A Functional Analysis of Technological Innovation Systems in Developing Countries: An Evaluation of Iran’s Photovoltaic Innovation System

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Abstract: For developing countries to catch up, it is vital that they develop emerging technologies and the system that supports that development. The literature suggests developing a technological innovation system (TIS) framework to investigate the development of technologies in a country. Nonetheless, most of this research focuses on developed countries without taking into account developing countries. Therefore, in this paper, we have two main goals. First, reviewing the indicators introduced to the functional analysis of TISs and modifying these indicators based on developing countries’ circumstances. Second, applying this framework to the specific case of Iran’s renewable energy program by using these indicators for analyzing Iran’s photovoltaic TIS to identify the problems. Accordingly, we review indicators used for a functional analysis by considering the needs of developing countries, and we propose a list of indicators that can be used for assessing functions in developing countries’ TISs. The results show that, to evaluate some functions of TIS, we need to use new indicators in developing countries. Finally, we propose some policy recommendations to tackle these functional problems.

Keywords: technological innovation system; photovoltaics; functional analysis; developing countries

1. Introduction

Environmental problems and restrictions on fossil fuels have pushed countries to invest in clean and renewable energy resources. Photovoltaic (PV) technology is considered to have an outstanding position in producing clean energy [1]. Total PV energy generation in the world has grown dramatically, from 4 GW in 2000 to reaching 227 GW in 2015. However, if the world was able to overcome economic, infrastructure, and policy obstacles, it could reach 3TW of PV power electricity by 2030 [2].

PV energy generation not only gives opportunities for developed countries, but it also has great potential for developing countries as well. For example, in order to supply its energy in a sustainable way, Iran intends to develop this technology. Therefore, ambitious goals were set by authorities to supply a substantial amount of the country’s energy from PV technology. However, no significant achievements have been made in this area yet. In order to evaluate and explain the problems in the development of technology, scholars suggested the technological innovation system (TIS) framework. They believe that, for diffusion and development of technology, a well-functioning TIS is required [3–5]. However, what determines the desired performance of the innovation system is the activities carried
out within it. These key activities are named “functions of innovation system” [3,6]. These functions include entrepreneurial activities, knowledge development, knowledge exchange, guidance of the research, market formation, resource mobilization, and legitimization [7,8].

Some researchers tried to focus on the functions of innovation systems while assessing their performances [3,8] and identifying their strengths and weaknesses by evaluating their functions [9,10]. However, most of these studies have been conducted in developed countries, and the circumstances of developing countries have not been considered [11]. This would mean the criteria used to evaluate the functions of innovation systems in these studies are not capable to accurately measure functions in developing countries. For instance, developing countries often have a gap in technology in comparison with developed countries. To cover this gap, they cannot only rely on local R&D. Therefore, for developing countries, we can use absorptive capacity and technical learning along with [12–14].

In that regard, the contribution of this study is two-fold. First, we try to review the indicators provided to evaluate the functions of TISs and improve these indicators by considering developing countries’ circumstances. Second, we will use these indicators in Iran’s photovoltaic TIS to explore its functional problems. In the end, we suggest related policy instruments to solve the problems. Our research questions include what the key indicators for assessing the functions of TIS in developing countries are and how these can be used to evaluate the problems of TIS in these countries.

To achieve these goals, we first review the TIS’s functions and the indicators used in the evaluation of these functions. Following that, we review innovation policy and policy instruments which are used to develop renewable energy. After that, we suggest new indicators considering the circumstances of developing countries. The main revised functions include knowledge development, resource mobilization, and market formation. Then, we evaluate the functions of Iran’s photovoltaic TIS using structured interviews and, consequently, to determine the problems that hinder the development of PV technology in Iran. Finally, we conduct semi-structured interviews to find policy recommendations to improve the performance of the TIS. The paper is structured as follows. In Section 2, we provide an overview of the innovation system, TIS framework, and innovation policy, and then we describe the functions of the innovation system. In Section 3, we present the indicators to improve the assessment of the TIS functions, considering the requirements of developing countries. In Section 4, the methodology is described. Then, in Section 5, Iran’s photovoltaic TIS will be evaluated empirically, and the functions that do not perform properly are determined. Finally, in Section 6, policy instruments will be proposed to improve these functions, and Section 7 will conclude the paper.

2. Literature Review

2.1. Innovation System and TIS Framework

The innovation system approach was developed about a decade after Freeman (1987), Lanolle (1992), and Nelson (1993) worked on this area [15–17]. This concept, first considered by the Organization for Economic Cooperation and Development (OECD) members, has recently been developed as a framework for policy-making for technology development and has attracted the attention of many researchers and policymakers. Furthermore, it is used as the most advanced and commonly used analytical model of the innovation system. Edquist defined the innovation system as “all economic, social, political and organizational factors, and other important factors influencing the development, dissemination, and use of innovation” [18]. The innovation system can be analyzed at various levels; these levels include: the national innovation system (NIS) [16], regional innovation system (RIS) [19], sectoral innovation system (SIS) [20], and technological innovation system (TIS) [21].

There is no consensus on the exact definition of the innovation system, and this concept is still developing. Innovation often occurs as the result of interactions among actors and institutions. However, Lundvall (1988) stated that interactions within national contexts might be more effective than across borders, which, in this case, means an NIS. Nevertheless, one can ask whether regions with relative autonomy, such as Scotland, could form an innovation system in terms of competitive advantage [22].
Introducing a regional innovation system arises from differences in economic growth and welfare between regions. The assumption is that the NIS approach is homogeneous across a country, an inaccurate assumption. As a result, researchers have developed an area-based approach, in which the areas usually refer to geographic regions within a country [23]. The RIS approach considers the regional dimensions of production and the discovery of new knowledge and, thus, helps explain regional differences in the capacity of innovation and economic power. Furthermore, other similar concepts, such as regional clusters, industrial district, technopole, and innovative milieu, also appeared [24].

Unlike national and regional innovation systems, both of which focus on the spatial dimension of defining the boundaries of the system, both the sectoral and the technological innovation systems consider a specific technology (extended in several sectors) or the sector in which it is used (incorporating different technologies) as the system boundaries [25, 26].

The emergence of the TIS concept can be attributed to Carlson and Stackiewicz (1991) [25]. They defined the TIS as follows: “Dynamic network of actors who interact in one economic and industrial context and with a particular institutional framework and participate in the creation, dissemination, and exploitation of technology” [21]. This concept is usually used to explain the emergence, growth, and diffusion of technology in a community, and hence, it can be called the innovation system of a specific technology or a technological innovation system [8]. In order for a technology to be developed and widely disseminated, there is a need for a technological innovation system that works well. This means that there is a technological innovation system for each technology, and each system is unique in terms of its capabilities for the development and diffusion of new technologies [6]. Accordingly, to understand and evaluate developments in photovoltaic technology in Iran, we will adapt the technological/sectoral innovation systems approach.

Many attempts to evaluate innovation systems have focused on the structural elements [7, 27]. Structural elements of an innovation system represent its relatively stable aspects [8]. These structural elements (such as institutions, infrastructure, actors, and networks) are interdependent [6, 28–30]. If one of these elements changes, it may also cause changes in other elements, and there would be a set of actions and reactions that either pushes the system forward or causes its failure [30]. In other words, this interdependency may cause a virtuous or vicious cycle [31].

However, gradually, researchers have found that, in order to evaluate innovation systems, not only is it necessary to focus on structural elements, but also, it must clearly identify what happens in these systems. Assessing the status of the structural elements of innovation systems is not possible without considering the effects of the innovation processes or system functions. Therefore, to evaluate the performance of an innovation system, researchers have attempted to identify and analyze the activities or functions that are performed in the innovation system [4, 7]. Some researchers have used a functional analysis approach to assess the innovation systems and identify their poorly performing functions [9, 32–34].

2.2. Innovation Policy

The innovation system perspective provided a holistic view for analyzing innovation processes and investigating systemic problems [30, 35]. According to researchers, any obstacle that disrupts the proper functioning of the innovation system is considered a systemic problem [4, 5, 36]. In other words, the innovation system provides a useful framework for policymakers to evaluate the functions of an innovation system in order to propose policy recommendations for systemic problems [37–40].

Innovation policy refers to the actions that governments do to affect the innovation process [41]. Innovation policy primarily concentrates on optimizing the innovation system in order to bolster its innovative capabilities and the fulfilment of its objectives [37]. Therefore, it must not only improve the economic competitiveness of the innovation system but also induce strategic directionality and lead to positive social changes [36, 42].

According to researchers, innovation policy instruments can be classified into three main types: namely, regulatory instruments, economic instruments, and soft instruments. The first type, regulatory
instruments, use legal tools for the regulation of social and market interactions (The logic behind regulatory instruments is the government tendency to define the framework of the interactions taking place in the economy and society). Economic and financial instruments provide specific pecuniary incentives (or disincentives) and support specific social and economic activities. Soft instruments are the third type, which are characterized by voluntariness and noncoerciveness. Soft instruments provide recommendations, make normative appeals, or offer voluntary or contractual agreements. Those who are governed by soft instruments are not subjected to obligatory measures, direct incentives, or disincentives by the government or its public agencies [41].

A meaningful point in selecting proper innovation policy instruments is the adaptation of the instruments to specific problems in the innovation system and, more crucially, to the specific features of the administrative structures. In other words, policy instruments, in order to be fruitful, need a certain degree of "customization" with the capacities of public administrators and dynamic needs of the system [41].

Policy instruments are unique and commonly selected, planned, and implemented according to a specific problem in mind, at a specific time period, in a specific political-ideological framework and in a specific policy context (innovation policy, in this case). The goal-oriented nature of these tools prompts us to reflect on the specific function of the technology in question. However, to solve the problems efficiently, we need to use several policy instruments at a time. Innovation policy mix is related to applying various policy instruments at multiple policy dominations to address the problems identified. Moreover, recent discussions in the literature leads to the conclusion that policy mixes are more appropriate than using individual instruments to facilitate innovation [43]. The literature indicates that fostering emerging technological innovation systems in the field of clean energy necessitates the application of policy instruments so that problems blocking innovation can be solved. Some of these policy instruments are presented in Table 1.

| Policy Instruments                              | References |
|------------------------------------------------|------------|
| Custom duty exemptions                          | [44]       |
| Feed-in tariffs                                 | [45–48]    |
| Funding to support R&D                          | [47,49]    |
| Venture capital in the field of energy          | [50]       |
| R&D equipment                                   | [46]       |
| Risk coverage support                           | [51]       |
| public-private partnership (PPP)                | [52]       |
| demand pull policy                              | [53,54]    |
| anti-dumping policy                             | [53,54]    |
| tariff policies                                 | [53,54]    |
| distributed energy policy and demonstration projects | [55–58]    |

To sum up, policymakers should be aware that innovation policies have a very wide range of tools, none of which are necessarily better than the other; rather, each are effective in their own way. However, policymakers need to select these tools concerning specific policy contexts and the country’s circumstances [41].

### 2.3. Functions of Innovation Systems

Hekkert, et al. (2007) described seven functions for innovation systems, which is the basis for this research [8]:

1. **Entrepreneurial activities**: The activities of the innovation system which relate to business startups, diversification, and testing of new technologies.
2. **Knowledge development (learning)**: Educational activities on the technical, social, and economic aspects of new technologies.
3. Knowledge exchange (through networks): Those activities and processes of innovation that focus on information dissemination, awareness raising, and capacity-sharing and resource sharing among system actors.

4. Guidance of the research: This function is about creating hope and optimism about the future of new technologies. The aim of this function is also reducing the uncertainty and risks associated with new technologies.

5. Market Formation: It covers functions, activities, and processes that can create tools for new technologies. This function will extend the market for new technologies by providing market protection standards.

6. Resource mobilization: Human and financial resources are economic variables for the emergence and success of an innovation. This function distributes the necessary resources for the development and diffusion of new technologies among actors of the innovation system.

7. Legitimization (neutralize resistance to change): New technologies often fail to gain approval from key actors and policymakers. This function carries out activities that provide legitimacy for new technologies [8].

3. Suggestions to Evaluate TIS Functions in Developing Countries

According to Edsand (2016), most of the functions proposed for innovation systems are primarily used for developed countries, and if we tend to use this list of functions in developing countries, we need to make some modifications [59]. In the following, some of these changes are proposed.

3.1. Knowledge Development

Knowledge development is one of the most critical functions of innovation systems. This function can positively affect innovation system functionality [4,8]. There are several sources of knowledge development (e.g., R&D, technological learning, and imitation) [4]. Developing countries often have a gap in technology in comparison with developed countries. To cover this gap, they cannot only rely on local R&D. These countries often use both internal and external R&D and other resources, such as technological learning and the absorption of knowledge to develop existing knowledge. Thus, for developing countries, we can use absorptive capacity and technical learning along with indicators such as the number of research and development projects, the number of patents, the number of scientific publications, and the amount of investment in R&D, which measures the performance of knowledge development in developed countries [4,8].

3.1.1. Absorptive Capacity

The ability of countries to absorb and use external knowledge, especially in developing countries, is crucial for the development and acquisition of knowledge. Researchers argued that two countries, which receive the same technology, might not be able to absorb the same amount because of a difference in ability to absorb knowledge [60]. Hence, a sufficient level of knowledge absorptive capacity plays a vital role in attracting and exploiting new knowledge. A Hong Kong case study indicates that companies need to be able to boost their knowledge absorptive capacity to increase their innovation performance. In addition, other studies in developing countries suggest that improvements in absorptive capacity would improve the acquisition of knowledge and technology from foreign countries [12,13]. Different indicators have been proposed to measure absorptive capacity. The indicators we used in this research include: the number of trained staff in the R&D sector and active in the development of knowledge [61,62]; the amount of investment in the development of human resources active in knowledge development [61], laboratories, raw materials, etc. [13]; expenditure on research and development in the private and public sectors [62,63]; the number of patents, prototypes, and initial designs for production [62]; and the number of papers and publications.
3.1.2. Technological Learning

Developing countries often import ready-to-use and mature technologies from developed countries. Therefore, the experience of such countries in technological learning begins with learning from ready-to-use technologies. In particular, East Asia countries such as Thailand, India, and China in the PV industry have specifically begun to use technology transfer to develop knowledge and to build technological capability [64–66]. As a result, the historical stages of technological learning in these countries consist of three stages, including engineering, development, and research activities. In developing countries, no changes are made on the technology imported at the first step. Nevertheless, the application of technology becomes more efficient because of the experience of workers and engineers. In the second phase, by way of reverse engineering, imported technology is imitated, and engineers are able to acquire the design knowledge of technology, and in the third phase, with the help of the R&D centers and universities, the improvement in the imported technology will be obtained. This trend is in contrast to the trend in the countries that own the technology. In developed countries, research activities come first, then development, and finally, engineering takes place [14]. According to this, the suggested indicators for assessing technology learning are as follows: How much learning and knowledge has been gained as a result of using technology (such as technology assembly and deployment)? How much knowledge has been gained as a result of copying, imitation, and reverse-engineering of technology (Is there the ability to imitate and copy technology?)? How much knowledge has been gained from improving imported technology (Is there the ability to improve existing technology inside the country?)?

3.2. Resource Mobilization:

Scholars seek to analyze the extent of technological innovation systems’ ability to mobilize human, financial, and infrastructure resources [3,4]. Developing countries such as Iran are not able to invest in emerging technologies such as photovoltaic technology due to a lack of financial resources. Resource mobilization can be both national and international [59]. In the area of renewable energy, with international treaties such as the Kyoto Protocol and the Paris Agreement, developing countries can use international funding, which can strengthen the resource mobilization function. Therefore, these funds can help to mobilize resources for such countries. Regarding human resource utilization, developing countries can enhance this function by attracting their experts and skilled citizens from developed countries. Previous studies indicated that Taiwan’s policies for returning Taiwanese specialists working in developed countries led the country to achieve success in the semiconductor industry [67].

3.3. Market Formation

Emerging technologies often compete with embedded technologies. Hence, the creation of protected space for these new technologies is essential [3]. Due to the uncertainties in market size and demand volume, the technological innovation system is limited to its actors. Therefore, to underpin the innovation system and increase the willingness of entrepreneurs to enter the market, protective actions should be considered for markets [4]. In addition, it is necessary to think about the formation of a new technologies market against the dominant technologies market.

Developing countries are far behind the developed countries regarding the innovation and delivery of products at the international level. Generally, entrepreneurs in developing countries face other problems as well. For example, the volume of the market for innovative products—which is the output of the innovation system—might be appropriate, but it is occupied by developed countries’ companies. Therefore, the proper margin to compete with these well-known companies for entrepreneurs and domestic startups in developing countries does not exist. Thus, developing countries will struggle to compete with developed countries, and they need to take appropriate preventive actions to protect their domestic markets. Therefore, the proposed indicator for this section is supportive policies to protect the market for local startup companies.
In Table 2, we presented our final indicators for the evaluation of an innovation system function inspired by existing indicators and other indicators reviewed in the above sections. In Table 1, we present our final indicators for the evaluation of innovation system functions inspired by existing indicators and other indicators reviewed in the above sections.

**Table 2. Indicators for the evaluation of innovation system functions.**

| Functions                  | Indicators                                                                                      | References |
|----------------------------|-------------------------------------------------------------------------------------------------|------------|
| **Entrepreneurial activities** | Related actors in the innovation system                                                        | [30]       |
|                             | The presence of a sufficient number of industrial actors in the innovation system              | [5]        |
|                             | Provide enough innovation from industrial actors                                               | [5]        |
|                             | Attention to large-scale production by industrial actors                                        | [5]        |
|                             | The amount of abandonment by entrepreneurs                                                     | [30]       |
|                             | The rate of entry of new entrepreneurs into the innovation system                               | [3,4]      |
| **Knowledge development**  | Number of projects, documents, and papers in this field                                         | [4,8]      |
|                             | The conformity between supplying technical knowledge (qualitatively and quantitatively) by universities and R&D centers with the demand of industry | [5]        |
|                             | Enough skilled staff, in the R&D department, to develop knowledge                              | [61,62]    |
|                             | Enough investment in human resource development for knowledge development                       | [61]       |
|                             | Sufficient physical infrastructure, such as R&D centers, laboratories, raw materials, etc., to develop knowledge | [13]       |
|                             | Sufficient budget and expenditure on R&D in the private and public sectors                     | [62,63]    |
|                             | The number of sufficient patents, prototypes, and designs for production                        | [5,62]     |
|                             | Learning and knowledge acquisition from the use of technology (such as assembling and deploying it) | Author     |
|                             | Acquiring sufficient knowledge of imported technology to copy, imitate, and reverse-engineer    | Author     |
|                             | Acquiring enough knowledge to improve existing technology (ability to improve existing technology inside the country) at research and development centers and universities | Author     |
| **Knowledge exchange**      | An adequate exchange of knowledge between universities and industry                             | [5]        |
|                             | An adequate exchange of information between the users of the technology and its manufacturers (industry) | [5]        |
| **Guidance of research**   | The amount, quality, and space for the dissemination and exchange of knowledge (conferences, meetings, etc.) among actors | [6]        |
|                             | Visions, clear forecasts, and expectations about how technology is developed                     | [5]        |
|                             | Policy goals (clear encouragement policies) related to this area (such as renewable energy incentives) | [5]        |
|                             | Supporting goals with specific programs and policies that guide the system                       | [4]        |
|                             | Transparency of specific objectives and regulations determined by government and industry       | [5]        |
| **Market formation**       | Sufficiency in the size and volume of the market                                               | [5]        |
|                             | The existence of legal incentives and barriers to the formation of a new technology market     | [3,4]      |
|                             | The existence of supportive policies to protect the market for domestic firms against the influence of international companies | Author     |
|                             | Positive and adequate forecast for the future                                                  | [5]        |
| **Resource mobilization**  | Use of human resources living abroad                                                            | Author     |
|                             | The use of international financial resources, including international donations and loans       | [11]       |
|                             | The existence of sufficient human resources (in complementary and managerial fields) within the country | [4,5]      |
|                             | The existence of sufficient funds (joint ventures, government credits, etc.) inside the country | [4,5]      |
|                             | The amount of access to these resources for actors                                              | [5]        |
|                             | The existence of sufficient physical infrastructures (such as roads, water, electricity, gas, automobiles, complementary infrastructure, etc.) | [4,5]      |
| **Legitimacy**             | The extent to which there are supportive comments about the use of new technology in the media | [59]       |
|                             | The extent and manner of support, and the introduction of technology in social networks and the Internet | [59]       |
|                             | The amount of media support and advertising for investment in new technology in social networks and scientific and industrial meetings | Author     |
|                             | The quantity and the quality of alliances or pressure groups (such as environmentalists) to legitimize and support technology | [6]        |
|                             | Resistance to change and use of new technologies                                               | [5]        |
4. Methodology

To answer the research questions, we used a qualitative approach. So, primary data was used to analyze the functions of the innovation system. This data was collected using a structured and semi-structured interview with renewable energy experts in Iran. Since PV technology is one of the emerging technologies in Iran, the community of experts who are working in this field is very limited. Moreover, the innovation system of PV has many stakeholders, namely, the government, industries, innovators, and researchers. Therefore, we tried to include all stakeholders and players in this field. We took into account criteria which helped us to choose appropriate experts in all areas. Our criteria are as follows:

- Researchers who have been working at least for five years at research centers where their main task is to develop green energies.
- Professors who have been working in the field of clean energy at least for five years.
- Managers of startups, companies, or power plants that have been working in the field of PV and other clean energies at least for two years.
- Managers who have been working in governmental bodies in which their main role is to develop green and clean energies, such as wind and solar.

These organizations carry out regulation and legislation, risky investment, and financial support activities. These organizations include the Ministry of Energy, Renewable Energy and Energy Efficiency Organization (SATBA), Vice Presidency for Science and Technology, and (headquarters for the development of renewable energy technology) Energy Commission of Islamic Parliament Research Center of the Islamic Republic of Iran.

Two rounds of interviews were conducted. In the first round, structured interviews by means of diagnostic questions (see Table 2) were conducted. Before conducting the interview, the questionnaire was given to five scholars (university professors) in order to ensure content validity. The first round of interviews was conducted during June—August 2019. In total, thirty-five experts, by using snowball sampling (for both rounds), were selected for the first round of interviews. In a structured interview, with the indicators outlined in Table 1, experts were asked to score the performance of each function using the Likert scale: very bad (1), bad (2), acceptable (3), good (4), and very good (5). After receiving the data, we used a simple mean method to analyze data, and the functions of the innovation system were evaluated. In the second round, the semi-structured interviews were conducted from September—October 2019. In this round, twenty-three experts were selected. Then, they were asked to express required actions and suggestions to improve the performances of the functions. To analyze the primary data in the second round, we used the thematic method. Thematic analysis is one of the most commonly used forms of analysis in qualitative research [68]. By using Nvivo software, we analyzed the interviews and extracted themes which included ideas (actions and policy suggestions) regarding the functions’ problems.

5. Results

In the first step, we tried to analyze the results of the structured interviews according to the experts’ opinions. Figure 1 represents the fulfillment of the photovoltaics TIS functions in Iran according to the experts. Lower scores illustrate the functions with lower performances.
5.1. Entrepreneurial Activities

As shown in Figure 1, the entrepreneurial activities are the weakest function of the innovation system. Looking at the indicators of entrepreneurial activities (Figure 2), it is clear that the rate of abandonment by entrepreneurs (2.1) is higher than the rate of entry of new entrepreneurs into the innovation system (1.7). In addition, these results indicate that the number of industrial firms in this field is low (1.01), and the level of innovation that is expected to come from these industrial firms is negligible. This illustrates that entrepreneurship in the field of photovoltaic energy in Iran is facing a serious problem. Furthermore, industrial actors who should be active in both production and innovation did not pay much attention to innovation. Accordingly, industrial companies working in this field focus exclusively on production, and they do not focus on the research, development, and presentation of innovative products. The amount of the production scale indicator (1.03) shows that production scale is very low, which indicates their low market share level.

5.2. Knowledge Development

By looking at the indicators for knowledge development (Figure 3), it is clear that the following functions are at the acceptable level in the photovoltaics TIS: adequate projects, documents, and papers (2.9); skilled staff in the R&D sector (3.5); and a sufficient number of patents, prototypes, and designs for
production (2.6). However, physical infrastructures (such as R&D centers, laboratories, raw materials, etc.) and sufficient budget and expenditure on R&D in the private and public sectors are at low levels. This indicates that there is no problem in attracting knowledge from outside due to the availability of skilled and well-educated human resources, scientific papers, and documentation, but there is a problem in the exploitation of knowledge that ultimately leads to the development and creation of wealth. Looking at other indicators that evaluate knowledge development, such as “learning from the use of technology” and “copying, imitating, and reverse-engineering of imported technology”, indicates that learning from technology has been done to an extent, but this learning has not led to the activation of internal research and development and the improvement of technology in Iran. In some of the developing countries, on the other hand, technological learning was the best way for the development of the electronics industry [69,70].

![Figure 3. Results for the knowledge development indicators in the photovoltaics TIS.](image)

### 5.3. Knowledge Exchange

When we look at the indicators of this function (Figure 4), it becomes clear that the "adequate exchange of knowledge between universities and the industry" and "adequate exchange of information between users of technology and its manufacturers (industry)" have low scores. These low scores indicate that created knowledge is not properly distributed among the industrial sector and the country’s entrepreneurs. In other words, the theoretical knowledge created by conferences and meetings is distributed among the actors of the system, such as researchers and research centers, policymakers, and designers. However, this theoretical knowledge has not been published among entrepreneurs. Therefore, the dissemination of knowledge remains at the theoretical stage.
5.4. Guidance of Research

The results for this function (Figure 5) indicate that, despite the proper identification of goals and visions for the future and the formulation of regulations by the government—considering the diversity of energy sources and sustainable energy supplies—relevant action plans to address these goals do not exist. The compilation of a renewable energy development documents in Iran shows that visions have been clearly elaborated and there are certain goals for it. However, the plans that ensure the achievement of these goals are not well designed.

So far, responsible organizations (renewable energy and energy efficiency organizations) have succeeded in providing a good opportunity for entering the private sector in the construction of solar power plants by providing attractive feed-in tariffs and establishing appropriate regulations. However, these regulations work at the end of the PV technology value chain and cannot have a tremendous impact on the circles of creating knowledge and technology. This is due to the fact that those involved in making solar power plants have been operating without the necessary knowledge and know-how with only the final product in mind (solar panels).
5.5. Market Formation

The results of the market formation function (Figure 6) indicate that, despite the appropriate market size within the country and proper prospects for future demands, there are no policies and laws to support the domestic market against dominant technologies and high-tech international companies. Entrepreneurs in developing countries have little competitive power over international companies and, therefore, must receive supportive policies in order to remain competitive.

![Figure 6. Results for the guidance of market formation indicators in the photovoltaics TIS.](image)

5.6. Resource Mobilization

Looking at the indicators’ scores (Figure 7) illustrates that the innovation system is in good condition in human resources in the complementary areas such as technicians, physical facilities, and public infrastructure (e.g., roads, water, electricity, and gas) and complementary infrastructure (e.g., Internet, etc.). However, there are problems with financial resources. Given the specific circumstances of Iran, it is not possible to use international financial resources, loans, and assistance to develop a technological innovation system in the field of PV. Moreover, sufficient domestic finances, such as joint ventures and government funding, are limited.

![Figure 7. Results for resource mobilization indicators in the photovoltaics TIS.](image)
5.7. Legitimization

The indicators of this function (Figure 8) show that supportive comments about this technology in the media and social networks are acceptable, and this suggests that public support of this technology can be positive. Resistance to change and the use of new technologies also have a medium score. This means that there is not much resistance in this way, and the development of new technology will not be problematic. The important point here is that the level of support and advertising for investing in this technology in the media, social networks, and scientific and industrial meetings are not desirable. This would lead to a low amount of investment in this area, and interested investors in this sector would be unaware of future opportunities.

![Figure 8. Results for legitimization indicators in photovoltaics TIS.](image)

6. Discussion and Policy Recommendations

In this research, we have tried to answer two questions: What are the key indicators for assessing the functions of TIS in developing countries regarding the differences between developed and developing countries? How does the TIS of photovoltaic in Iran as a developing country work?

According to first research question, we reviewed literature about the evaluation indicators of TIS, and we found a research gap. There was plenty of scientific research in which TIS were evaluated. However, nearly all of these articles considered developed countries’ circumstances. Therefore, the criteria, which were used in those studies, are not capable to accurately measure functions in developing countries [11]. As a result, we focused on introducing indicators according to developing countries’ circumstances (main contribution). We found three functions which need to be redesigned.

Knowledge development is a vital function in an innovation system. However, developing countries usually lag behind in this function. In contrast, developed countries usually work at the cutting-edge of technology and knowledge, helping them to be more innovative. To fulfill this gap, developing countries are not able to rely on domestic R&D; therefore, they should use another source of knowledge. There are several sources of knowledge development (e.g., R&D, technological learning, and imitation) [4]. Thus, developing countries must use internal and external knowledge sources. It means that, along with domestic R&D, technological learning and the absorption of knowledge from abroad to develop existing knowledge are options. As a result, we proposed several indicators concerning absorptive capacity, including enough skilled staff in the R&D department to develop knowledge [61,62]; enough investment in human resource development for knowledge development [61]; sufficient physical infrastructures, such as R&D centers, laboratories, raw materials,
etc., to develop knowledge [13]; sufficient budget and expenditure on R&D in the public and private sectors [8,62,63]; and the number of sufficient patents, prototypes, and designs for production [8,62].

Technological learning is another way of acquiring knowledge. Developing countries, by using reverse-engineering, imitates imported technology, and engineers are able to acquire the design knowledge of technology [14]. According to this, the suggested indicators for assessing technology learning are as follow: How much learning and knowledge has been gained as a result of using technology? How much knowledge has been gained by copying, imitation, and reverse-engineering of technology? How much knowledge has been gained from improving imported technology?

Regarding human resource utilization, developing countries can enhance human capital by attracting their experts and skilled citizens from developed countries. The former studies show developing countries (such as China and Taiwan) have used this method to improve resource mobilization [67]. As a result, we added the indicator to consist of human resources (use of human resources living abroad).

Emerging technologies often compete with embedded technologies. Hence, the creation of protected spaces for these new technologies is essential [3]. Developing countries are far behind the developed countries regarding innovation and the delivery of products at the international level. Therefore, the proper margin to compete with these companies for entrepreneurs and domestic startups in developing countries does not exist. Therefore, we proposed an indicator for the analysis of the function of market formation (the existence of supportive policies to protect the market for domestic firms against the influence of international companies).

The second research question was how the TIS of photovoltaic in Iran, as a developing country, works. In order to answer the second question, we applied the indicators for evaluating the TIS of photovoltaic. The result shows problems concerning the functions of TIS. According to Figure 1, three functions, including entrepreneurship, knowledge exchange, and the guidance of research, are weaker than the others (under 2), and the function of legitimacy is in a better situation in comparison with the others. Hence, in this section, according to interviews with experts, efforts have been made to suggest policies to improve the performance of the photovoltaic TIS in Iran.

One of the main functions that should be considered in innovation systems is entrepreneurial activities. This function is faced with difficulties, according to our evaluations. The number of entrepreneurs in this area is low, and furthermore, these entrepreneurs do not show good performance in introducing innovation. As experts have argued, entrepreneurs in this field are few in number, merely importing technology and equipment, and then producing the final product on a finite scale, and there is little activity in R&D in new products’ developments and improvements.

If the process of development in the PV TIS is divided into (1) power plant construction and the use of technology, (2) research and development, and (3) the provision of innovative products, Iran has achieved successes in the first, but in the research section and the development of technology and new products, has not made much improvement. According to experts, the reason was the existence of supportive laws and market policies in the field of the utilization and construction of power plants. The introduction of attractive tariffs and transparent regulations for the construction of solar power plants, such as feed-in tariffs [46,47,71]) and custom duty exemptions [44,47] by the private sector, has led to relative success in the field of power plant construction and the use of technology compared with acquiring technology, developing, and improving technology. The examples of these market policies are also visible in China and Germany [45,55,56].

Currently, existing technologies are imported, and the country faces problems in applied research in this area. Therefore, in addition to paying attention to market policies, it is necessary to pay attention to the policies that bring about technical knowledge and the localization of technology. According to experts, there is insufficient applied knowledge and funding resources for R&D projects. The results of the knowledge development function indicated that there are adequate academic papers, training, and skilled human resources in this field. In fact, there is theoretical knowledge in the field, but there is a problem in applying this knowledge and transferring it to the industry and
eventually introducing an innovative product. The suggestions of experts in this field indicated that the existence of supportive policies for funding domestic R&D [46,47] and the supply of laboratory and raw materials, etc.—which requires the acquisition of applied knowledge—is one of the methods of developments in this area. Indeed, these above-mentioned policy instruments have been used in developing countries [46,47]. For example, in order to finance research and development, Taiwan has provided financial support to companies which are working in the microelectronic industry and has boosted research and development in this field [72].

Moreover, in the field of renewable energy, China has also provided financial support to companies which are focusing on improving research and development [45,46,73]. Supportive funds can also be applicable to the Iranian PV community. For instance, in the case of companies that have innovative designs, they will be given a loan if they meet the following conditions: an innovative plan, economic feasibility, high-skilled employees, and R&D units, as well as meet the minimum financial conditions to continue the company’s activity. It is also possible to force sponsored companies to hire consultants from universities to advise them on innovative initiatives. This increases the chance of turning theoretical knowledge into applied knowledge. These actions, which are more successful in the field of emerging technologies in developing countries, will improve the performance of knowledge development and knowledge exchange.

Furthermore, they have a direct positive impact on the entrepreneurial function of innovation systems. Other available actions are supporting companies that invest in new ideas and patents in the field of PV technology among academics and designers for the commercialization of ideas (venture capital). It is possible that any company that invests in new ideas or buys a patent and pushes them into commercialization can benefit from tax breaks or long-term loans [50].

In the field of laboratory centers, effective actions include equipping these centers, integrating and networking these laboratories, and facilitating the use of laboratory facilities for specialists. Such actions can lead to achieving the theoretical knowledge that is created at universities and the R&D centers of the industrial enterprises and sharing knowledge between universities and the industry.

Given that the resource mobilization function has a direct impact on the entrepreneurship function and also affects the knowledge development function, the weakness in mobilizing financial resources can also affect both entrepreneurship and knowledge development [4,8]. According to the results of the analysis, domestic and international financing problems are the major problems of this function. International financing is difficult due to Iran’s specific circumstances and economic sanctions. On the other hand, for domestic financing, it should be noted that private sector funding is considered. The government’s limited budget may not be able to respond to investment and financing in R&D in emerging technologies such as PV. Hence, domestic and foreign investors should be attracted to this field. For example, public-private partnership (PPP) is an effective way to fulfill this goal [51,52]. Tax exemption policies for foreign companies that conduct joint research projects with domestic companies, as well as providing incentives such as tax exemptions for the entry of equipment for private domestic companies, are among the preferred policies [47]. In addition, the domestic market guarantees policies for these companies (e.g., purchasing final products from R&D and domestic production) [47], and massive disclosure of these incentives not only can be instrumental in mobilizing funds for R&D but also strengthen the legitimacy of the technology. Experiences in developing countries such as Taiwan and China can be instructive in mobilizing resources in the microelectronics industry [72].

The results of the market-formation functioning evaluation indicated that, despite the sufficient size of the market within the country and the proper prospects for future demand, there are no policies or regulations that protect the domestic market against dominant technologies, as well as high-tech international companies. Researchers believe that new technologies often struggle to compete with embedded technologies. Hence, a protected space for these new technologies is essential [8]. Market protection measures should also be taken to improve the innovation system and increase the willingness of domestic entrepreneurs to enter the market [4]. Supportive policies of domestic markets, such as
anti-dumping and tariff policies, can be beneficial for developing countries [53,54]. Entrepreneurs in developing countries have little competitive power against international companies. Therefore, they must receive supportive policies in order to remain competitive.

7. Conclusions

In line with the research question, we have two main contributions. First, to evaluate the TIS in developing countries, we introduced indicators that help researchers and policymakers to evaluate TIS more effectively than before, because researchers believe that we should consider the differences between developing and developed countries [11]. For instance, the process of learning, knowledge development and market formation, and capability to invest in emerging technologies are different. Hence, based on this research gap, we reviewed the literature and identified three functions that need to be revised. These functions include knowledge development, resource mobilization, and market formation. Based on the research results, in order to evaluate the knowledge-developed function accurately in developing countries, we have to take some new indicators into account, because most developing countries use both internal and external sources of knowledge, such as technological learning, knowledge absorption, and imitation [66,74]. These vital methods for knowledge development were missing in previous studies.

Thus, we need indicators that can evaluate the function more accurately, namely, learning and knowledge acquisition, from the use of technology (such as assembling and deploying it) to acquiring sufficient knowledge of imported technology to copy, imitate, and reverse-engineer, acquiring enough knowledge to improve existing technology.

When it comes to resource mobilization, developing countries can benefit from international and national resources. According to the Kyoto Protocol and the Paris Agreement, developing countries can use international funding. On the other hand, attracting expert citizens from developed countries can provide those countries with very rich human resources [67].

Developing countries, in order to form a market for emerging technology, in addition to solving domestic barriers, must be able to protect the domestic market against international companies who can easily take over the market because of the economical scale production and dumping [53,54].

We applied these indicators to the photovoltaic TIS of Iran as a developing country. This helped us to examine the indicators in the experimental research. This was the first time that the TIS of photovoltaic in Iran has been evaluated, and the results showed problems in the function of TIS. Moreover, in the end, we conducted interviews to introduce policy instruments to solve the identified problems. These suggestions are very valuable for policymakers that are interested in utilizing the photovoltaic energy in Iran.

Iran, as one of the largest oil producers, can be affected by the increase or decrease in oil prices, and this effect can be demonstrated in the research and development budget and the use of new technologies for greater energy efficiency, considering the effects of large factors such as economic growth or the crisis in oil prices—which were considered as factors influencing the innovation system [75,76]. In future research, the role these factors play in the functioning of the innovation system can be examined. In addition, the role of political and macroeconomic factors in the PV TIS could be examined. Moreover, an effort in extending these studies and linking them to different levels of analysis may be beneficial, both for research on the TIS and for innovation literature in general [77].

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