Entrepreneurship development in photovoltaic technological innovation system: a case study in Iran

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Abstract

Purpose – This paper aims to develop a causal feedback structure that explains the dynamics of entrepreneurship development in Iran's photovoltaic (PV) technological innovation system (TIS) to design effective policy interventions for fostering PV innovation.

Design/methodology/approach – This study adopts the system dynamics approach to develop the causal structure model. The methodology follows a systematic method to elicit the causal structure from qualitative data gathered by interviewing several stakeholders with extensive knowledge about different aspects of Iran's PV TIS.

Findings – Lack of technological knowledge and financial resources within Iranian PV panel-producing firms are the main barriers to entrepreneurship development in Iran's PV TIS. This study proposes two policy enforcement mechanisms to tackle these problems. The proposed feedback mechanisms contribute to the domestic PV market size and knowledge transfer from public research organizations to the PV industry.

Practical implications – The proposed policy mechanisms aid Iranian policymakers in designing effective policy interventions stimulating innovation in Iran's PV industry.

Originality/value – The main contributions of this study include conceptualizing the causal structure capturing entrepreneurship dynamics in emerging PV TIS and proposing policy mechanisms fostering entrepreneurship and innovation in PV sectors.

Keywords Entrepreneurship, Technological innovation system, Innovation policy, Photovoltaic panels, System dynamics, Qualitative data

Paper type Research paper

1. Introduction

During the past decades, urgent concerns about climate changes, energy security issues and sustainable economic growth have induced many countries to develop clean technologies not only for their own use but also for export to other countries. With this aim, many governments worldwide have strived to foster innovation in various green technological fields (Aflaki *et al.*, 2021). Despite the crucial importance of renewable technology advancement, most firms in developing countries avoid involving in innovation activities due to inherent cost and risk of innovation (Chang *et al.*, 2021). In this regard, many studies in the literature have stressed the role of government and policy interventions, particularly in emerging sectors (Soltanzadeh *et al.*, 2020). This study is aimed to analyze the main barriers that have hindered innovation development in Iran's photovoltaic (PV) panel industry over the last three decades, with the objective of proposing policy interventions to stimulate innovation within this sector.

There is an extensive literature arguing that innovation takes place within a so-called "innovation system" (Hekkert *et al.*, 2011). Innovation system is fundamentally characterized

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by complex dynamics arising from interactions among heterogeneous actors over time (Samara *et al.*, 2012). Understanding this dynamics is vital for policymakers to effectively manage the opportunities and bottlenecks associated with a specific technological trajectory. Taking the systematic and dynamic perspectives of innovation systems into account, this study uses the system dynamics (SD) approach to analyze the main mechanisms shaping the dynamics of Iran's PV innovation system.

The SD model of this study is developed using the concept of technological innovation system (TIS), a well-accepted framework for analyzing policy issues in a specific technological field (Miremadi and Baharloo, 2020). The literature on TIS introduces several concepts that facilitate the analysis of innovation system dynamics. The most well-known ones are "development phases" and "motors of innovation" as proposed by Hekkert *et al.* (2011) and Suurs (2009), respectively. Hekkert *et al.* (2011) divide the evolution process of TIS into four development phases. Suurs (2009) characterizes four motors of innovation, corresponding to the four development phases introduced by Hekkert *et al.* (2011). These motors should be successively activated throughout the life cycle of a TIS. Figure 1 represents the four development phases along with the four innovation motors.

According to the Hekkert and Suurs, specific functions are key drivers of TIS dynamics in each development phase. Hekkert *et al.* (2011) argue that to identify the policy issues and solutions regarding a TIS, the maturity of the TIS must be taken into account. Based on this viewpoint, we first analyze the development phase of Iran's PV TIS to specify our exact system of interest.

Iran's PV industry was born in 1991 when the first PV panel producing company with a capacity of 3 MW was established. Based on the distinct socio-technical patterns in the history of Iran's PV TIS, we deliberately divide the historical path of the system into three main periods, including 1991–2005, 2006–2012 and 2013–presence, to better represent the evolution of the PV TIS. Over the last three decades, the number of Iranian PV panel producers has increased to six with a collective production capacity of 375 MW, and the total PV system installed capacity has risen to 502 MW (Figure 2a) (*SATBA*, 2023). Moreover, over the past two decades, the capacity of the branch titled "Renewable Energy Engineering" in the PV-relevant majors such as Physics, Electronics, Mechanical Engineering and Metallurgical Engineering has been expanded at some Iranian universities

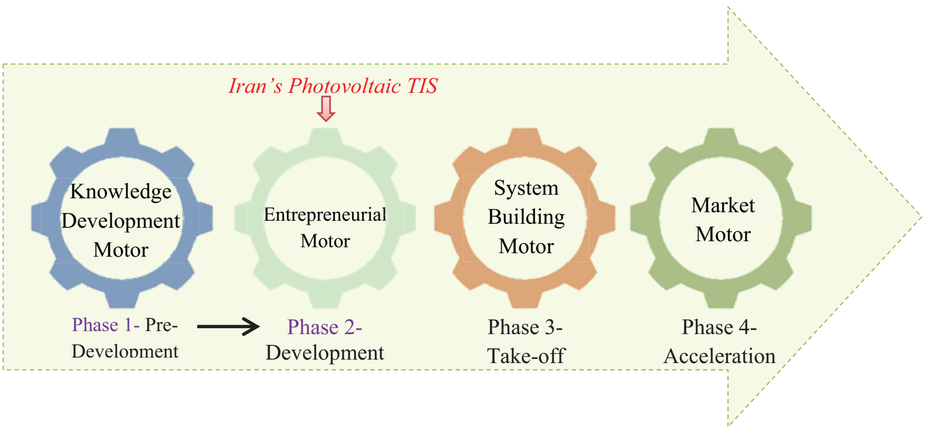
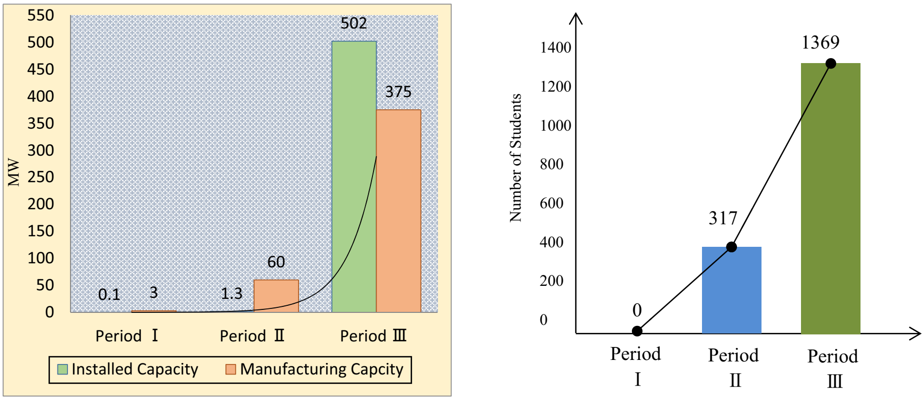


Figure 1.
TIS development phases and their corresponding innovation motor

Source: Authors' own work



(a) **(b)**

Figure 2. Historical data related to Iran's PV TIS

Source: Authors' own work

(Figure 2b) (Sanjesh, 2023). As a result of this event [1], over the third period, 130 [2] peer-reviewed papers have been published by Iranian research organizations in the field of PV panels. This achievement is considered acceptable when compared with Germany, a leading PV country with almost the same population as Iran's, which produced 204 articles during the same period (*Scopus*, 2023).

Imitation of PV panels existing in the global market by Iranian PV manufacturing firms and the deployment of the produced panels in the local market over the past decades have led to the promotion of knowledge – both technical and non-technical (i.e. market-related and management knowledge) – in the field of PV panels. Moreover, the research and development (R&D) activities conducted by Iranian public research organizations have contributed to knowledge accumulation within Iran's PV TIS. Based on the presented evidence, it is acknowledged that the first development phase, namely, the knowledge development phase, has been already activated in Iran's PV TIS. However, based on our survey, Iranian PV panel producing companies have not yet engaged in developing any innovative PV panels with the aim of entrepreneurship. This indicates that the second development phase (i.e. entrepreneurship phase) has not been initiated in the PV TIS.

Given the critical role of policy intervention in entrepreneurship development (Soltanzadeh *et al.*, 2020), there is lack of evidence indicating that effective innovation policies have been implemented in Iran' PV sector. Global innovation index reports for Iran reveal that the performance of the Iranian Government in terms of facilitating innovation activities has not been satisfactory over the last two decades. The details of these reports show that Iran has averagely ranked 90th in innovation inputs among approximately 130 countries (Global Innovation Index, 2022). Given that the main part of innovation inputs pertains to governance activities, such as policy and law making, this suggests a lackluster performance by the Iranian Government. In particular, based on global innovation index, Iran has averagely ranked 105th in Business Environment index, which is measured via two subindexes including policies for doing business and entrepreneurship policies and culture (Global Innovation Index, 2022). Accordingly, lacking effective policies is a barrier to entrepreneurship and innovation development in Iran. In this regard, the main questions in this study are what obstacles hinder entrepreneurial activities and what policies can facilitate entrepreneurship and innovation development in Iran's PV TIS.

To address these questions, this study develops a causal feedback structure that explains the dynamics of entrepreneurial behavior within the PV TIS. Through mapping the causal structure governing this dynamics, we provide insight into the primary barriers hindering entrepreneurial activities in the PV sector, thereby guiding Iranian policymakers in the development of effective policies. The causal structure was developed using the systematic method introduced by Kim and Andersen (2012) for eliciting causal structures from qualitative data. Qualitative data for this study was acquired through interviews with diverse stakeholders across various domains within Iran's PV TIS. Hence, the presented causal map reflects the mental models of the interviewed stakeholders, who possess extensive knowledge about different aspects of Iran's PV system. Section 3 provides more details about the interviewed stakeholders.

Inspired by the insights generated from the causal map, we propose two policy solutions aimed at fostering entrepreneurship in the PV TIS. The feedback structure related to each policy is delineated to illuminate how the proposed policies would be implemented over time and to highlight the requirements that should be considered during policy formulation. Briefly, these proposed policy mechanisms contribute to the growth of the domestic PV market size and facilitate knowledge transfer from public research organizations to the PV industry.

The remainder of this article is structured as follows. The next section, Section 2, reviews pertinent literature, followed by Section 3, which elaborates the steps taken to develop the proposed causal map. In Section 4, the feedback structure of Iran's PV TIS is delineated. Section 5 explains our recommended policies and associated feedback mechanisms. Finally, conclusions, implications and a discussion on future research are presented in Section 6.

2. Literature review

Studies in the literature on the innovation evolution revolve mainly around the investigation of factors inside organizations and contextual factors outside organizations that impact the development of innovation. Regarding the factors inside companies, Alawamleh *et al.* (2023) assessed the extent to which 11 internal factors influence firms' performance in terms of innovation development. Naveed *et al.* (2022) examined the influence of organizational culture on organizational innovation and in turn organizations' effectiveness.

The present study aims to analyze the dynamic behavior of a TIS, where different actors interact with each other to develop technological innovation. Therefore, our focus lies within the research strand that addresses TIS dynamics. Various studies in the literature have addressed the dynamics of TIS through different approaches. The critical review of these approaches in this section highlights a methodological gap in the analysis of TIS dynamics. This study contributes to the literature of TIS dynamics by conceptualizing of a causal feedback structure that explains the dynamics of TIS in the second development phase, namely entrepreneurship development.

Moreover, there are few research works addressing policy analysis for innovation development in the PV sector, particularly in Iran. Previous studies addressed TIS dynamics using approaches and methodologies different from those adopted in this study. We believe that the approach and methodology used in this study offer a more comprehensive insight into TIS dynamics, thus, providing more effective guidance for Iranian policymakers involved in PV innovation development.

To illuminate these two research gaps, this section first critically reviews approaches developed in the literature for analyzing TIS dynamics. Subsequently, it assesses the contributions of prior studies to policy analysis in PV sectors. Finally, in this section, the entrepreneurial process is delineated as the theoretical underpinning of this study.

2.1 Literature review on technological innovation system dynamics

The dynamics of TIS has been studied in the literature through various approaches. One strand of the literature concentrates on TIS building blocks (i.e. actors, networks and institutions) to examine structural strengths and weaknesses influencing the development of a technology (Ng and Thiruchelvam, 2012; dos Santos e Silva *et al.*, 2019). This approach, which is called the "structure approach," is criticized for its failure to evaluate of TIS performance in terms of new technology development, diffusion and utilization (Bergek *et al.*, 2008). To deal with this limitation, the "function approach" was introduced by Hekkert *et al.* (2007), who characterized seven functions for TIS. This approach suggests that TIS performance can be assessed by evaluating its functions – i.e. the key activities or processes that contribute to the development, diffusion and use of innovations (Bergek, 2002). According to the function approach, as much as the functions are conducted well, TIS experiences a higher performance. Bergek *et al.* (2008) developed this approach into the structure–function approach enabling the assessment of TIS building blocks and functions within an integrated framework.

Studies that used the function approach to analyze TIS dynamics can be categorized into two groups. One research strand analyzes TIS dynamics by mapping the fulfillment of each TIS function over time (Haddad and Uriona Maldonado, 2017; Kebede and Mitsufuji, 2017; Gruenhagen *et al.*, 2022). Within this research strand, TIS functions are examined independently, and the causal relations among them are often overlooked. Suurs (2009) argues that the causal relations among the functions have significant effects on the dynamics of TIS.

Accordingly, another strand of the literature addresses TIS dynamics by exploring the interplay among TIS functions. The most popular researches in this area were conducted by Suurs (2009) and Hekkert *et al.* (2011). To characterize different phases of TIS evolution, these scholars delineated "motors of innovation", the functional feedback mechanisms made up of interactions between TIS functions. Following these researchers, several studies in the literature have developed functional feedback structure to explore the dynamics of TIS in various technological domains, such as agricultural technologies in The Netherlands (Hermans *et al.*, 2019) and flywheel energy storage in German-speaking Europe (Wicki and Hansen, 2017). Bagheri Moghaddam and Nozari (2023) investigated the dynamics of TIS associated with natural gas storage technology in Iran. Using the concept of "motors of innovation", they identified the main barriers impeding technological development in the TIS and provided several policy recommendations. Notably, their analysis took into account the maturity of the TIS while assessing the current state of the gas storage technology in Iran.

In addition, some studies have exploited SD models to delineate the interplay among TIS functions and the four motors of innovation with a focus on exploring the dynamics of transition from one motor to another in TIS (Walrave and Raven, 2016; Azad and Ghodsypour, 2018). Sadabadi *et al.* (2023) studied the dynamics of interplays among functions in the Iranian PV TIS using an SD model. This study used the SD model to identify the TIS functions with lackluster performance and evaluate their impacts on the overall TIS performance over time.

The main issue related to using the functions as a basis for exploring TIS dynamics is that these functions only highlight the overall main processes contributing to TIS performance (Hekkert *et al.*, 2011). This implies that the analysis of functional dynamics provides insights solely into the general causal mechanisms influencing TIS behavior. When the (seven) TIS functions are considered as the system variables to explain TIS dynamics, the modeling is constrained by a limited number of system variables.

Consequently, this approach would inevitably overlook some variables and feedback loops crucial for describing TIS dynamics in a more accurate and reliable. Therefore, there is need for more detailed causal feedback structure to capture the complexity of TIS dynamics.

To tackle this issue, this study develops an SD model using more detailed variables instead of the TIS function. The analysis of TIS at the level of detailed variables allows the identification of a broader array of variables and causal loops influencing the dynamics of the system, thereby communicating more information about main mechanisms underlying the dynamics of a TIS. In this sense, detailed causal feedback structures would assist policymakers in better comprehending the sources of unfavorable behaviors and designing more effective policy interventions. Figure 3 [3] illustrates the position of the SD approach within the literature on TIS dynamics.

Several studies in the literature have tried to explore the dynamics of innovation systems through the SD modeling approach, but they are rare and fragmented. A systematic review of these studies was conducted by Uriona and Grobbelaar (2019). Some studies concentrate on innovation processes within companies while overlooking the external environment of firms (Stamboulis *et al.*, 2002; Choi and Kim, 2008; Cui *et al.*, 2011). Others have broadened their system boundaries by incorporating subsystems related to the external environment, such as public education (Allena-Ozolina and Bazbauers, 2017; Gunadi *et al.*, 2018) and market (Ahmadian, 2008; Milling and Maier, 2009) subsystems. Galanakis (2006) incorporated an array of variables associated with different subsystems, including financial, market and human resources into his model, but these variables were largely considered as exogenous factors.

In recent years, other research have applied the SD approach to explore the impact of specific factors on the dynamics of innovation ecosystems. Yung *et al.* (2023) investigated the effects of collaboration among actors on the dynamics of an innovation ecosystem using an SD model. Their study reveals that the innovation collaboration significantly contributes

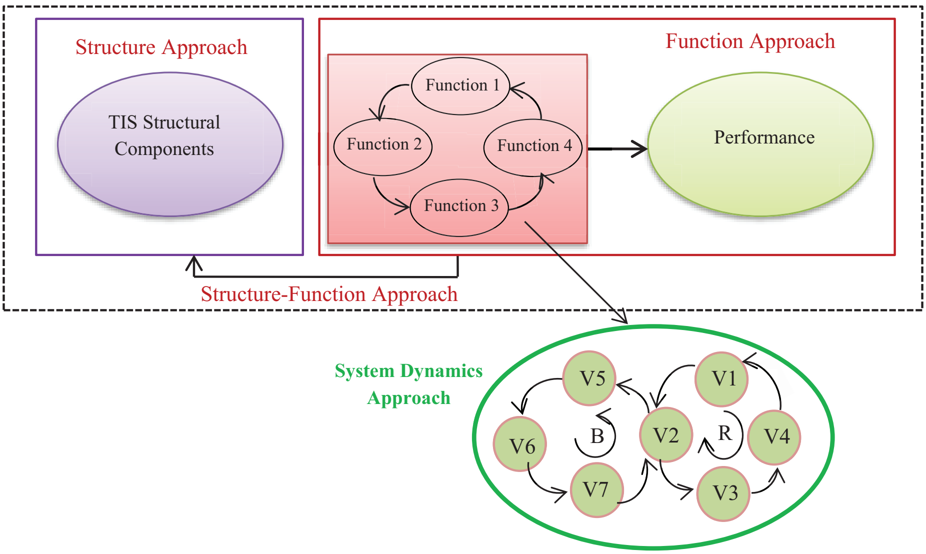


Figure 3. Positioning SD approach in the literature of TIS dynamics

Source: Authors' own work

to the performance of innovation ecosystems. Paasi *et al.* (2023) identified the actors influencing the dynamics of innovation ecosystems and explored the causal relations among these actors using an SD model. Their findings highlight the crucial role of knowledge flow in innovation development within innovation ecosystems. Eghbali *et al.* (2022) analyzed the effectiveness of policy interventions designed to stimulate green innovation in competing firms. This study suggests that government should encourage collaboration between firms and start-ups in situations where start-ups are mature and possess high technological capabilities.

The SD model presented in this study significantly differs from those found in the existing literature in terms of system boundary and causal structure. Taking into account the development phase of TIS, this research specifically concentrates on the dynamics of TISs in the second development phase, namely entrepreneurship development. While several research in the literature studied the dynamics of entrepreneurial ecosystems, they often lack a holistic approach. Cantner *et al.* (2021) categorized the lifecycle of entrepreneurial ecosystems into four phases and characterized the features of each phase. Using structural equation modeling, Rocha *et al.* (2022) analyzed the impact of knowledge and socioeconomic dimensions on entrepreneurial ecosystem dynamics. Their findings indicate that the both dimensions have positive effect on entrepreneurial ecosystem dynamics, but the impact of socioeconomic ecosystem is higher than knowledge ecosystem. Buratti *et al.* (2022) explored the positive effects of entrepreneurial and intrapreneurial activities on the dynamics of entrepreneurial ecosystem using a regression model.

In the literature, only a few studies have linked the SD method, known for its holistic approach, with entrepreneurship. These studies have developed a system dynamics model to explain the dynamics of the entrepreneurship process within organizations (Ross, 2005; Oganisjana and Matlay, 2012; Bloodgood *et al.*, 2015), but they did not considered environmental factors such as market and external knowledge sources, such as public research centers.

2.2 Innovation policy analysis in the photovoltaic sector

The literature review indicates that analyses of innovation policy in the PV sector have been mainly conducted through the innovation system concept. These studies generally adopted the innovation system approach at the sectoral and technological levels. The former research strand focuses on analyzing the coevolution of building blocks in sectoral innovation systems, as defined by Malerba (2002) including actors, networks, institutions and market. These studies adopted both static (Marinova and Balaguer, 2009) and dynamic approaches (Akoijam and Krishna, 2017; Shubbak, 2019).

Studies based on TIS approach primarily use functional analysis to identify barriers to PV technological development in different countries such as Japan and Netherland (Vasseur *et al.*, 2013) and China (Goess *et al.*, 2015). Through the analysis of TIS functions in the Mexican PV sector, Fernandez and Watson (2022) suggest that, in comparison with other policies, the Mexican Government should give higher priority to policy instruments encouraging knowledge development. Zhang *et al.* (2023) highlighted the importance of talent policies in fostering innovation in China's PV industry. In addition, several scholars have investigated the impact of different policy instruments on PV innovation development using econometric models (Che *et al.*, 2022a, 2022b).

Several studies in the literature also investigate factors affecting PV TIS dynamics in Iran. Using the function approach, Esmailzadeh *et al.* (2020) identified several functional problems related to Iran's PV TIS and proposed policy recommendations to tackle these issues. Rad and Sadabadi (2022) explored functional deficiencies associated with the Iranian PV TIS and proposed several strategies to improve the TIS performance. Sadabadi *et al.* (2023) examined the performance of TIS functions in Iran's PV industry to identify the positive and negative factors affecting the PV TIS dynamics, leading to several policy recommendations to foster PV innovation.

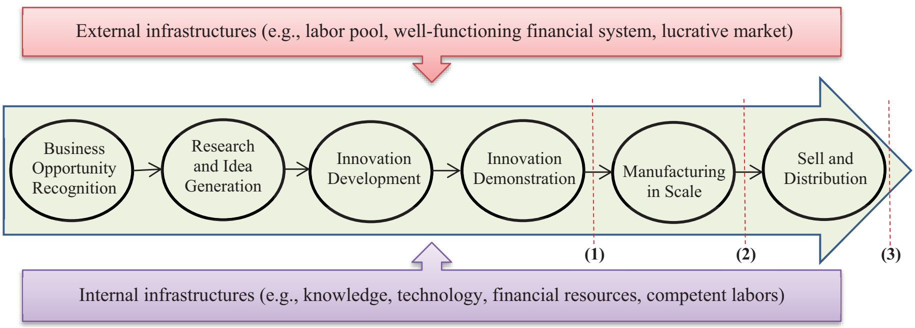
The prior studies have commonly concluded with the identification of a list of policy issues or policy recommendations concerning PV innovation. A common shortcoming in these studies is the lack of discussion about the requirements and mechanisms affecting the implementation of the proposed policies. This insight is crucial, considering that many policies encounter challenges during the implementation phase (Hudson *et al.*, 2019). Recognizing this shortcoming, the present study will delineate the causal feedback structures for the recommended policies to shed light on the main mechanisms governing the dynamics of the policies implementation.

2.3 Theoretical background on the entrepreneurship process

Entrepreneurship is defined as a process through which entrepreneurs convert knowledge into technological innovation [4] to exploit a specific business opportunity (Suurs, 2009). Bergek *et al.* (2008) argue that a TIS without entrepreneurial activities will stagnate. Figure 4 represents the main components of the entrepreneurship process. The first step in this process involves identifying different business opportunities and selecting the most attractive one based on its prospect profitability and firms' capability to exploit it. Subsequently, entrepreneurs should seek viable technological solutions that can potentially respond to the business opportunity. These solutions may be derived through internal research or sourced externally, such as from universities.

After selecting the most promising technological idea, firms should develop it into a marketable product or prototype. In this stage, the technical soundness of the product is tested in a laboratory environment. Following this, during the demonstration stage, the firm tests the prototype application in a real environment (pilot project) to assess the innovation's usefulness under actual conditions and scale. The final and crucial step, distinguishing entrepreneurship from innovation and marking the success of an entrepreneurial project, is the commercialization of innovation (Datta *et al.*, 2013). Entrepreneurship is, in essence, accomplished through the introduction of the newly developed product to the market.

The commercialization of innovation can be done in three stages, as indicated by the red lines in Figure 4. Entrepreneurs may opt to sell their innovations to other entities for them to scale up (Line 1). This scenario often occurs when entrepreneurs, typically newly established



Source: Authors' own work

Figure 4. The schematic representation of entrepreneurship process

small firms or small university spin-offs, lack the necessary human capital and financial resources for scaling up their innovations, or when they face challenges in appropriating the possible income (Lindholm-Dahlstrand *et al.*, 2019). Conversely, large incumbent firms engaged in entrepreneurship typically choose to internally develop and manufacture their innovation. They may adopt the strategy of outsourcing the deployment (sell and distribution) of the new product to save their resources (Line 2) or directly engage in selling and distribution to fully exploit their commercial potential (Line3).

Entrepreneurial activities within a particular technological field typically necessitate various infrastructures (Lindholm-Dahlstrand *et al.*, 2019). Innovating firms are expected to possess diverse resources, such as knowledge and technologies related to technical and nontechnical aspects, financial resources and skilled labor. The availability of these resources is significantly influenced by external (national) infrastructures such as a public education system, a well-functioning financial system and a lucrative market (Sanchez, 2018). Although all of these functions can be conducted by an international TIS, the specific characteristics of different countries in terms of economic, cultural and institutional conditions make national boundaries critical for TIS analysis (Vasseur *et al.*, 2013).

3. Research method

To capture the dynamics of Iran's PV TIS, we apply an SD approach, which highlights a holistic approach. SD is acknowledged as a powerful tool for describing and analyzing dynamically complex systems (Zahedi Rad *et al.*, 2023). Based on the SD approach, there is always an underlying causal feedback structure that are responsible for problematic behaviors (Sterman, 2000). SD maintains that problematic behaviors must be corrected through revision to the feedback structures (Sterman, 2000). Accordingly, the analysis of feedback structures breeds practical insight into the sources of a problem, aiding policymakers in developing more effective policy interventions.

In causal structure models, variables are linked together by arrows marked by positive or negative signs. A positive link indicates that two variables change in the same direction, while a negative link signifies opposite changes. In real systems, these relations between variables often create feedback loops. In a feedback loop, a change in one element indirectly affects itself through the other elements participating in this loop. If the initial change is compounded by further change, the loop is a positive or so-called reinforcing loop; whereas, if change in one direction is counteracted by changes in the opposite direction, the loop is negative or so-called balancing feedback. Typically, the structure of a system comprises both positive and negative feedback, which are responsible for the behavioral patterns of the system (Sterman, 2000).

To develop the causal structure explaining entrepreneurship development in Iran's PV TIS, we apply a systematic method introduced by Kim and Andersen (2012) for eliciting a causal map from qualitative data. By involving the mental model of various stakeholders and experts in the procedure of model building, Kim and Andersen shift the power from modelers to the data. This reduces the subjective influence of modelers and instead involves expert knowledge of various stakeholders in the model building, thereby enhancing confidence in the resulting model and its policy recommendations. The five-step method of Kim and Andersen follows (i) open coding to identify and classify various phenomena related to the problem in the data, (ii) the identification of individual causal relationships among variables, (iii) visualizing these relationships through words-and-arrow diagrams, (iv) generalizing the causal structure and (v) representing the links between different parts of the final causal map and the data source within a data source reference table.

The introduced method would add methodological transparency and rigor to the process of building causal structure from qualitative data, but at the expense of considerable time and effort by modelers (Kim and Andersen, 2012). To address this challenge, several studies in the literature have proposed revisions to Kim and Andersen's method (Yearworth and White, 2013; Eker and Zimmermann, 2016; Kenzie, 2021). The discussion of these modifications is beyond the scope of this paper. In this study, we adopt two modifications, including (1) identifying various causal structures (including individual variables, causal links and feedback loops) throughout the coding phase rather than identifying only individual causal relations as offered by Kim and Andersen (2012), and (2) using MAXQDA computer-aided qualitative data analysis software instead of the mentioned data source reference table to maintain the links between the resulting causal relations and the data source. Figure 5 represents the steps taken in this study to develop the proposed causal map.

According to the methodology steps, we conducted 15 semi-structured interviews involving various stakeholders: five senior managers from different Iranian PV panel-producing companies, five university faculties who have recently published peer-reviewed papers elaborating on technological innovation ideas in PV panels and five government officials with relevant backgrounds. The interviews generally lasted for about one and a half hours and followed open-ended focused questions covering various topics. These questions aimed to extract the mental models of interviewees regarding the dynamics of entrepreneurship development in Iran's PV TIS. Data collected through the interviews were recorded by audio and then transcribed into written form. The interview transcripts were inputted into MAXQDA software for the coding analysis. In step 2, codes were identified by carefully reading the text of the transcripts. During the coding process, causal structures at different scales were described in quotation comments (see Table A1 in Appendix for coding examples). The MAXQDA software facilitates easy access to the coded segments (quotation) related to each comment. In addition, all the quotations can be numbered via software according to the document number and the order of the quotation (see Table A1 in Appendix). This numbering system allows for later tracking of the link between causal structures and the source data.

In Step 3, we compiled a table detailing all identified causal structures along with their corresponding quotation number, facilitating efficient navigation of the source data. In the next step, we transformed variables and causal links recorded in the causal mapping table

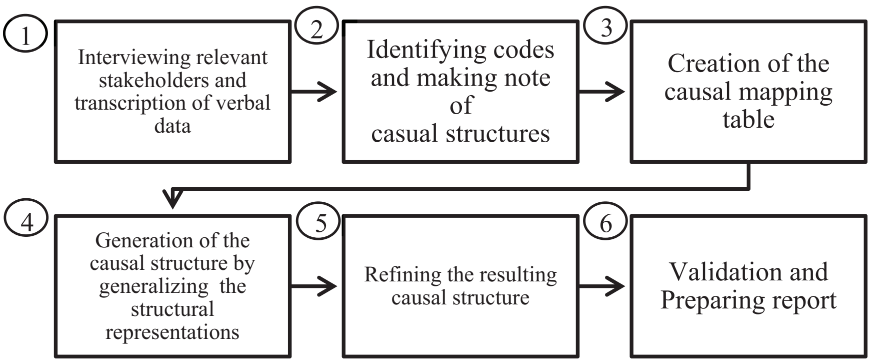


Figure 5.
The research method's steps

Source: Authors' own work

into a causal structure consistent with the conventions and approach of system dynamics modeling. To integrate multiple structures into one composite map, we generalized the causal structures by using more general terms for common variables. Once all variables and causal links were positioned, the authors reviewed the causal map for any possible edits. For example, some causal relations were decomposed to enhance the clarity of causal relations, and model sections related to synonyms or causal structures with the same idea were combined.

The validation of a causal map developed through the systematic method is inherently tied to the accuracy of the method's execution, contingent on the modelers' proficiency in extracting and transforming interviewees' mental models into a coherent causal structure (Kim and Andersen, 2012). We have strived to execute the method's steps accurately with a reasonable degree of confidence based on our background knowledge of SD methodology, Iran's solar system and TIS-related concepts. Furthermore, after the completion of the model building, we presented the generated causal map to two senior managers of Iranian PV panels manufacturing companies, two government officials, and two academic individuals who were previously interviewed to check the models' validity. In the validation sessions, we provided a brief overview of system thinking and dynamics, guidance on how to interpret causal diagrams and a description of the different parts of the generated feedback structure. Subsequently, we asked the interviewees if the diagram accurately reflected their mental model, if any aspects were overlooked and if they had any comments on the terms used to describe the variables. Based on their comments, the authors refined the model and finalized it for reporting.

4. The causal model

In this section, we present our findings gained through the implementation of the research method. Based on the variables identified in the source data, the causal structure incorporates three subsystems, including internal R&D, joint R&D with public research centers and market subsystems. In Iran's PV industry, PV panel manufacturing firms are supposed to be the only potential entrepreneurs. Iranian research organizations are not anticipated to engage in entrepreneurial activities due to lack of financial resources and technology knowledge. Moreover, Iranian PV manufacturers are expected to handle the entire process of entrepreneurship depicted in Figure 4, given the absence of independent distributors handling the deployment process.

Figure 6 represents the causal structure extracted from the interview transcripts. We present the developed causal structure in the form of stock-and-flow diagram to communicate extra information about the nature of variables (i.e. stock, flow and auxiliary). The following subsections elaborate on the causal structure of each subsystem while elucidating the connection between the structure and the source data. Positive and negative feedback loops in the model are indicated by "R" and "B," respectively.

4.1 The internal research and development subsystem

Figure 7 shows the causal structure related to the internal R&D subsystem.

Based on our interviews, all the industry participants agree with the entrepreneurship process shown in Figure 4. Accordingly, the behavior of entrepreneurship activities is initially influenced by the number of business opportunities identified by domestic firms. Interviewees from the industry emphasized that the opportunity recognition should be based on customers' needs, wants and expectations identified through market research. They stressed that prior sales facilitate this process by providing the opportunity to gather feedback from customers (Loop R1), as is illustrated in the following quote from one of the industry participants:

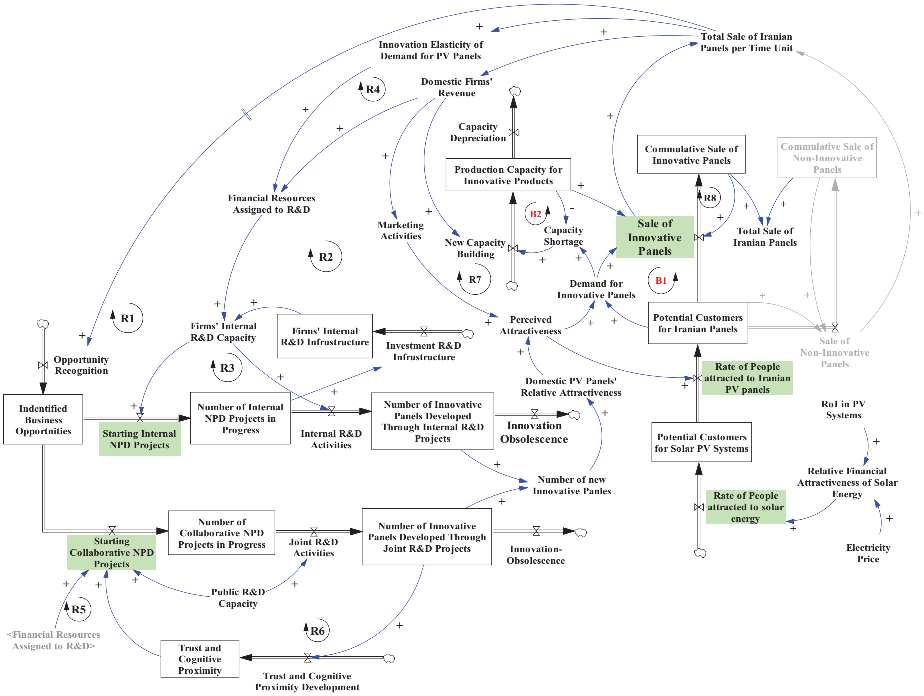


Figure 6.
The causal structure elicited from the qualitative data

Source: Authors' own work

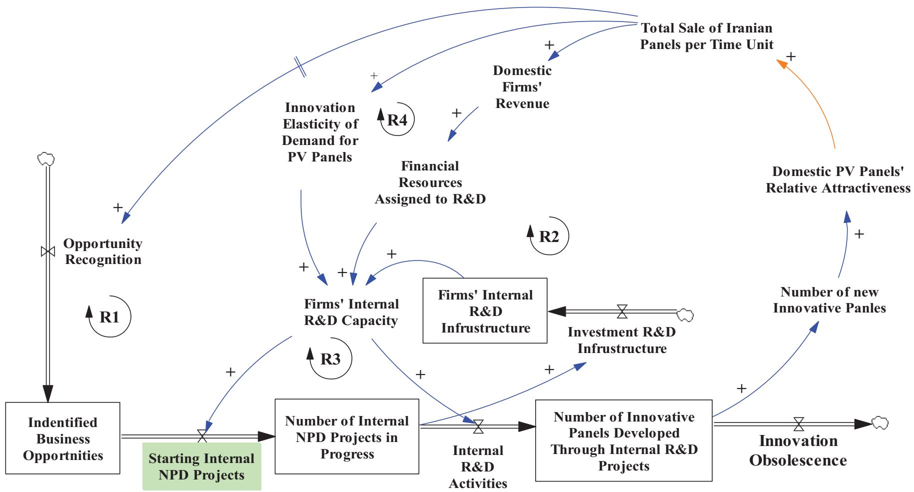


Figure 7.
The causal structure related to the internal R&D subsystem

Source: Authors' own work

[. . .] the ultimate objective of new product development is to satisfy customers [. . .] our firms have not had any chance to communicate with vast customers because of lack of a large market and sale in the past years.

In Figure 7, the delay sign (||) between sale and opportunities recognition variables stresses that it takes time for customers to apply the purchased panels and give feedback.

Although our interviews show that some of the firms have already identified a number of business opportunities, none of them has initiated any new product development (NPD) project. This implies they lack some infrastructures required for starting an entrepreneurial project. According to our interview with industry participants, the shortage of financial resources is the most significant barrier to starting NPD projects in Iranian PV firms (Loop R^2). This is captured in the following quote from the industry:

Given the present [low] turn-over in Iranian PV panel producing companies, our business is not bankable, nor is it interesting to venture capital. Therefore, the only source we can count on for investing in NPD is our income from our sales. [. . .] with such a weak PV market in the country, [. . .] we cannot bear the cost and risk of innovation projects. [. . .] if we had adequate financial resources, we would know how to cope with our other deficiencies.

Another obstacle mentioned by the industry participants is lack of technical laboratory equipment required for R&D activities. Regarding such equipment, one of the industry representatives mentioned:

[. . .] one of our primary problems is that we do not have laboratory equipment [. . .] what we do need is the laboratory enabling us to examine the performance of a newly developed panel under different conditions. [. . .] what we currently have in our laboratory is not those required for R&D.

The equipment examples mentioned by interviewees include the sun simulator, thermal camera and standard laboratory equipment such as radiometers and thermocouples. Based on these examples, we can perceive that laboratory assets have an evolutionary nature (Loop R3), meaning they can be accumulated over time through each investment in NPD projects.

The final factor affecting firms' decisions to engage in an NPD project is the innovation elasticity of the PV demand, referring to the relative sensitivity of the demand to the degree of innovation in PV panels. Industry participants maintained that a larger market size increases the chance of a new product being adopted by potential customers, and, thus, enhances innovation rents (Loop R4). This is reflected in this quote:

[. . .] the level of knowledge about PV technologies is fairly low in our country. [. . .] while we have trouble selling double-glass panels [a new innovative panel already existing in the world], you cannot expect us to put our effort into developing an innovative panel. [. . .] when it is reasonable to do so that you see PV systems on the rooftop of more than 80 % of houses in Iranian cities [. . .] [or] see more than 200 megawatt annual demand in the country.

It is worth mentioning that none of the industry identified access to skilled knowledge workers as an obstacle to R&D activities in their companies. This perception is likely attributed to the substantial capacity expansion in relevant fields at Iranian universities over the last decades.

4.2 The joint research and development with public research centers subsystem

Along with internal R&D, joint R&D with public research centers can be considered a means to convert identified business opportunities into technological innovation (Kim and Castillejos-Petalcorin, 2020; Ruangpermpool *et al.*, 2020). The bold part of Figure 8 represents the causal structure pertaining to the joint R&D with public research centers subsystem.

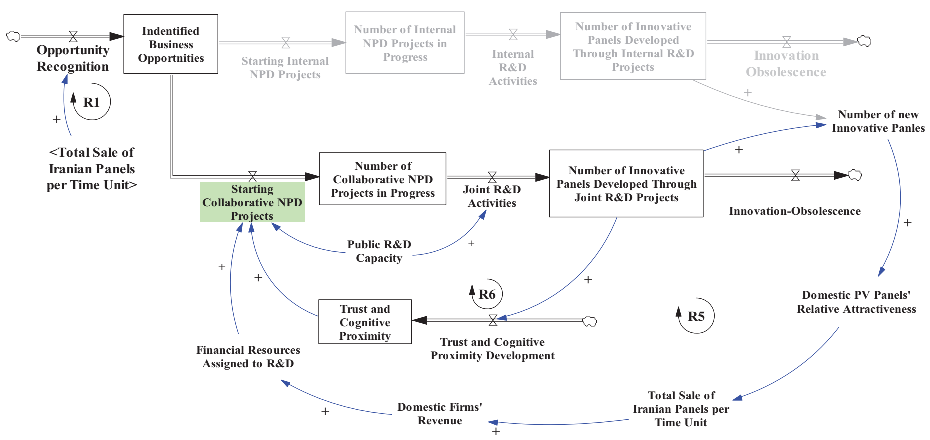


Figure 8.
The causal structure related to the joint R&D subsystem

Source: Authors' own work

As mentioned earlier, many practical peer-reviewed papers have been published by Iranian researchers about improving the performance of PV panels. However, none of them has been exploited by the industry for developing improved PV panels. Participants from research organizations believe that involving local researchers into industrial R&D projects related to their published idea would enhance these projects efficiency, as is reflected in the following quote:

> *[. . .] the person who has published a paper has a good command of the subject [. . .] naturally, it is not possible to bring and explain all details in manuscript, while some of these details serve as a panacea in practice [. . .] we cannot say that the industry is not able to put our idea in practice, but this would be probably done through a large trial-and-error and by consuming high cost and time [. . . .] the presence of the idea owner in NPD projects can enhance the agility of firms' R&D activities and reduce cost and time of R&D accomplishment remarkably.*

Despite the potential benefits, no collaboration between Iranian research centers and the PV industry has been shaped so far. The primary obstacle from the industry side is their financial distress and cash-flow crisis (Loop R5), as evident from the quotations mentioned in the previous subsection. Nonetheless, there are other barriers mentioned by interviewees. One of these barriers is that the R&D capabilities of universities have not been perceived by the industry appropriately. While most academic interviewees stressed that their research was experimental and they had used laboratory setup, including equipment like a sun simulator, thermal cameral and so on, to conduct their research, the industry participant tended to assert that these researches are not practical. This suggests that the industry might not be fully cognizant of R&D capacity within public research organizations. This is reflected in the following quote from an industry interviewee: "most of our researchers' studies are simulation-based and theoretical rather than practical, and they are not tested in a laboratory or real environment."

Another barrier to the university-industry collaboration is lack of cognitive proximity and trust among these stakeholders, as indicated in the following quote from the industry: ". . .the main drawback of these [domestic] studies is their negligence in business aspects of a technical issue [. . .] they mostly lack a cost-and-benefit analysis."

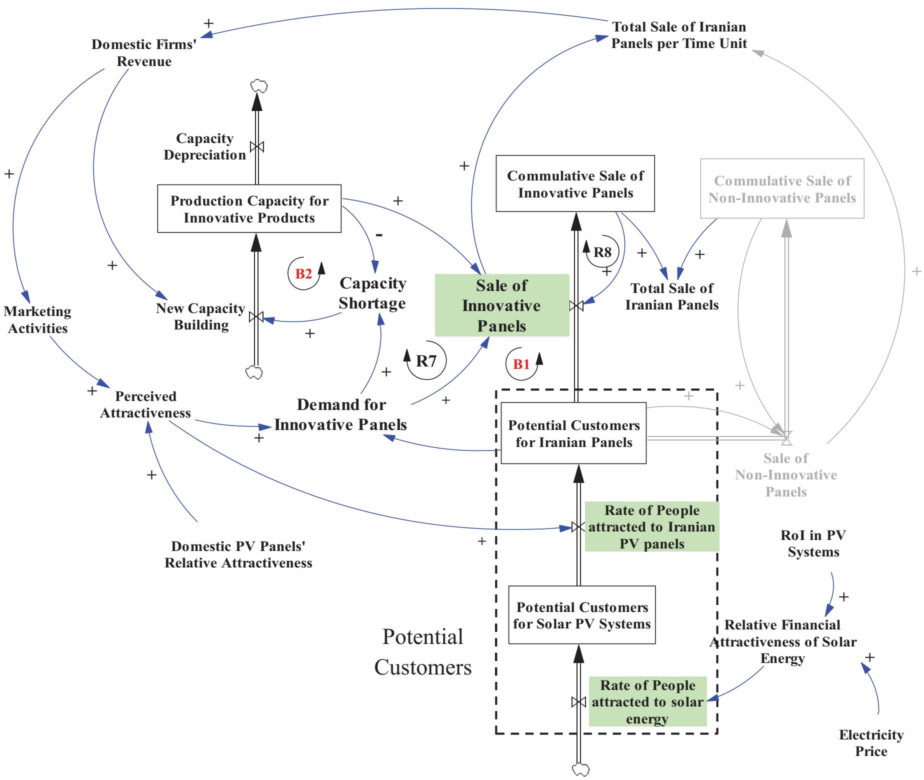
However, one of the government officials stated (Loop R6):

if we take into account the generated capability in our universities in the field of PV panels, initial collaboration between university and the industry would strengthen mutual understanding and trust among these two stakeholders because I think university is able to, pursuant to the agreement document, deliver R&D work on assignment for the industry.

The rate of NPD progress in internal R&D and joint R&D are directly related to firms' internal R&D capacity and public R&D capacity, respectively. Both forms of R&D lead to product innovation. The innovative features of newly developed products contribute to the relative attractiveness of Iranian PV panels compared to foreign panels, thereby leading to increased sales of Iranian panels. The resulting revenue can be reinvested in R&D and yield further innovation and revenue [5] in the future. This forms the main reinforcing mechanism that contributes to entrepreneurship development within the PV TIS.

4.3 The market subsystem

Figure 9 represents the causal structure of the market subsystem. According to the responses from industry participants, local firms' sales are influenced by their marketing activities (Loop R7) and their prior customers (Loop R8), who can communicate



Source: Authors' own work

Figure 9.
The causal structure related to the market subsystem

information about domestic panels to potential customers who think about buying Iranian panel but have not adopted it yet. This is reflected in the following quote from the industry: "Iranian PV market is not a hot market and potential customers generally know Iranian producers [. . . .] currently, a considerable part of our sale emanates from our previous customers."

According to our interviews, the main factor influencing the adoption of PV systems in Iran is the relative financial attractiveness of solar energy compared to conventional fossil-based electricity, as it is illustrated in the following quote from a government interviewee:

> *our main issue is the unrealistic low price of electricity in Iran. This makes investment in the PV system unjustifiable [. . .]. Government cannot induce people to spend on PV systems by just making them aware of environmental issues [. . . .] if PV systems become profitable then people will naturally invest in solar energy.*

Potential customers who intend to adopt the PV system must decide whether they want to use Iranian panels or foreign ones. This decision is highly influenced by the relative attractiveness of Iranian panels in terms of price and quality, as is indicated in the following quote from the industry:

> *The main reason that our panels have been increasingly bought by customers over the last years was our competitive price compared to foreign panels [. . . .] we are using a full automatic production line, therefore we can produce panels with the same quality as that of foreign panels, but with a lower price.*

The production capacity related to the innovative panels is controlled by the market demand (Loop B2), as is illustrated by the following quote from the industry: "[. . .] due to lack of remarkable financial resources in our company, we usually spend on raw materials or invest in production line, if needed, with extreme caution."

5. Discussion and policy recommendations

In Iran, increasing electricity consumption, which is supplied mostly by gas-fired power plants (Zahedi Rad *et al.*, 2019), is one of the major sources of air pollution. Addressing this issue requires a significant boost in the diffusion of PV technologies. However, over the past three decades since the inception of the PV industry, Iran has not achieved satisfactory progress in PV technological development, despite its favorable geographical conditions. With around 300 sunny days per year covering two-thirds of its land area and an annual solar radiation of about 2,200 per square meter – higher than the global average (Khalil Gorgani, 2018) – the untapped potential for solar energy and technology in Iran is evident. Analyzing the root causes of the current unsatisfactory performance of Iran's PV TIS, it becomes apparent that ineffective policy-making in both the electricity and solar sectors has played a significant role in hindering progress.

The primary deficiencies in the policies implemented in the PV sector in Iran include a focus solely on knowledge generation activities in the field of PV panels, neglecting the crucial aspect of knowledge transfer to the industry. In addition, the issues of extremely low electricity prices, a relatively low Feed-in Tariff (FiT) for solar energy and exclusive concentration on PV systems' implementation without adequate attention to the diffusion of domestic PV panels have contributed to the unsatisfactory performance. In this context, we critically analyze these deficiencies using the presented causal structure, and subsequently, propose policy interventions designed to rectify these shortcomings.

Over the past decade, the government has allocated a considerable budget to knowledge development in the field of PV panels. As a result of this policy, the number of scientific peer-reviewed articles published by Iranian scholars in this field has considerably increased, as explained in Section 1. This event has contributed to the promotion of the "Public R&D Capacity" variable mentioned in the second subsystem. However, there are two drawbacks to the formulated knowledge development policy. First, the knowledge development practices by Iranian researchers lacked direction from the PV industry, resulting in the generated knowledge not being perceived and welcomed by domestic PV manufacturing firms. Second, the government neglected designing supportive policies that would facilitate the transfer of the knowledge to the PV industry.

Moreover, over the last years, the supportive policies implemented to promote domestic PV market have not led to a remarkable market size contributing to domestic producers' sale and in turn revenue. Based on the proposed causal structure presented in third subsystem, "electricity price" and "solar FiT" are two exogenous variables through which government can intervene in the system. Over the last three decades, the average electricity in Iran has always been less than 0.05 US dollar per KWh while the world average electricity price was 0.16 dollar per KWh in 2022 (Globalpetrolprices, 2023). The heavily subsidized electricity price has dramatically impaired relative financial attractiveness of PV systems in Iran. As a consequence, only a few electricity subscribers have switched from conventional electricity to solar energy in recent years.

To increase financial attractiveness of PV systems, the Iranian Government introduced FiT for solar energy in 2015 for the first time. In 2017 and 2018, the FiT reached to its highest level, namely 0.15 dollar per KWh. As a result of that event, the average deployment of PV systems in these years reached about 120 MW per year (*SATBA,* 2023). However, this deployment size was still insufficient to stimulate innovation activities within Iran's PV industry, as mentioned by the industry interviewees in the previous section. Furthermore, the FiT policy was not formulated in a way that gives higher priority to the use of locally made PV panels in PV systems. According to our survey, less than 10% of the 500 MW PV systems installed in Iran so far (Figure 2a) have been supplied by Iranian PV panels. In reality, the advertised FiT has been largely embraced by foreign investors who imported their required PV panels from abroad, mostly their own country. Therefore, it can be inferred that although the implemented FiT policy has contributed to the PV systems installed capacity within the country, it did not provide adequate financial resources for domestic PV producers.

Given that knowledge development and market formation are two key functions in the "entrepreneurship phase" of TIS (Hekkert *et al.*, 2011), we revise the aforementioned knowledge and market development policies and propose two new policy mechanisms to foster innovation in the PV TIS. In this regard, we come up with solutions for the deficiencies explained above. Table 1 represents several policy options and their corresponding policy instruments, drawn from the literature or provided by interviewees, on both innovation demand and supply sides. These policies directly or indirectly contribute to entrepreneurship development. Through a critical analysis of these solutions, we will delineate our proposed policy mechanisms in the subsequent subsections.

This study adopts the goal-seeking approach in designing policy mechanisms. In a goal-seeking approach, governments typically increase the budget allocated to the subject of interest, but with a decreasing pace, until reaching a predetermined target (Edquist and Borrás, 2015). This target is typically defined based on the government's overall policies and budget constraints.

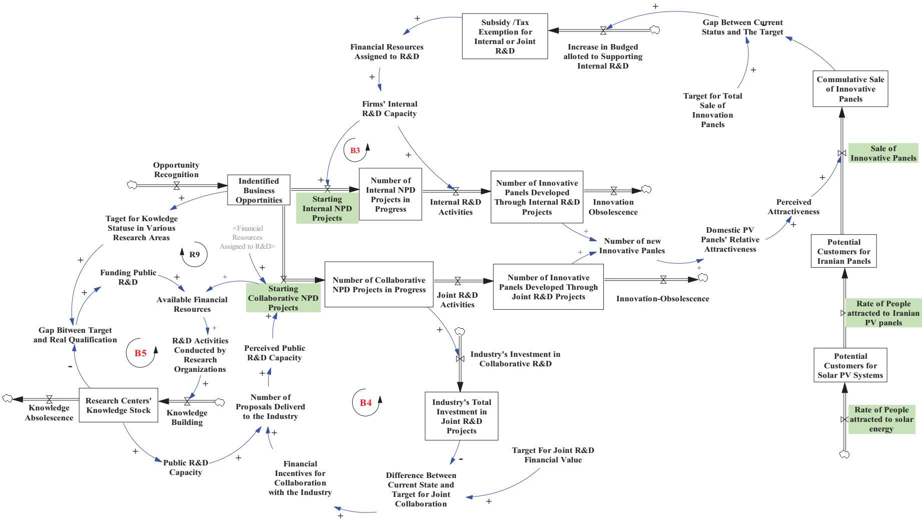
5.1 Technology-push policy mechanism

Figure 10 represents the causal structure related to the technology-push policy mechanism.

Table 1. The proposed policy options and instruments

Sector		Policy option	Policy instrument
Technology-push policies	Direct	Supporting Iranian PV firms' internal R&D activities	Tax exemption and subsidy for internal R&D
		Urging the firms to contract joint R&D projects with research organizations	Tax exemption and subsidy for joint R&D
	Indirect	Urging public research organizations to contact the industry	• Revision of the performance evaluation and rewarding systems at Iranian universities • Developing and supporting intellectual property rights regimes, technology parks, spin-offs and business incubators
		Knowledge development in technical problems announced by Iranian PV panel producing companies	Assigning governmental grants to the R&D projects focusing on the PV industry's problems
Market-Pull policies	Direct	Supporting marketing activities related to Iranian innovative PV panels	Assigning subsidy to such marketing activities in a goal-seeking manner
	Indirect	Supporting PV power plants equipped with Iranian technologies	Increasing PV FiT for PV systems equipped with Iranian panels
		Increasing the cost of using fossil-based electricity	Increasing fossil-based electricity price
		Increasing the relative attractiveness of domestic PV panels	Increasing customs tariff on imported PV panels

Source: Authors' own work



Source: Authors' own work

Figure 10.
The causal structure related to the technology-push policy mechanism

As explained in the previous section, the most critical barrier to entrepreneurship activities in Iranian PV panel producing companies is the lack of adequate financial resources. Financially supporting the firms' internal R&D and joint R&D projects through subsidy or tax exemption for such projects emerges a viable solution to encourage firms to engage in NPD activities (Loop B3). However, lack of sufficient technical knowledge and laboratory equipment within the domestic firms makes internal R&D less cost-effective. In this sense, this study stresses the importance of joint R&D collaboration with home research organizations that have notably developed their R&D capacity over the past years to promote entrepreneurship in the PV industry.

Based on the interviews with academia participants, university faculties lack adequate time and incentive to engage in collaboration with the industry. To deal with this problem, the literature suggests various policy instruments, including the development and support of intellectual property rights regimes, science parks, spin-offs and business incubators (Bodas Freitas and Verspagen, 2017). These initiatives aim to diminish the time and effort required for making a joint R&D agreement between university and industry. However, in Iran, there is a lack of compelling evidence of the success of these initiatives, often due to lack of non-technical (i.e. market-related and management) knowledge among university faculties, as well as the spatial distance between Iranian science organizations researching PV technologies and between these organizations and PV manufacturing firms. This study proposes a revision of performance evaluation and reward systems at Iranian universities. The existing promotion and reward criteria, which currently concentrate on publishing papers, should be shifted toward the commercialization of research outputs.

Although this policy incentivizes university faculties to contact the industry, it is insufficient because, for faculties who usually suffer from lack of time, publishing paper is still easier than persuading PV firms to invest in joint R&D projects. To address this problem, this study recommends the establishment of a governmental [6] intermediary technical organization that facilitates networking among university and industry. This organization should be responsible for communicating the R&D proposals received from the faculties to the industry to exchanging joint R&D contracts. In the cases that the proposals lack feasibility study, this organization should conduct these studies (cost-and-benefit analysis) via its expert personnel and communicate the results to the industry. In return for its services, the intermediary organization can receive a membership fee or contract commission from the university and industry. This business model would enable the organization to compensate for all or at least part of its costs through income-generating activities.

We propose a balancing feedback loop that offers increasing promotions or award-based incentives for faculties who have contracted joint R&D projects with the industry (Loop B4). This incentive is designed to encourage more faculties to submit technically and financially attractive R&D proposals to the intermediary organization, which will present them to businesses. The proposed balancing loop is governed by the target defined based on total earnings from joint R&D contracts.

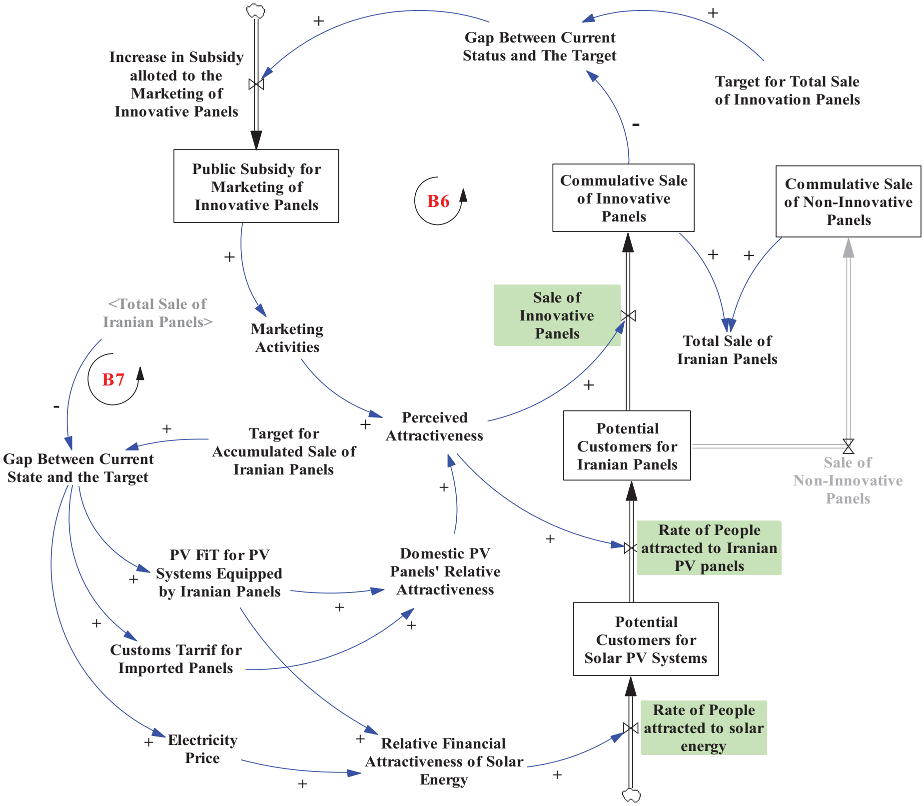
The proposed mechanism will sustainably work over time provided that there exists any scientific knowledge that can be transformed into commercial projects. Therefore, knowledge development has been incorporated in the proposed mechanism. In this regard, we introduce a balancing loop (Loop B5) that governs spending public funds on knowledge development in PV technological issues. The target of this loop, which is considered the number of research in various fields related to PV panels, receives feedback from the industry (Loop R9). In this context, we recommend that the intermediary organization contacts Iranian PV firms to compile and update a list of PV technical issues derived from the firms' identified business opportunities. This list would then be communicated to the research organizations to guide future public R&D. Currently, there is no such guidance in Iran's PV TIS, leading to a disconnection between the research conducted by Iranian scholars and the needs of the industry. This is also one of the primary reasons why much of the research conducted by Iranian researchers has not been perceived or found relevant by the firms. Our suggestion does not impose an additional financial burden on the government; we propose that the public funding for R&D be directed toward the industry's issues identified by the intermediary organization.

5.2 Market-pull policy mechanism

Figure 11 represents the causal structure associated with the market-pull policy mechanism. The government can provide financial support to the PV-producing firms during the R&D stage or when introducing an innovative product. The former has been implemented by the Iranian Government in recent years, but it has not led to desired innovation outputs as the R&D subsidies were not conditioned upon the introduction of a new product. This study stresses the latter approach to ensure that the government financial support would end in innovation. Accordingly, we propose assigning subsidy to the marketing of locally made innovative PV panels (Loop B6). This policy will assist domestic firms in effectively presenting the innovation features of their new products to potential customers, thereby increasing the likelihood of selling these innovative panels.

We have also reformulated the mentioned FiT policy by suggesting a higher FiT, not for all PV systems, but specifically for those equipped with Iranian panels (Loop B7). This adjustment would enhance the financial attractiveness of such PV systems, contributing to installation rate of PV systems and increasing the demand for Iranian panels. According to the proposed balancing loop B7, the FiT magnitude in different years will be governed based on a predetermined target for the total adoption of Iranian panels.

Based on our survey, financial limitation has posed a significant barrier for the Iranian Government to consider a FiT as high as needed for driving large-scale PV deployment. In



Source: Authors' own work

Figure 11.
The causal structure related to the technology-driven policy mechanism

this sense, we suggest a gradual increase in electricity price and custom tariff on imported panels, proportionate to the increase in the FiT. These measures not only provide the financial resources required for the FiT policy implementation but also contribute to the PV market size for domestic panels. The former encourages people to explore alternative energy sources such as solar energy, and the latter enhances the relative attractiveness of domestic panels by increasing the price of imported panels.

6. Conclusion and managerial implications

Over the last decade, Iran's PV TIS has witnessed the initiation of the first motor of innovation, i.e. knowledge development. However, the second motor – the entrepreneurship motor – which is responsible for transforming the generated knowledge into innovation has not been activated yet. In this study, we developed a causal feedback structure capturing the dynamics of entrepreneurship development in the PV TIS to design effective policy interventions fostering entrepreneurship activities. To develop the causal structure, we interviewed several stakeholders from different domains, including industry, academia and government. Using a systematic methodology, we extracted the causal map from the interviewees' mental models.

Based on the interviews, Iranian PV panel manufacturing firms face significant barriers to entrepreneurship activities, primarily stemming from a lack of technological knowledge, financial resources and essential R&D equipment. The developed causal map indicates that investment in internal and joint R&D with external entities would pave the way for innovation development, subsequently leading to increased revenue for the firm. This augmented revenue can be reinvested in ongoing R&D and innovation activities, establishing a key reinforcing mechanism integral to steering the dynamics of the PV TIS during its second development phase. However, this mechanism remains dormant within Iran's PV TIS at present.

Accordingly, this study has proposed several policy solutions pertaining to both the innovation supply and demand sides to strengthen the aforementioned mechanism. To promote the innovation supply side, we have proposed two goal-seeking balancing feedback loops: one aimed at fostering knowledge development in technical issues identified by Iranian PV firms, and the other focused on facilitating the transfer of the generated knowledge to the industry. Emphasizing the importance of establishing a governmental intermediary technical organization that facilitates interactions between research centers and firms, we assert that such an organization is crucial for the effective implementation of the proposed collaboration mechanism.

Concerning the innovation demand side, we propose a goal-seeking feedback mechanism that involved subsidizing the marketing of locally made innovative PV panels with the aim to contribute to the demand for such products. In addition, we recommended the implementation of a higher FiT for PV systems equipped with Iranian panels. In this regard, we developed a balancing loop that regulates the FiT magnitude over different years. To cope with the financial barriers associated with implementing the proposed FiT policy, we suggested that the government should increase the electricity price, which is currently quite low in Iran, and custom tariff on imported PV panels. Both the solutions not only provide the financial resources required for the FiT policy implementation but also contribute to expanding the potential market for domestic PV technologies.

This study carries several main implications: first, it facilitates system dynamics thinking among policymakers involved in PV TISs by providing insight into the main subsystems and causal feedback mechanisms influencing the dynamics of the TIS in the second development phase. Understanding the sources of TIS's dynamics – i.e. the identified feedback loops – empowers policymakers to design more informed and effective polices to foster innovation in the PV TIS. Although, the presented model focuses on Iran's PV sector, the identified variables and feedback loops offer a useful framework for comprehending the dynamics of PV TIS in other countries, especially those in transition from the first development phase (knowledge development) to the second (entrepreneurship development).

Moreover, the policy solutions delineated in this study shed light on the TIS aspects that should be enhanced by the policymakers to stimulate entrepreneurship, as the main functional driver in the second development phase. The proposed policies were designed based on these recognized aspects. During policy formulation, we took into account real concerns that might hamper policy implementation in Iran, such as financial restrictions. This realistic and practical mindset gives the proposed policies appropriate legitimacy for implementation within the PV TIS.

Ultimately, the existing research would pave the way for the advancement of Iranian PV panel technologies, which, with respect to the abundance of solar radiation in Iran, have significant environmental, economic and social implications for the Iranian society. Progress in PV panels typically contributes to PV technology diffusion, thereby mitigating green-house gas emissions in Iran. Moreover, given that PV module production accounts for about 46% of the value generated across its value chain, the diffusion of locally made PV panels within the country and the export of this technology to neighboring countries would produce significant financial benefits for Iran. From a social perspective, the PV industry has a good potential for job creation and social welfare. Due to increasing interrelations between PV technologies and other industries such as battery, nanotechnologies, electric vehicle and construction, diffusion of domestic advanced PV panels would lead to knowledge spillover in related industries. Moreover, the accumulation of technical knowledge within domestic PV firms paves the way for them to join to global PV value chains and make joint production or R&D collaboration with leading international PV panel producers.

This study has taken into account the characteristics of the first and second phases of TIS development, consistent with the current maturity level of Iran's PV TIS, to develop the proposed causal structure. Future research could extend the proposed causal structure by delving into the specifics of TIS' third and fourth development phases. One of the main structural drivers in these phases involves the establishment of technological and institutional infrastructures, such as a central R&D laboratory housing all required instruments and services of which could be used by manufacturers and scientist for a nominal charge.

Notes

1. This event has also played a key role in providing educated knowledge workers who can be hired in R&D positions in Iranian PV panel-producing companies.
2. The search protocol used for searching in the Scopus database: TITLE ("solar panel" OR "photovoltaic panel" OR "solar module" OR "photovoltaic module") AND [LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"re")] AND [LIMIT-TO (LANGUAGE,"English")] AND [LIMIT-TO (AFFILCOUNTRY,"Iran")] .
3. V1 to V7 denote possible variables of a hypothetical TIS. R and B refer to reinforcing and balancing loops respectively, which are described in Section 3.
4. This study focuses on entrepreneurship through innovation rather than arbitrage and also, among different kinds of innovations, including product, process, marketing and organizational innovation, concentrates on product innovation.
5. The level of the revenue is affected by the market mechanism that is simply represented by an orange arrow in Figure 7 but will be discussed in detail in the subsequent subsection.
6. The business model of this intermediary organization may not be as attractive as private investors decide to establish it. But the existence of such organization is necessary for the effective implementation of the knowledge transfer policy. Therefore, we suggest that this organization be governmental.

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Appendix

Quotation	Interviewee's type	Code	Source data	Comment
The marginal profit of PV panel production is not very much. So, the income of production on a small scale is negligible, and it is even hard for us to make both ends meet, let alone invest in R&D. . .. the companies in the world that engage in R&D all produces on the Gigawatt scale	Industry – participant 3	Causal link- market effect on R&D	I3:9	Sale Firms' internal investment in R&D
Lack of common language and trust is an obstacle to the collaboration between industry and university. . .. Based on my prior experience in the regulatory sector of industry, I maintain that Iranian [PV panel producing] firms lack the courage to trust [Iranian] research centers and collaborate with them. If I now go to the panel producing companies and say that "come and produce a new panel with my innovative idea," they will say let us produce the present panels; we are selling well. This means they are not risk takers. But I think our universities are able to help the industry with their R&D. I believe that if the industry gives the joint R&D collaboration a start, the distance [cognitive gap] between these two actors will become narrow and narrow over time as a result of their continuous interactions	Government –participant 2	Causal feedback- trust and cognitive proximity development among industry and university	G2-14	Trust and cognitive proximity Number of university–industry joint R&D projects Trust and cognitive proximity

Source: Authors' own work

Table A1. Two samples of coding the qualitative data