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Analysis of stakeholder roles and the challenges of solar energy utilization in Iran

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Abstract

Growing energy demand, rising greenhouse gas emissions and the depletion of fossil fuels necessitates the development of renewable energy sources. In order to improve renewable energy utilization, it is necessary to determine the most important factors influencing energy strategy. The energy system of Iran is highly dependent on fossil fuels; however, Iran has a high potential for solar energy development and several policies are being pursued by the government to develop power generation by renewable energy resources. This study presents and discusses several important parameters of energy policy and security which make the installation of photovoltaic (PV) systems crucial for the future. Installation of solar PV will improve energy security, foster job creation and reduce environmental problems. It also introduces and investigates those institutions and organizations involved in developing renewable energies, especially solar energy. These include the Ministry of Energy and universities, both of which play key roles in the development of solar energy.

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1 INTRODUCTION

Energy is one of the most essential factors in sustainable development and industrial activity. Most conventional approaches to energy generation, as well as the majority of transformation technologies, have a damaging impact on the environment [1]. Recent years have seen a marked growth in primary energy consumption. Several studies have been carried out on the effect of gross domestic product (GDP) growth on energy consumption [2], which show that an increase in GDP leads to higher energy demand. Figure 1 shows the trend of primary energy consumption over the last three decades, which is attributed to factors such as the development of industrial activity, population growth and higher demand for transportation. The average annual growth of global primary energy consumption was ~6.67%.

In recent years, renewable energy development has become more appealing to policymakers [4, 5] due to concerns over both the air pollution created by the burning of fossil fuels and the rapid depletion of these fuels [6, 7]. The number of renewable energy power plants is growing significantly as a result of falling costs and evolving technologies.

The accessibility of solar energy in particular has made it one of the most attractive sources of renewable energy. Solar energy is one of the cleanest energy sources in existence and its development mitigates global warming and greenhouse gas emissions [8]. Solar energy can be harnessed for both small-scale, such as residential power generation, and large-scale consumption, such as in power plants [9]. Solar energy can be used by extracting its thermal content [10] or by using PV cells for direct electricity generation. Supportive energy policies in various countries in recent years, along with the falling cost of technologies, have accelerated the development of solar energy [11]. As shown in Figure 2, solar PV capacity has risen significantly in recent years, and this trend looks set to continue in future.

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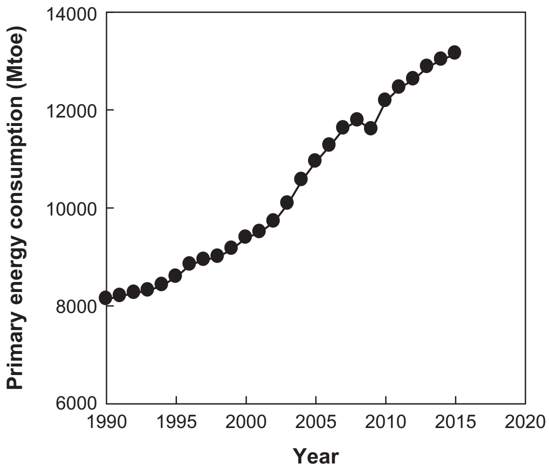

Figure 1. *Global primary energy consumption, 1990–2015 [3].*

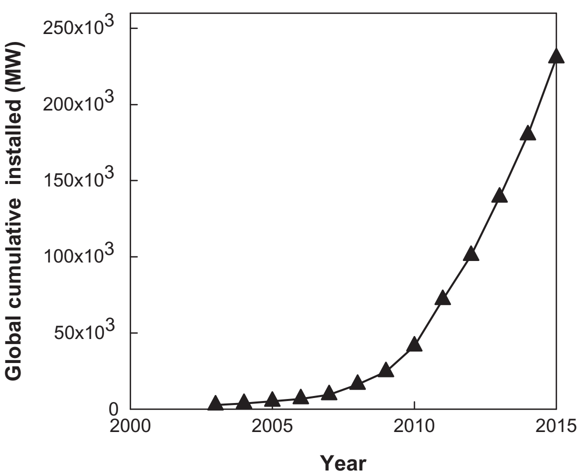

Figure 2. *Global cumulative installed PV capacity [3].*

According to a report from the International Energy Agency (IEA), the global installed capacity of solar PV will exceed 400 GW by 2020 [12].

The approximate latitude and longitude of Iran are 32°00′ N and 53°00′ E [13]. Iran has considerable potential for the development of solar energy technologies due to its geographical location and weather conditions. The average solar irradiance in Iran is 4.5–5.5 kWh/m^2 [14]. The country has initiated a program to increase its renewable capacity to 1000 MW, with particular focus on solar and wind power. The falling cost of photovoltaic (PV) modules has led to cheaper electricity generation and made them a more attractive prospect. Figure 3 shows the trend in PV module prices in recent and coming years [12].

In addition to changes in structures and technologies, the implementation of new energy sources has a number of social, economic and environmental effects [15, 16]. The economic impact of the use of solar energy has been discussed in several studies [17].

This study first outlines the need for new solar power plants and the advantages of developing PV solar power generation in Iran. It then goes on to discuss the advantages of an expansion of PV systems for energy security, job creation, the environment and other challenges for the future. Patents, academic publications and web searches relating to PV technology are used as three indicators of improvement and to identify the main stakeholders. Comparisons are made with two other Asian countries (China and Japan). In addition, the role of stakeholders and organizations which have a significant impact on the development of solar energy in Iran is discussed.

2 ANALYSIS OF THE ENERGY SYSTEM IN IRAN

Iran is located in the Middle East, with a population of approximately 80.6 million as of 2017. The country's GDP in 2017 was

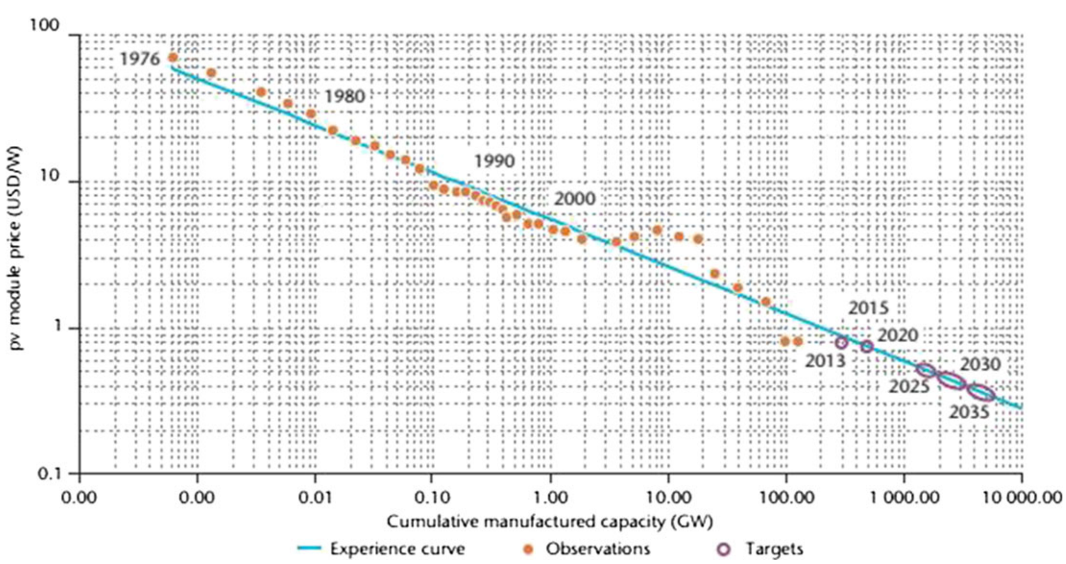

Figure 3. *PV module price change [12].*

439.5 billion USD [18]. The total primary energy supply (TPES) of Iran from 1990 to 2015 is represented in Figure 4. As shown in Figure 4, the total final consumption of energy increased over the 25-year period.

In addition to the rising trend in energy consumption, the total primary energy supply per population in Iran increased from 2.24 toe/capita in 2004 to 2.86 toe/capita in 2013. Iran's CO_2 emissions per capita in 2006 were 6.94 t CO_2/capita, far higher than the global figure (4.49 t CO_2/capita). The country's CO_2 emissions per GDP in 2013 (1.20 kg CO_2/2010 USD) were significantly higher than global standards for the same year (0.26 kg CO_2/2010 USD and 0.45 kg CO_2/2010 USD for OECD countries and the world, respectively). All these statistics show the need for renewable energy development in Iran [19]. The proportion of renewable energies in global energy production is presented in Figure 5. Although the proportion of renewable energies in total energy production is influenced by various factors, such as weather conditions, the fact that they account for 22.8% of global electricity production illustrates the important role they play in power generation.

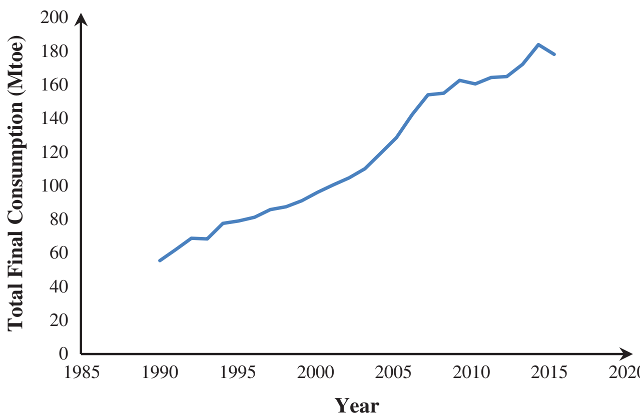

Figure 4. *Total primary energy supply in Iran, 1990–2015 [19].*

Iran generated less than 10% of its electricity from renewable sources in 2015. The main sources for energy production in Iran remain fossil fuels. According to the World Energy Outlook 2017 report, Iran ranks sixth in the world in oil production [20]. Figure 6 illustrates electricity production in Iran over the last three decades. The significant gap between the proportions of conventional and renewable sources in electricity production indicates the extent to which renewable energies such as wind or solar are ignored in Iran.

The favorable geographical situation of Iran, which enjoys approximately 300 days of sunshine per year, places the country in a strong position to exploit solar energy, using either PVs or thermal approaches, to address its energy crisis. There is a sizable body of research on the feasibility of solar energy use in Iran. Alamdari *et al.* have investigated 63 power stations in Iran and concluded that the country has immense potential, recommending a number of regions suitable for the development of solar power [21]. Another study was conducted by Mohammadi *et al.* in three industrial zones in Iran; Chabahar, Kish and Salafchegan. These three regions were considered extremely promising for wind and solar power generation, using either thermal systems or PVs [22]. These investigations highlight both the potential for solar energy use in Iran and the country's failure to realize that potential before now.

2.1 Energy security

Energy security is one of the most critical concerns in energy policy [23]. Energy security has various definitions; however, it is highly dependent on energy import independence [24]. Energy security can be defined as the availability of adequate energy supplies for economic activities and residential and transportation demands at an acceptable price. Figure 7 illustrates the energy flow balance of Iran.

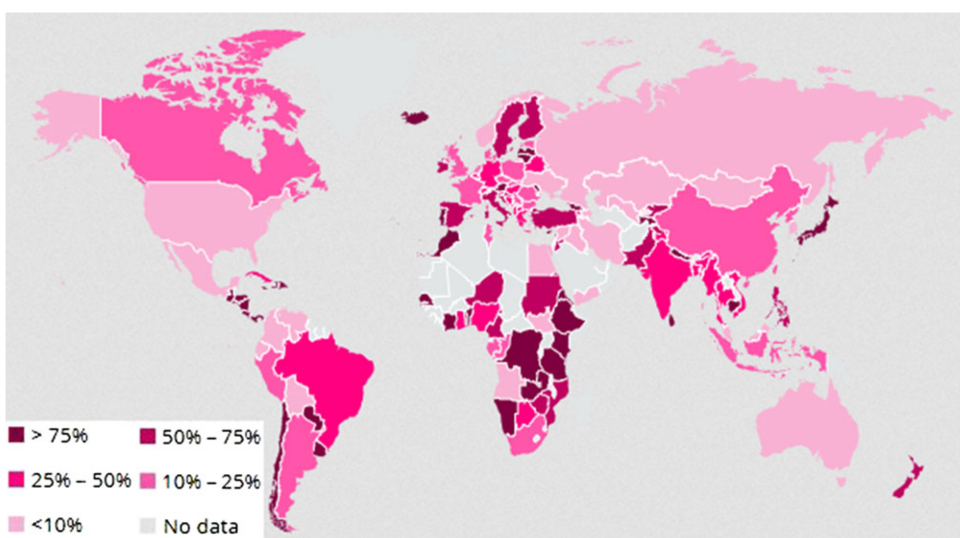

Figure 5. *Proportion of renewable energies in total energy production, 2015 [20].*

High dependency on oil and gas places Iran's energy sector in a precarious position. Aside from the hidden costs of fossil fuels, such as environmental damage, rapid depletion is the fundamental problem. There are a number of possible approaches to improve energy security, including damping consumption, using indigenous energy resources, and ensuring social and political stability. Energy and fuel diversification also improves energy security, and secures the modern economy against price shocks and disruptions to energy supply [24].

Iran's electricity consumption has risen in recent years, as shown in Figure 8.

Diversity of energy sources is a key indicator of energy security. The total electricity consumption of Iran was ~21 2274 GWh in 2014, of which 7.2% was generated from hydropower and other renewable energy sources. Based on some predictions, Iran's electricity demand will reach 37 6114 GWh in 2020 [26]. According to EnergyPLAN software simulations, the installation of PV modules with a total capacity of 5000 MW would add approximately 9500 GWh of capacity. If these power plants were installed, without any other changes in renewable energy infrastructures, renewable energy sources would account for around 6.6% of total power generation by 2020. In order to match the current share of renewable energy in the supply mix, greater renewable capacity will be required.

Another aspect of energy policy is the availability of energy at an acceptable price [27]. Solar energy is developing as a result of falling costs and predictions of an increase in the price of fossil fuels, this in turn due to increased demand and falling supply. The levelized cost of electricity generated by PV modules saw a 50% decrease from 2010 to 2014. The trend of the levelized cost of electricity generated by PV plants in the USA is shown in Figure 9.

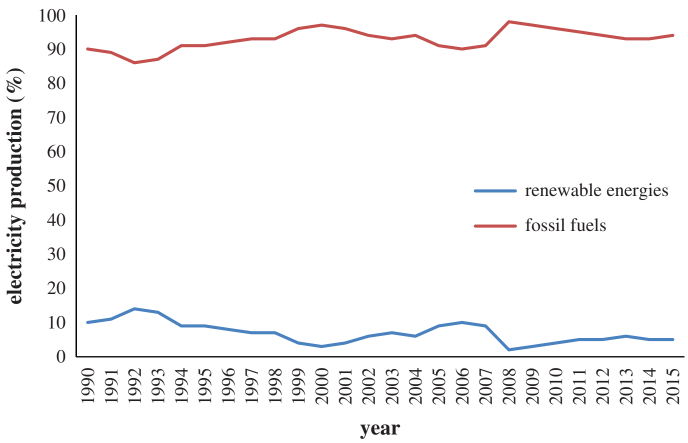

Figure 6. *Share of fossil fuels and renewable energies in Iranian electricity production (%) [19].*

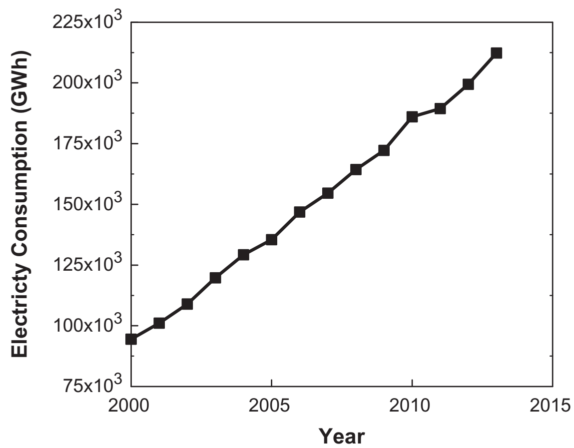

Figure 8. *Electricity consumption in Iran [25].*

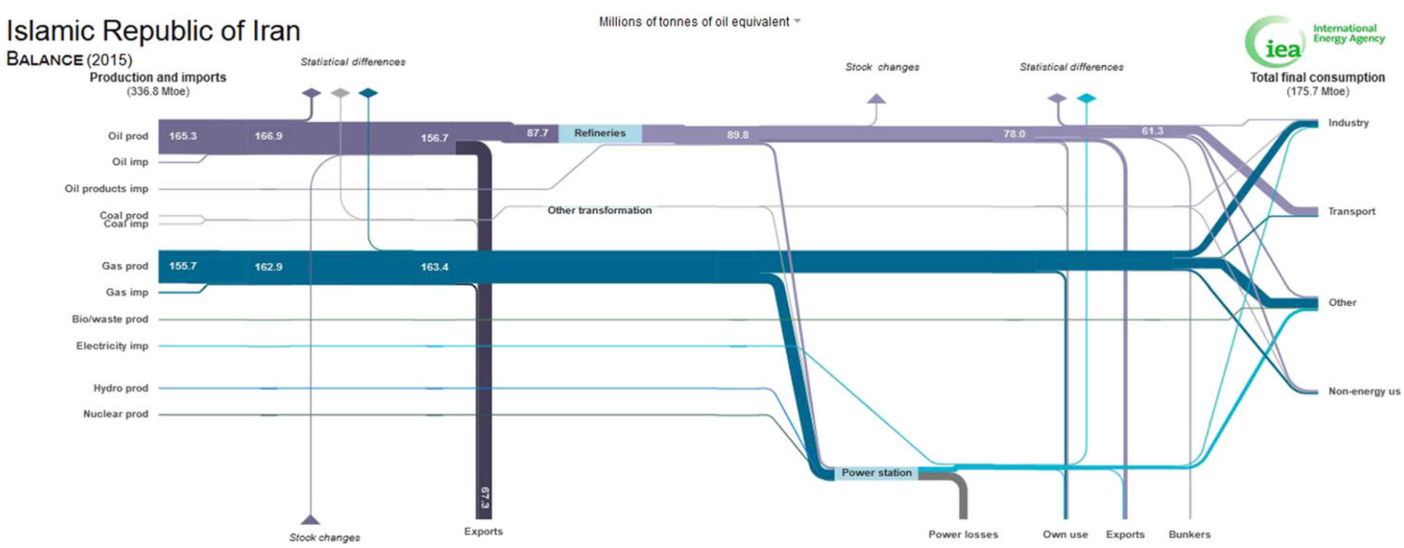

Figure 7. *Energy flow balance of Iran [25].*

The levelized cost of electricity is dependent on the technology applied, the region and a number of other factors; however, Iran is expected to see a similar trend. For instance, the levelized cost of electricity obtained from solar PV will reach approximately 80 USD/MWh in 2020 [28]. Indeed, it would seem that it is already possible to generate electricity from PV cells in Iran with a levelized cost of 80 USD/MWh, due to its high level of solar irradiance.

It can be concluded that using solar PV modules for electricity generation improves energy security by achieving a higher level of diversification and electricity generation at reasonable cost.

2.2 Economy

The Iranian economy is highly dependent on oil exports and the price of oil. Figure 10 shows the relationship between GDP and oil prices in recent years.

By developing renewable energy sources, Iran would be in a position to conserve its oil resources for export, thereby increasing its GDP. The installation of 5000 MW PV power plants would add ~9500 GWh of capacity. Generating this amount of electricity currently requires ~16 million barrels of crude oil, based on Iran's plant efficiency.

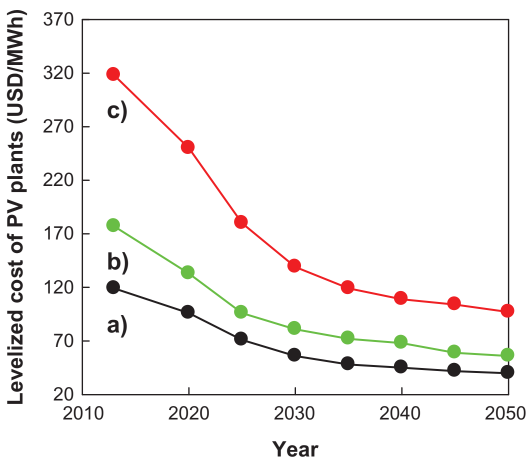

Figure 9. *Levelized cost of newly built utility-scale PV plants in the hiRen scenario, (a) minimum, (b) average, (c) maximum levelized cost [12].*

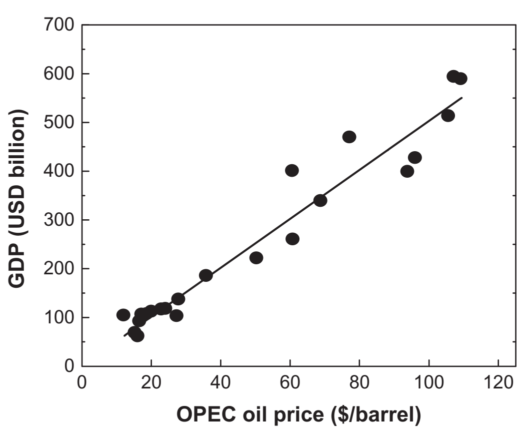

Figure 10. *GDP of Iran and OPEC oil prices [29].*

2.3 The role of distributed generation by renewables in job creation

In addition to improving energy security, renewable energy development would lead to job creation. More jobs will be created if PV plants are constructed in the country. The chain of job creation relating to PV power plants is shown in Figure 11 [30].

Based on the reports of the EPIA (European Photovoltaic Industry Association) [30], PV cell construction would create jobs both directly and indirectly. Direct jobs are those involved in construction, installation and maintenance; indirect jobs include those created in academic institutions, insurance, banking and so on. In 2014, solar PV use led to the creation of ~2.5 million jobs globally, a figure higher than that of other renewable energies [31]. Based on the IRENA2015 report, the installation of 5000 MW solar PV modules would create a large number of jobs in Iran. Table 1 shows the maximum and minimum estimates of jobs created in Iran as a result of the installation of PV modules with a total capacity of 5000 MW.

It can be seen that the installation of 5000 MW solar PV modules has the potential to create up to 55 000 jobs in Iran, in addition to other related benefits. However, the development of solar energy infrastructure requires investment and appropriate policy changes. In addition, experts in the field must be trained, which calls for additional investment in the academic sector.

The main components of a PV system are the PV modules, the inverter, the battery and the support structure [30]. Most PV modules and inverters are imported by Iran; however, batteries and support structures are manufactured domestically. Investment in the manufacturing of PV modules and inverters would also stimulate job creation. In addition to PV manufacturing, PV installation and related services such as insurance, assembly and banking require experts and create job opportunities [30].

Economic incentives such as feed-in tariffs, subsidies and loans must also be taken into account. Greater social awareness is another parameter which would attract people to focus on

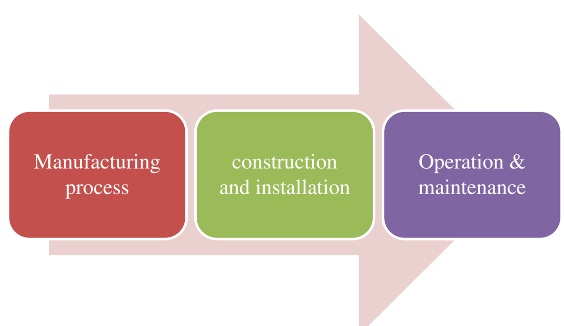

Figure 11. *Chain of job creation [30].*

Table 1. *Average jobs created over life of solar PV facility [32].*

Skill and average career created over life of solar PV facility	Min.	Max.
Manufacturing, construction, installation	5.76	6.21
Operation and maintenance	1.2	4.8
Total per megawatt over life of facility	6.96	11.01
Total based on scenario over life of facility	34 800	55 050

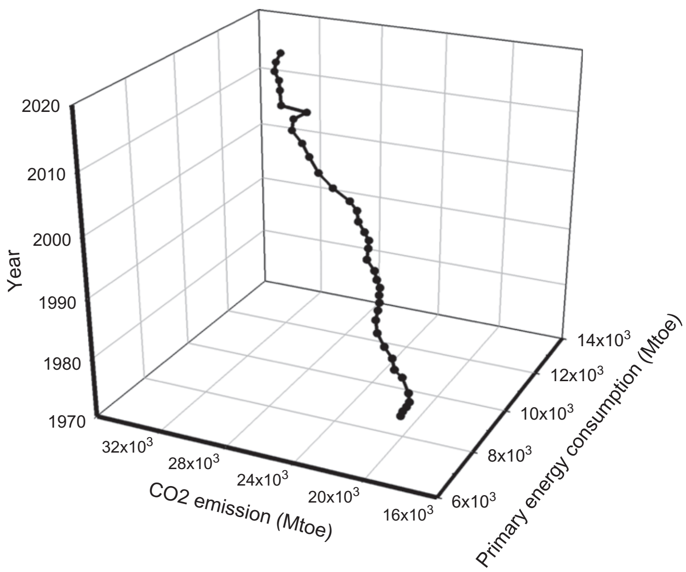

Figure 12. *CO_2 emissions and primary energy consumption [19].*

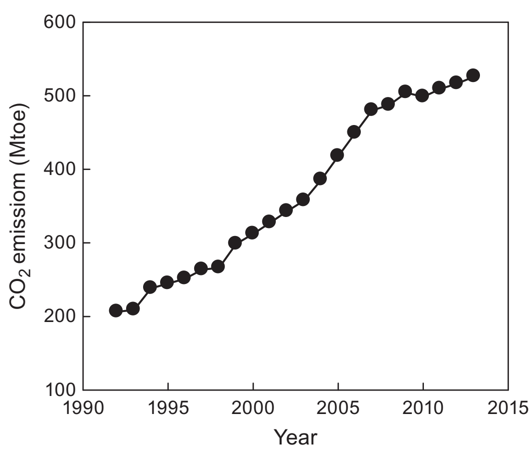

Figure 13. *CO_2 emissions in Iran [19].*

this field and acquire expertise, which would in turn provide the country with more experts in solar energy.

2.4 Environment

Climate change is a crucial subject and one of the most important challenges faced by humanity [27, 33]. The use of fossil fuels is widely considered the main cause of global warming and climate change. Greenhouse gas emissions are growing sharply as a result of industrial activity. Figure 12 shows global primary energy consumption and CO_2 emissions in recent years.

Iran is ranked 10th for CO_2 emissions, producing ~1.65% of total global emissions. Figure 13 shows the country's CO_2 emissions in recent years, which are on the increase. Thermal power plants with low efficiency and a high degree of air pollution contribute significantly to this problem. Improving energy efficiency, using combined heat and power (CHP) plants and appropriate fuels in industries would help to overcome this problem. In addition, the development of renewable energies plays an important role in decreasing air pollution [34, 35].

Several countries, including Japan and Germany, have pursued policies of renewable energy development in order to protect the environment [36]. CO_2 emissions from electricity generation using PV technologies are between 30 and 80 $g/kW.h$ depending on the technology used [37]. The existing thermal power plants in Iran produce approximately 410–980 $g/kW.h$ CO_2 [38]. The installation of solar PV modules with 5000 MW capacity would therefore reduce CO_2 emissions significantly, as shown in Table 2.

As shown in Table 2, by using PV power plants instead of conventional thermal power plants, Iran would be able to reduce CO_2 emissions by between 3.135 and 9.025 million tons per year. In addition to the environmental concerns, this is more urgent as a result of recent international energy policies, which may subject countries to financial sanctions for excess CO_2 emissions.

3 SOCIAL ASPECTS OF SOLAR ENERGY DEVELOPMENT

In addition to the factors mentioned above, which relate to energy policy, the social aspects of renewable energy development must also be considered [39]. Improving knowledge and awareness of renewable energies and their advantages will increase the social acceptance of these technologies, greatly facilitating their development. Wustenhagen *et al.* [40] indicated that social acceptance comprises three dimensions: community acceptance, socio-political acceptance and market acceptance. The process of solar energy technology development can be seen in Figure 14 [41]:

As can be seen in Figure 14, industrial investment is crucial to the development of a particular technology. It is necessary for industries to invest in R&D to produce more efficient and cost-effective technologies [42]. In addition, R&D improvement leads to solutions to possible flaws in the technology. Advances in R&D allow technical development to be refined. Technical development leads to improvements in the education system. Human awareness and training experts will then improve human capacity, which in turn affects industrial investment due to higher demand for the technology. The cycle shows

Table 2. *CO_2 emissions for various power generation technologies.*

CO_2 emissions for various technologies	Min.	Max.
Thermal power plant (g/kW.h)	410	**980**
Solar PV modules (g/kW.h)	30	**80**
Difference (g/kW.h)	330	**950**
Difference (tons/year)	3 135 000	**9 025 000**

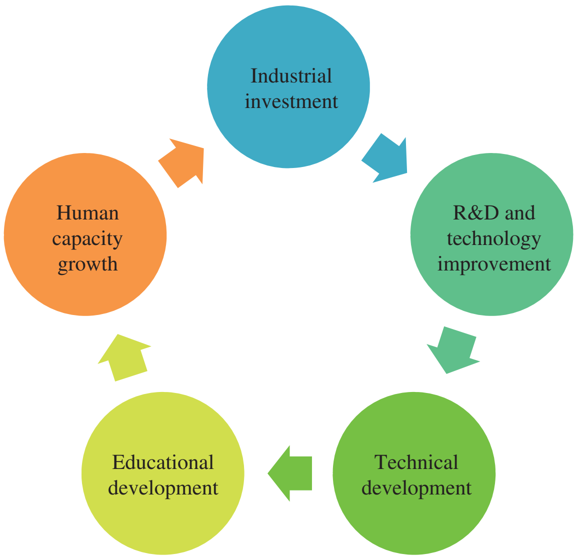

Figure 14. *Chain of technology [41].*

parameters which are effective in the technology development process.

4 THE TRIPLE HELIX APPROACH

The Triple Helix approach illustrates the importance of government, academic institutions and the industrial sector to the capacity for innovation in a society [43]. It can be concluded that all three parameters play key roles in the development of new ideas and technologies. Figure 15 illustrates the Triple Helix approach.

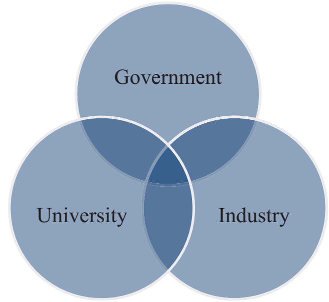

Figure 15. *The Triple Helix approach.*

4.1 Industrial sector

The PV industry is underdeveloped in Iran. However, the searching on google has shown that there are four companies which are working on the design and manufacture of PV systems and related products. These companies are listed in Table 3.

As mentioned above, most of these companies import PV modules and inverters, but have the capacity to manufacture batteries and support structures.

If patents are taken as a marker of technological development, the number of patents filed by Iranian companies can be used to gauge the development of solar technology in Iran. Patents have two sites of impact, based on their applicant and their assignee. Those patents filed by universities may be used to demonstrate government impact. On the other hand, private firms generally file patents to protect their products and increase their market share [44, 45]. Figure 16 shows the number of patents published in the field of PVs in China, Japan and Iran. The figures for each country have been taken from the patent analysis website PatentInspiration.[1]

The number of patents published in each country is illustrated in Figure 16. The number of patents published in China and Japan between 2000 and 2017 were 11 090 and 63 394, respectively. In contrast, only 11 patents were published in Iran from 1995 to 2017. China and Japan are the leading countries in both Asia and the world with regard to PV energy capacity. By adding approximately 35 GW to its PV energy capacity in 2016, China singlehandedly increased the global PV capacity by some 45% [20].

It has been shown that when technology firms start to determine their areas of specialization, the number of patents increases; subsequently, the technology life cycle will reach its mature level. At this level, the technology no longer undergoes major changes, aside from those to its appearance or other minor details. Financial benefits also start to become apparent at this stage. Text mining has been applied to the patents from each country in order to determine the most active areas of technology R&D in each. The ten terms that occur most frequently in patents from Japan, China and Iran are depicted in Figures 17, 18 and 19, respectively.

China and Japan exhibit similar patterns in their development of solar technology. 'Battery,' 'silicon' and 'glass' are the three most frequently occurring terms in the patents of both countries. On the other hand, as mentioned above, Iran relies on imports for many of its solar technology products and has only researched solar cell construction.

The Iranian government is investigating the possibility of acquiring PV manufacturing technology. The most important point to consider is the purchasing of appropriate technology for PV manufacturing, which requires a comprehensive understanding of the PV global market [46]. Industries might have a variety of motivations for developing PV manufacturing, such as economic gain, policy and government support [47].

International experiences show that government support, through policies such as tax reduction, loans for renewable energy

[1]www.patentinspiration.com

Table 3. *Companies actively manufacturing PV systems in Iran.*

COMPANY NAME	COMPANY TYPE	LOCATION	TYPE OF PRODUCT	PROJECT
HEDAYAT NOOR SOLAR ENERGY[a]	Private	Yazd Province	• Photovoltaic monocrystalline panels • Photovoltaic polycrystalline panels	• 45 kW in Taleghan • 50 kW on-grid power plant in Kish • 20 kW and 10 kW on-grid power plants in Yazd
SOLAR SANAT FIROUZEH (SSF)[b]	Private	Razavi Khorasan Province	• Photovoltaic monocrystalline panels • Photovoltaic polycrystalline panels	• Regional and rural
PAK ATIEH[c]	Private	Razavi Khorasan Province	• Photovoltaic monocrystalline panels • Photovoltaic polycrystalline panels • Mini solar panels	• 540 kW in Mashhad • 130 kW Khorasan Regional Electricity • 220 kW in south of Khorasanr Razavi • 137.5 kW of electric power distribution in Yazd province • 50 kW of panels installed in Fars
TABAN ENERGY[d]	Private	Shiraz Province	• Photovoltaic monocrystalline panels • Photovoltaic polycrystalline panels	• Annual production capacity is 130 MW and will develop to 250 MW

[a]http://www.hedayatenoor.ir
[b]www.ssf-solar.com/
[c]www.pakatieh.ir/
[d]www.tabanenergy.ir

and feed-in tariffs for industries, play an important role in PV industry development [48]. However, there is no specific government support for the PV industry in Iran. In addition, there are few academic centers focusing on renewable energies; therefore, there is a lack of experts in the country who might contribute to the development of the industry. A related problem is the lack of appropriate planning for the development of the PV industry, which inhibits its growth [49]. There are some cases in developed countries of industries co-financing scholarships with academic institutions in order to encourage research on renewable energies at master's or doctoral level [48]. Universities can therefore help the industrial sector to achieve a higher level of success in the advancement of PV manufacturing.

4.2 University sector

Universities have a significant role in knowledge development. A 2015 report from the World Economic Forum ranked Iran third in the number of annual graduates in engineering, manufacturing and construction majors, with 233 695 graduates across the three fields per year [50]. This shows a high level of interest in engineering fields; however, there are few universities which specialize in renewable energies. The lack of internship programs related to renewable energies in Iran's universities is another problem which must be solved.

The publication of academic research is the first stage in the emergence of a new technology. New ideas are first developed in the university library, then published in scientific papers. After a while, as the number of papers on a topic continues to increase, the related technology starts to emerge. The numbers of scientific papers on PV energy published in Iran, China and Japan, taken from the Scopus abstract and citation database,[2] are presented in Figure 20.

[2]www.scopus.com

The number of papers on PVs published in Iran from 2000 to 2017 was 3617, while the same period saw 54 889 and 22 692 papers published in China and Japan, respectively. The University of Tokyo, the National Institute of Advanced Industrial Science and Technology and the Japanese Science and Technology Agency are the top three research centers in Japan in this field. The corresponding institutes in China involved in publishing PVs research are the Chinese Academy of Sciences, the Ministry of Education and Tsinghua University. In Iran, meanwhile, the University of Tehran takes the top spot, publishing around 12% of Iranian papers on PVs. Sharif University of Technology and the Islamic Azad University occupy second and third place. In his 1965 article, Toynbee likened science and technology to a pair of dancers, adding that it was often difficult to determine who was the leader, and who the follower [51]. The lead dancer might be said to be science, which is shaped by academic institutions, while technology, which is influenced by industry, might be described as the follower. The science index can be understood as the number of scientific papers published and, as mentioned above, the technology index relates to the number of patents published. New ideas emerge in the university laboratory or library, and are subsequently published in academic journals. Industrial companies, meanwhile, in order to remain on the cutting edge of technological development and thereby stay ahead in the technology race, have an interest in maintaining close links with universities to avoid losing out to their rivals. The university therefore becomes the leading partner in the dance. Sharif University of Technology and Tehran University both have energy departments and carry out professional work in the area of renewable energy. These universities recruit students for postgraduate study of renewable energy systems. In addition, other institutions, such as the Institute of Materials and Energy (MERC), conduct applied research in the field of energy, especially solar energy.

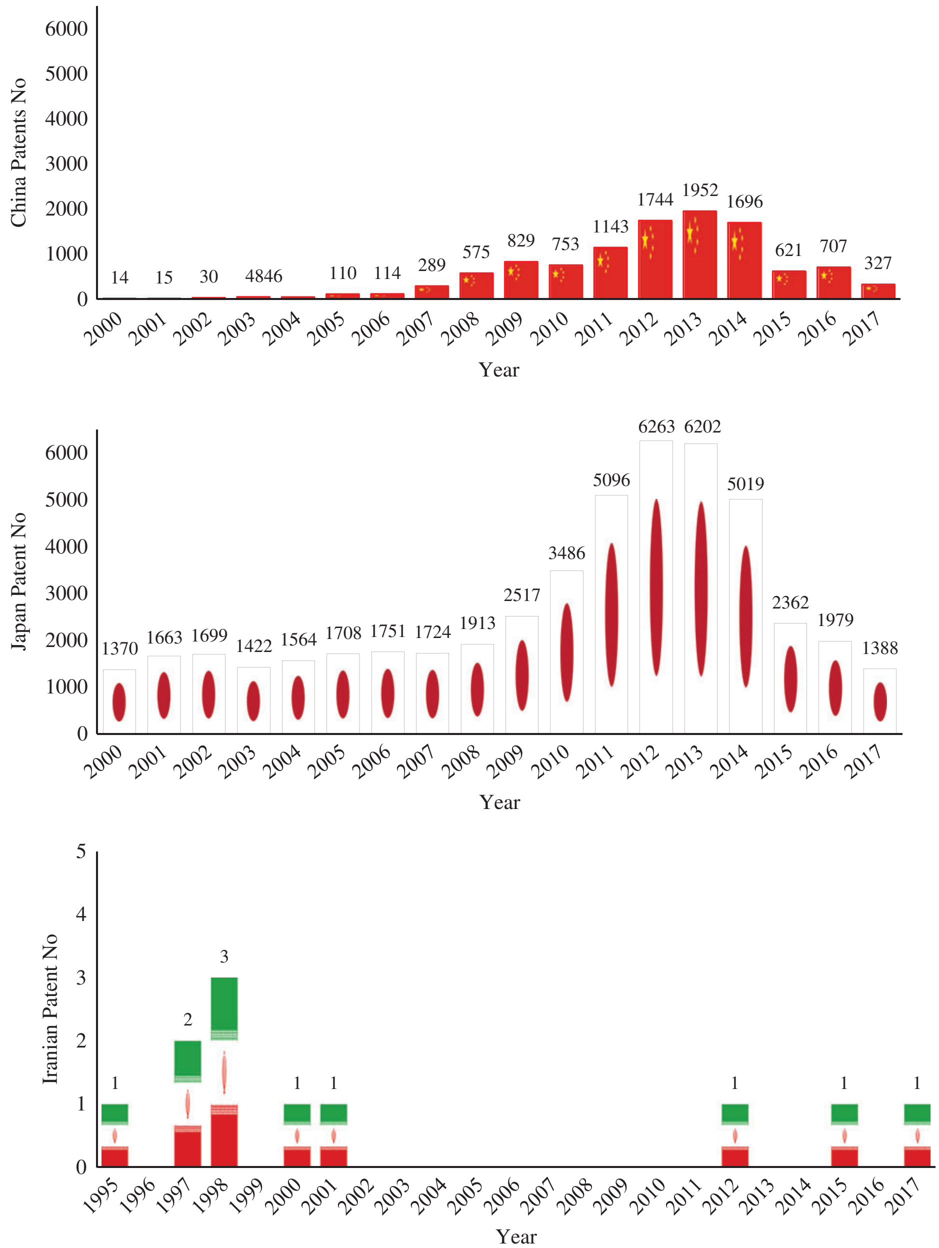

Figure 16. *Patents published in the field of photovoltaics in China, Japan and Iran.*

Universities influence the social acceptance of solar energy by advancing scientific development and increasing knowledge [41]. In addition to fostering social awareness, universities are able to improve the efficiency of existing technologies, which leads to lower electricity production costs. Universities play a role in the decision-making process as well as in research and development. However, the question remains of where the missing link in the chain lies in Iran. Universities have been working on solar energy for a long time, but the number of patents published remains very low. Has the government been doing its part? Or is the social awareness of solar energy and its benefits too weak in Iran? Figure 21 illustrates the trend in Google searches by Iranian, Chinese and Japanese citizens from 2004 to 2017. The search terms for each country are chosen from their native languages.

In 2009, the Japanese Ministry of Economics, in association with other related agencies such as the Japan Photovoltaic Energy Association, implemented an economic instrument policy. This policy provided grants and subsidies for any individual installation of a solar cell in the residential sector. This correlates with the fact that Google search interest in solar energy in Japan peaked in the same year. The interest of the Chinese public in solar energy shows a similar trend, albeit to a lesser extent. The search behavior of Iranian citizens, however, forms

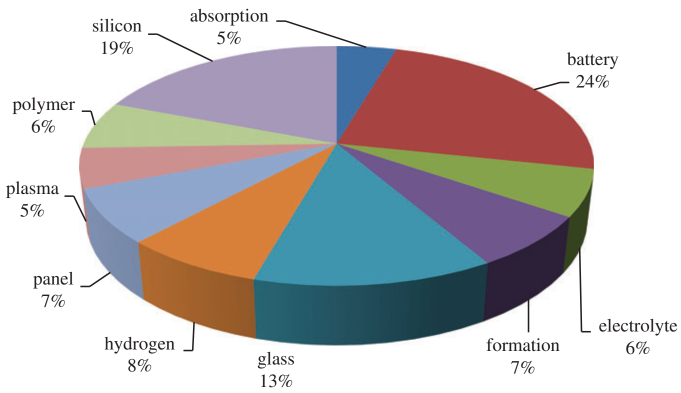

Figure 17. *Top ten most frequently occurring terms in Japanese patents.*

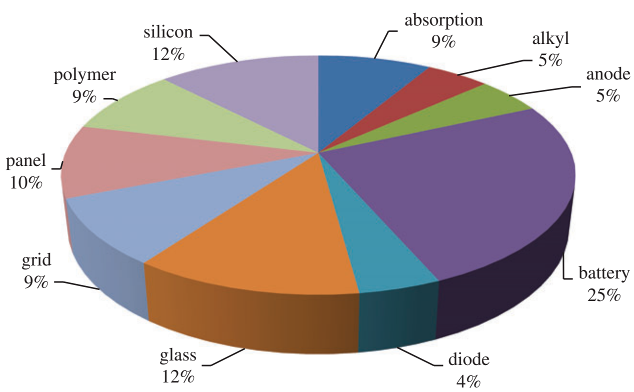

Figure 18. *Top ten most frequently occurring terms in Chinese patents.*

a striking contrast. In comparison with China and Japan, there has been almost no search interest in the term ‘solar cell’ (سلول خورشیدی). Both social media and the broadcasting industry in Iran are under government control. Since the promotion of renewable energies is a vital part of raising of social awareness in Iran, government neglect may be the missing element. Other organizations, such as the Renewable Energy Organization of Iran (SUNA) and the Iran Energy Efficiency Organization (SABA), are heavily involved in raising social awareness.

4.3 Government sector

The development of utility-scale PV installation is not possible without favorable government policies. A government can develop solar technologies in several ways. As mentioned above, government support and policy are key parameters in the development of the PV industry. Investment in the research and development of solar energy is another tool by which government can foster PV development and manufacturing. The main governmental organizations involved in the energy sector are the Ministry of Petroleum, the Ministry of Industry and Mining, the Ministry of Science, Research and Technology, the Ministry of Energy and the Department of Environment [49].

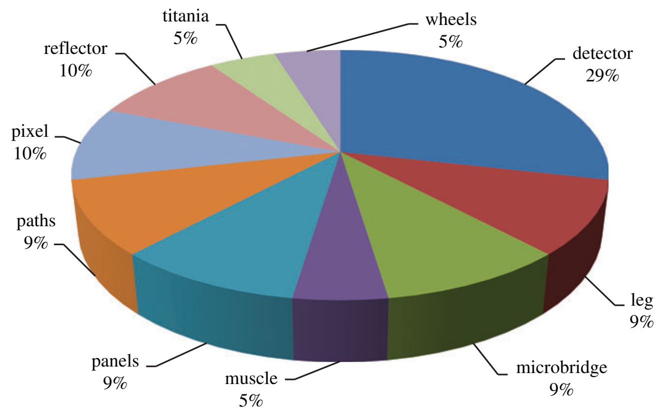

Figure 19. *Top ten most frequently occurring terms in Iranian patents.*

Of these, the Ministry of Energy has the most significant role in renewable energy development. SUNA and SABA, both managed by the Energy Ministry, are the main organizations working in the R&D field.

- Renewable Energy Organization of Iran (SUNA)
  SUNA is a part of the Energy Ministry, founded in 1996 with the aim of providing knowledge and expertise and developing new technologies in order to encourage the growth of the renewable energy sector. The organization is also responsible for studying existing research policy and preparing plans for the development of renewable energies in the country [14].
  SUNA’s main social activities include conducting scientific visits, publishing books on the advantages of renewable energy and holding exhibitions in a bid to improve public awareness [14]. Moreover, SUNA guarantees the purchase of electricity generated from renewable sources, which provides an economic incentive for renewable energy development.
- Iran Energy Efficiency Organization (IEEO-SABA)
  SABA was established in order to improve the efficiency of the energy sector and conducts work in a number of related areas, such as the development of electricity generation, energy consumption management and the reduction of environmental pollution. The main tools used to achieve these goals are research, publication, scientific services and training.
  For solar PV energy development, SABA works to improve the energy efficiency of PVs and to publicize the environmental benefits of solar power, which will lead to greater social acceptance and encourage policymakers to consider PVs for electricity generation.
- Renewable Energy Initiative Council of Iran (REIC).
  REIC was founded with the goal of providing infrastructures to develop research on renewable energies in Iranian universities. REIC supports innovative studies in solar energy

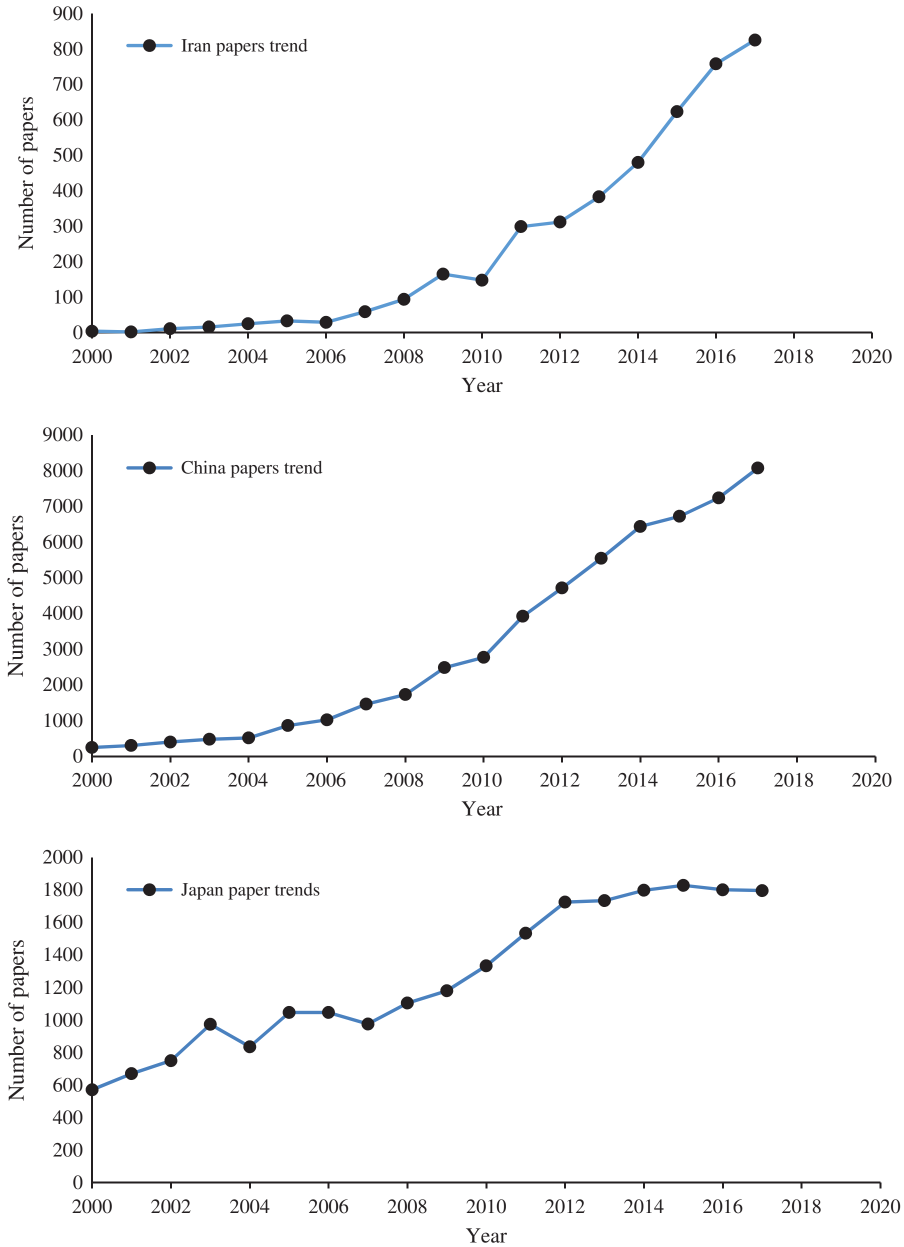

Figure 20. *Number of scientific papers on PV technology published in Iran, China and Japan.*

technology, such as the application of nanotechnology and the optimization of solar systems. In recent years, REIC has supported a plan to install PV plants with a capacity of 20 kW in 23 academic centers. While SABA and SUNA are subsidiaries of the Energy Ministry of Iran, REIC belongs to the Science and Technology Vice-Presidency, a distinction that makes it difficult to coordinate their activities.

Investments in solar energy technology and changes in energy policy are among the other tools at a government's disposal for the development of renewable energies. The Iranian Energy Ministry guarantees the purchase of electricity generated from utility-scale solar power plants at a price of 3200 IRR/kWh (approximately 0.105 USD/kWh), which is above the residential rate [14]. In addition, the FIPPA (Foreign Investment Promotion and Protection Act) law encourages international investment in the country's renewable energy sector, and has succeeded in convincing foreign companies to invest in solar energy in recent years [52].

A well-organized relationship between these three sectors—industry, universities and government—will be required for the

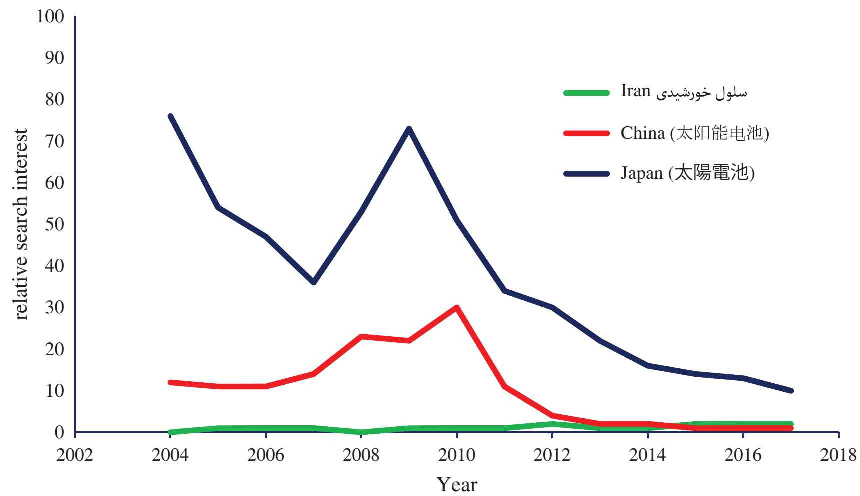

Figure 21. *Google search interest in solar energy in Iran, China and Japan, 2004–17.*

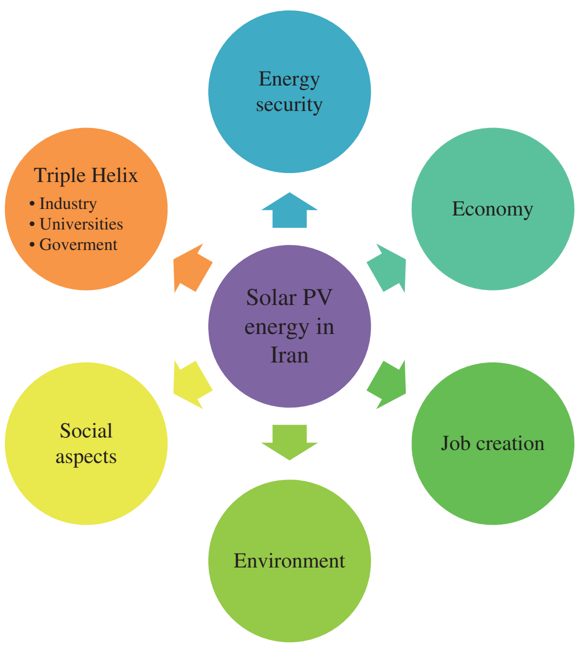

Figure 22. *Summary of the factors discussed (conceptual framework).*

success of plans for the development of solar power in Iran. Of these parties, the government is arguably the most influential, since many industries and universities are dependent on government support. In addition, the government is responsible for enacting energy policy.

In an attempt to summarize this study, the different areas that have been examined are shown in Figure 22.

There are many constraints on PV development in Iran, the most important of which is investment. Attracting investment in renewable energy is crucial for making progress in the implementation of renewable energies, especially PV energy. In addition, it is necessary to organize those government bodies and organizations involved in PV energy to accelerate activities. Improving the coordination between government, industry and universities is also a vital step. The advantages of PV energy for Iran have been presented and investigated in this study. Future studies should focus on selecting appropriate technologies and sites for PV systems installation. A further fruitful avenue would be to compare energy policies being pursued in pioneer countries in solar energy development.

5 CONCLUSION

These results show that the Iranian government needs to do more to promote and develop solar energy. One possible explanation is the abundance of oil and gas in Iran. The government constitutes the missing link in the chain between private companies, universities and the public. The most appropriate energy policy for Iran is the expansion of solar PV, due to its high solar irradiance. The development of solar PV for electricity generation is a necessity for Iran due to both environmental problems and the country's economic dependence on crude oil. This paper has outlined various aspects of solar PV development in Iran, and concludes that the installation of PV power plants with 5000 MW capacity would have many advantages, including:

- improved energy security compared with the use of thermal power.
- creation of up to 55 050 jobs.
- reduction in CO_2 emissions by up to 9.025 million tons per year.
- reduction in oil consumption by approximately 16 million barrels annually.

In addition, social acceptance of new technologies plays an important role in their development. The main organizations involved in improving the social acceptance of these technologies, such as universities, SUNA and SABA, have been briefly introduced.

It can be concluded that those institutions involved in solar energy development must be reorganized to work more efficiently. Moreover, the government must invest in solar energy and work harder to attract domestic private and foreign investment.

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