission" or "Deputy for Operation." This department is responsible for maintaining, operating, and enhancing transmission lines and substations. Because TAVANIR owns and manages all 16 Regional Electric firms, the transmission industry is still regarded as a regulated monopoly [21].

Why a large-scale PV power plant in Iran?

In 2012, Iran initiated its feed-in tariff scheme to promote the creation of renewable energy. However, according to Bloomberg New Energy Finance, by the end of 2015, the country had only installed 35 MW of solar photovoltaic (PV) and 195 MW of wind energy. In collaboration with the Renewable Energy Organization of

Iran (SATBA), the government has recently introduced guaranteed twenty-year power purchase contracts. These contracts provide developers with a fixed and appealing price for electricity generated from renewable sources [22]. The study "Enabling PV Iran," commissioned by the German government and conducted by the German Solar Industry Association, emphasizes Iran's favorable solar irradiation and significant electricity demand as essential factors indicating the considerable growth potential of Iran's solar energy sector. This is despite Iran's abundant reserves of hydrocarbons [23]. The survey stated that Iran has the potential to be one of the most suitable areas for solar energy. The country benefits from three hundred sunny days annually, covering two-thirds of its area. Given these circumstances, the paper proposes that photovoltaic electricity generation (solar power) in Iran has the potential to increase by double compared to certain established European nations [24, 25]. At the beginning of 2016, the Iranian Ministry of Energy announced its intention to authorize contracts for 1 GW of wind and solar energy projects. A key feature of this initiative is the feed-in tariff program, which offers substantial benefits to projects incorporating domestic content. These projects can potentially enjoy a tariff rise of up to 30% under the FIT program, a significant boost. Notably, the advantageous tax rates associated with this program will remain in effect until 21 March 2017, providing a clear timeline for stakeholders to plan their investments [26]. The PPA proposed under this FIT regime will be a 20-year agreement supported by a Government Agreement to secure the PPA payment regime. The PPA further reduces the Tariffs for all power plants under this FIT regime by 30% after the first ten years until the conclusion of the contract. The Tariff is also linked to fluctuations in the Euro exchange rate against the Rails in Table 1. FFT of the solar PV plant is presented [27].

Table 1. FiT of solar PV plant in Iran

Technology	Capacity	Price (IRR per kWh)
Solar PV	>30 MW	3200
	10 MW<and ≤30 MW	4000
	100 kW<and ≤10 MW	4900
	20 kW<and ≤10 kW	7000
	≤20 kW	8000

4. Iranian sanctions

Iran has faced international sanctions for an extended period. In 2014, certain restrictions on trade, known as sanctions, imposed by the European Union (EU) were partially repealed. These sanctions, specified in Regulation 42/2014, targeted specific sectors such as petrochemicals. The US secondary sanctions were suspended as part of the Joint Comprehensive Plan of Action, which was agreed to by Iran, China, France, Russia, the UK, the USA, and Germany on 14 July 2015. Additional relaxation of sanctions would be provided once the International Atomic Energy Agency (IAEA), a trusted international body, confirms that Iran has fulfilled its obligations regarding nuclear activities. In January 2016, following a thorough secondary examination, the IAEA declared that Iran had fulfilled its nuclear-related obligations, and the EU and US had officially lifted sanctions [3]. EU sanctions have, since the announcement, been mostly lifted, including the following:

- The unrestricted movement of funds
- The restoration of SWIFT services in Iran
- The majority of individuals and organizations on the list were removed, but a few well-known names remain
- The restrictions on most forms of commerce were withdrawn

The US secondary sanctions were suspended, which included:

- The US would no longer seek to penalize non-US persons and entities who enter business in specific sectors in Iran (e.g., oil and gas, automotive, etc.)
- The US still seeks to prohibit non-US persons and entities from entering into business with persons and entities who remain on the SDN List (terrorism, human rights abuse, WMD, IRGC)

The critical remaining sanctions are that the US primary sanctions remain in place, which implies:

- Persons and entities subject to US jurisdiction will continue to be prohibited from entering into Iran-related transactions

In principle, this would include non-US subsidiaries owned or controlled by US persons or entities. Following the lifting of EU and US Secondary sanctions, business with Iran for EU companies has been largely normalized as of January 2016. However, practical difficulties continue to be encountered in Iran, primarily due to the ongoing reluctance of international banks to re-enter the Iranian market [28]. However, under growing pressure from business, some banks are actively working on returning to the Iranian market. Recent announcements from the Japanese, Italian, and Chinese governments have committed them to supporting business finance in Iran.

5. FIPPA and foreign investment protections and incentives

Iran has been trying to attract Foreign Direct Investment into the country since the implementation of Sanctions with some success. Since the lifting of Primary Sanctions, some of the legislation passed has opened the way for Foreign Investment with protections, most notably the FIPPA Legislation, Iran's Foreign Investment Promotion and Protection Act. The Investment Organization administers the Act to the Foreign Investment Council. Each company seeking its protections must apply for the incentives, and it receives such protections through a Permit being issued to the company.

Wishing to Invest in Iran: The following guarantees and protections are afforded to companies who make use of the FIPPA incentives:

- Foreign capital is at risk of being nationalized and dispossessed. In such situations, the foreign investor will be allowed to obtain coverage.
- If laws or authorities decide to prohibit or temporarily halt authorized financial transactions under this Act, the authority will assume responsibility for and compensate for any resulting damages.

- The purchase of assets and producer services in international investment is facilitated when a state-run entity is the sole client or provider of products or producer services at a subsidized price.

FIPPA further provides the following rights to companies:

- International investments subject to this Act shall use the same protections and tools as possible for national assets in a non-discriminatory way.
- The exterior investment and its interests may be given in foreign money or assets.
- Approval of international investments in all the product, manufacturing, farming, transport, information, and services areas, as well as in fields linked to water and energy.
- The reference to investment-related discussions in international courts.
- The possibility of land purchase in joint ventures in the company's name (registered in Iran).
- Issuance of permits for three years in Iran for foreign investors, directors, specialists, and their direct families, and the chance of visa renewals.
- The investors are informed of the last settlement of their applications within 45 days.
- Having an opportunity to pick the investment process and method.
- Approval of expenditures by any actual or legal non-Iranian or Iranian person using the capital of a foreign source and investing the equipment envisaged in FIPPA to them.

The international investor needs to choose an audit institute from the audit institutes approved by the Iranian authority. In this article, new strategies are reviewed according to the feed-in tariff policy, which encourages the application of large-scale photovoltaic power plants in the power sector. These policies have not been studied in earlier articles. The economic factors, such as the IRR of the assets, the simple, and the equity payback, are analyzed together for assessment. In this article, a 30 MW PV power plant is investigated. The project site is about 220 kilometers from the Iranian Capital, Tehran, the country's largest electricity user. The other project site is about 55-hectare land at 35th km of the Tehran-Qom old road after IKIA. Both sites have been simulated in PVsyst software, and the economic parameters have been analyzed in Ret Screen software. All the results are presented.

6. Site condition

In this article, we will examine Qazvin province regarding solar energy potential. In terms of days of radiation, this province has 280 days of radiation throughout the year, which means it has a capacity of 1800 to 1900 kilowatt hours of solar energy radiation. In this sense, it is one of the best areas to use and benefit from the sun's energy to produce electricity. The best place to construct solar power plants in Qazvin is the plain land. Although all regions of the province are prone to the construction of this type of power plant, in terms of cost, the installation of structures and panels will naturally be expensive in mountainous areas such as Alamut, Lower Tarem, and Auj. At the same time, Qazvin is prone to using renewable energies, including solar and wind power, in two ways: the location of parts of the province, including Siahposh and Kahek, on the way to the wind tunnel, as well as the benefit of all its areas in terms of water purity. The weather and being above sea level for installing solar panels have made the province a special place in this field. However, for the construction of wind power plants, particular windy areas are considered, to the extent that in Qazvin, only limited areas such as Siahposh and Kohek are suitable for doing this work, or for the construction of scattered production power plants, areas that benefit from gas should be considered. Naturally, these power plants cannot be built in any region. However, in the solar power plant section, it must be said that all parts of this province are prone to benefit from this issue, and installing and operating them anywhere is possible. He installed solar panels in it. The electricity generated from solar power plants can be installed in transmission lines all over the province. This problem also increases the efficiency of electricity, and at the same time, they can be installed at low power, such as 5 or 10 kilowatts. The annual average temperature at the site is a low 14.1°C with maximum monthly summer temperatures of between 32°C and 36°C and average monthly minimum temperatures in Winter of below 10°C (Figure 1).

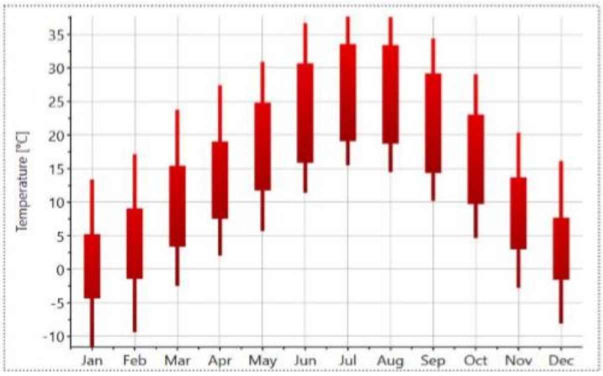

Figure 1. Average annual temperature

7. Modelling

The priest software is widely used and continues to be developed at the University of Geneva, Switzerland. This software designs and simulates solar power plants connected to the grid, off-grid, solar pump, and DC microgrid at kilowatt and megawatt levels. Overall, this software is a robust and comprehensive program with many features.

7.1 Design of grid systems (Grid Connect) in PVsyst software

With the help of this section, you can design and simulate all types of power plants connected to the grid on different scales. In Iran, systems connected to the grid have only one use: transmitting and injecting all electricity produced by solar panels. Meanwhile, in European countries, electricity can be fed into the grid simultaneously, and the energy created from the panels can be used to supply electricity to domestic consumers. PV System software is a well-known and leading software in the world. There are no actual high wind speeds in the region. However, the wind does blow consistently year-round, ranging between 1.0 m/s to 2.0 m/s all year round. The level of direct sunlight is low from November to March, where we see only 5–6 hours of direct sunlight. In contrast, 9 – 11 hours of direct sunshine are experienced in summer. Figure 2 reflects the annual average hours of daylight the project site receives.

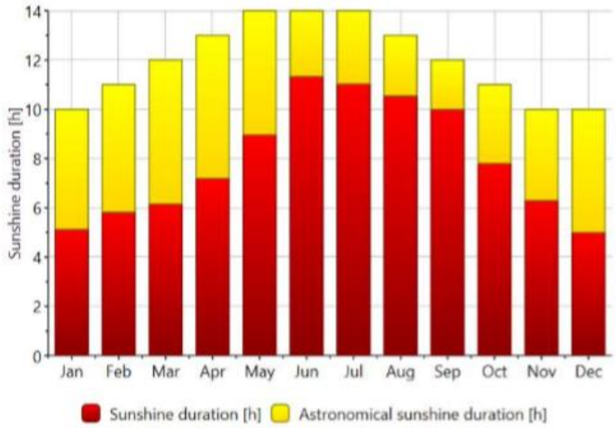

Figure 2. Hours of daylight

The observed irradiation in Qazvin is relatively low in Winter but very high in summer, with the annual average Global Horizontal Irradiation [kWh/m²] of the area at a moderate 1852 kWh/m². According to Table 2, from the point of view of solar energy production in 1852 KW hours per square meter, the highest amount is in July and June, which has the best efficiency and the most increased production, which is 225- and 227-KW hours per square meter, respectively, and the lowest The value is for January, which is equal to 79 KW hours per square meter. The characteristics of PV modules are presented in Table 3. It is a mono-silicon panel from the Canadian Solar company. According to Table 3, the efficiency of this panel is 20.5 to 21.5%.

This panel type is PERC, its dimensions are 182 x 182 mm, and its power tolerance is 10 watts. Monocrystalline solar panels are made of a single crystal structure, usually silicon, which allows for higher efficiency and better low-light performance than other solar panels. This makes them popular for residential, commercial, and industrial solar installations. The design of this panel utilizes advanced solar cell technology and PERC (Passively Emitted Rear Cell) technology, which helps improve light absorption and energy conversion.

The characteristics of the inverter are presented in Table 4. To design the inverter for this power plant, we tried to use the best inverter available in the market, which is also economical. This inverter has characteristics that distinguish it from other inverters: its standard PV power is equal to 78 kW, and the maximum panel power supports up to 113 kW.

8. Results and discussion

An actual annual normalized production (per installed kWp) pattern for a 30 MW PV power plant in Qazvin is shown in Figure 3. Figure 4 is the result of PVSYST software. Qazvin is one of the Iranian states with great solar potential, and there is a plan to install a 200 MW renewable energy power plant, mostly PV and wind. The production of a 30 MW PV power plant in Qazvin and its main results are shown in Table 5.

As shown in Table 5, the annual production of the PV plant is about 53497 MWh. Utilizing Table 1 data, economic calculations can be made. In this regard, we used RetScreen software. The results of the financial analysis are shown in Table 6.

Table 2. Monthly solar resource data

Month	Gh (kWh/m2)	Dh (kWh/m2)	Bn (kWh/m2)	Ta °C	Td °C	FF m/s
Jan	79	34	110	-1	-5.4	0.9
Feb	103	37	131	3.6	-4.3	1.6
Mar	149	58	161	9.1	-2.9	1.9
Apr	171	59	175	13.4	3	1.8
May	207	70	202	18.3	5.7	1.6
Jun	227	68	230	23.8	7.5	1.9
Jul	225	72	221	26.4	9.6	1.9
Aug	215	61	230	26	8.2	1.7
Sep	176	45	214	21.9	6.1	1.6
Oct	133	47	157	16	3.5	1.3
Nov	94	31	145	8	-0.2	1.1
Dec	74	31	107	2.8	-2.9	1.2
Year Total	1852	613	2083	14.1	2.3	1.5

Table 3. The characteristics of PV modules

Nom Power	305
Voc	45.2
Isc	8.84
Vmpp	36.6

Table 4. The characteristics of the inverter

Minimum MPP Voltage	460
Maximum MPP Voltage	820
Frequency	50/60
Nominal PV Power	78 kW
Maximum PV Power	113 kW
Maximum PV Current	255 A

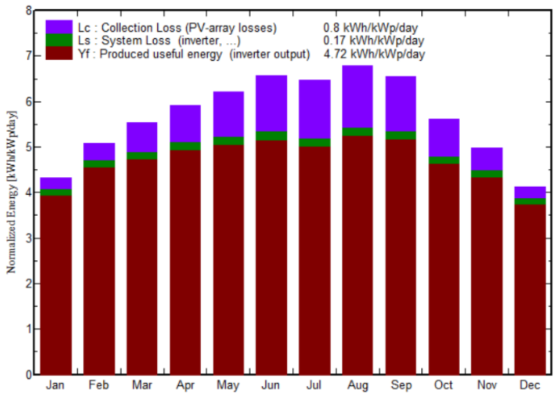

Figure 3. The normalized production (per installed kWp)

The 23 million$ is the initial cost for this project. 23000$ is considered for operation and maintenance costs. The financial viability is presented in Table 6, which demonstrates the application of economic calculations using the software. The cumulative cash flow graph in the mentioned situation is shown in Table 7. Metrics are used to measure the rate of ROI and allow an investor to evaluate and compare investment performance. This rate measures a company's profitability; the higher the pace of the index, the better the company can utilize its capital, and profitability is improved. According to the mentioned conditions, the loan capital return period will be short, and the IRR for the overall project will be approximately 34.8 percent.

Figure 5 illustrates the development of large-scale PV power plants across Iranian states. Most of the power plants installed after 2016 demonstrate the impact of sanctions on the development of renewable energy in Iran. Five provinces, Yazd, Hamedan, Kerman, and Fars, hold the largest share. In 2017, the new fees in the tariff system applied to investors' interest in PV power plans increased.

Table 6. Financial parameters

Inflation rate	%	15.0%
Project life	yr	25
Debt ratio	%	70%
Debt interest rate	%	4.00%
Debt term	yr	10

Table7. The financial viability of a 30MW PV power plant

Pre-tax IRR - equity	%	34.8
Pre-tax IRR - assets	%	20.5
Simple payback	yr	10.6
Equity payback	yr	5
Pre-tax IRR - equity	yr	10

Table 5. Balances and main results for 30 MW PV, Qazvin

	GlobHor	T Amb	GlobeInc(kWh /m2)	GlobeEff(kWh/ m2)	Earray (MWh)	E_Grid(MWh)	EffArrR %	EffSysR %
Jan	83.1	0.03	134.3	131.4	3809	3670	15.02	14.47
Feb	99.6	3.38	142.5	139	3964	3828	14.74	14.23
Mar	140.9	9.14	171.6	166.9	4565	4405	14.09	13.6
Apr	169.1	13.11	177.6	171.2	4613	4452	13.76	13.28
May	205.3	18.27	192.4	185	4879	4711	13.44	12.97
Jun	221.4	23.33	197	189.2	4879	4651	12.95	15.51
Jul	220.2	26.41	200.6	192.6	4815	4675	12.79	12.35
Aug	207.8	25.91	210.5	203.4	4840	4884	12.71	12.29
Sep	168.9	21.47	196.7	191	5051	4667	13	12.57
Oct	126.6	16	173.9	169.8	4826	4312	13.6	13.14
Nov	91.9	7.86	149.3	146.2	40534464	3915	14.39	13.89
Dec	74.3	2.71	127.7	124.7	3619	3493	15.02	14.49
Year	1809.1	14.03	2074.2	2010.3	53497	51663	13.67	13.2

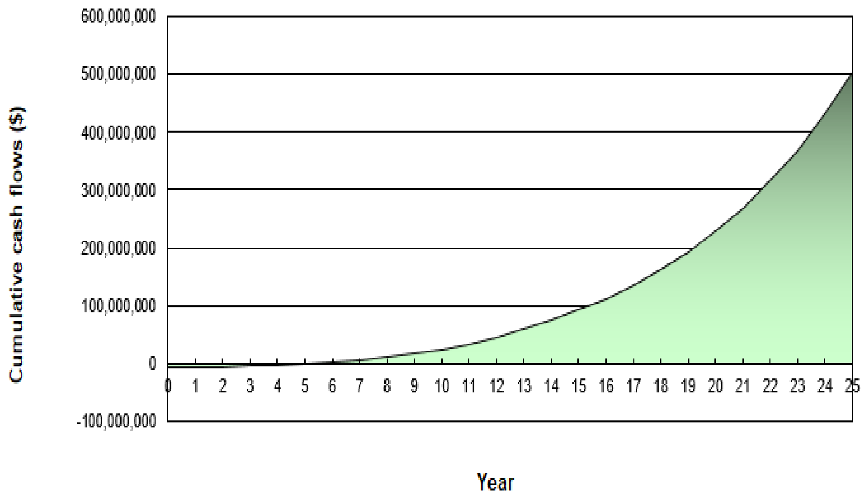

Figure 4. Results obtained by RETScreen software for cash flow

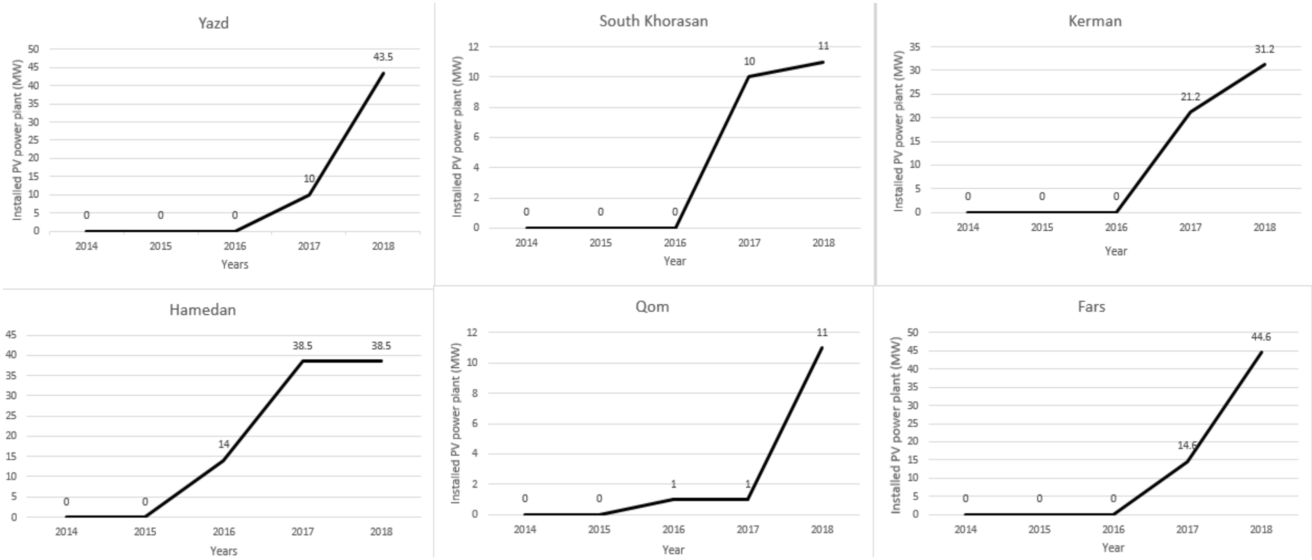

Figure 5. PV power plant development by the States in Iran

9. Conclusions

The PV power plant project has been sized at 30 MWdc to benefit from the favorable tariff for such a project size. We have further assumed an annual escalation of 6% each year based on the combined Euro to Rial exchange and CPI indexation. The PPA also provides a 30% reduction in the valid PPA tariff applicable from Year 11 to 20. The results show that, although from a technical point of view, Iran has excellent potential for a PV power plant, financial problems do not allow investors to enter the market quickly. The currency exchange rate has recently become the main problem; new sanctions pose a higher risk to foreign investors. It seems a new policy instrument requires a bank guarantee and different insurance policy instruments to encourage more investors. The decrease in the costs of photovoltaic modules will help the authority to implement further investment impulses in this field as electricity costs increase and address the fundamental values in Iran.

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 corresponding author.

Conflict of interest

The authors declare no potential conflict of interest.

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