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The status of the hydrogen and fuel cell innovation system in Iran

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ABSTRACT

Hydrogen energy in combination with fuel cell technology plays an important role in addressing the growing energy demand in the coming decades. This paper analyses the functional and structural factors which affect the development of this technology in Iran. We apply the Technological Innovation System (TIS) approach. The analysis shows that compared to the progress of the Hydrogen and Fuel Cell Technology (HFCT) in leading countries, Iran is far behind the desired phase of development. This gap is partly explained due to the weak structure and functions of the HFCT system in Iran. Thus, the technology has remained in the demonstration phase for a long time. The analytical results show that the fulfillment of "entrepreneurial activities" is required for the transition of the technology to the *pre-commercial* phase. In turn, considerable financial resources are needed to accomplish "entrepreneurial activity". Considering the current situation of renewable energy resources in Iran, supportive laws and regulations are urgently needed as prerequisites for the mobilization of financial resources.

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1. Introduction

Renewable energies (REs) are becoming more and more desirable due to their attractive features. REs remarkably mitigate undesired environmental impacts. Compared to fossil fuels, REs are more inexhaustible and adaptive. They ensure high energy security, provide vast opportunities for distributed technology-intensive production and increasing both employment and export [1,2]. A proper share of REs in developing countries may enhance economic growth [3], improve technological capability [4], and even increase high-tech exports [5].

"Hydrogen energy", in combination with "fuel cells", is a substantial type of RE. It may play an important role in the sustainability of energy systems in the future [6–10]. The promising global horizon of "hydrogen energy" has also been attractive in Iran; some technological measures towards making use of hydrogen energy have been taken for the last two decades. This research studies the current status of Hydrogen and Fuel Cell Technology (HFCT) in Iran, using the Technological Innovation System (TIS) approach. Furthermore, the structural and functional factors of the system are analyzed, and the main reasons for the sluggish development of the HFCT in Iran are discussed.

Section 2 introduces the TIS approach. The structural factors of the Hydrogen and Fuel Cell Technological Innovation System (HFCTIS) in Iran are analyzed in Section 3. Section 4 determines the functional factors of the system. Section 5 presents the main reasons for the slow development of the HFCT in Iran. Section 6 contains a summary of the findings and concluding remarks.

2. TIS approach

This paper focuses on the HFCTIS in Iran, defined as "a set of actors that interact under a particular institutional infrastructure to develop, diffuse, and use HFCT". Among the existing approaches, including National Innovation System [11], Regional Innovation System [12] and Sectoral Innovation System [13], TIS [14] is more aligned with the aim of the research. Therefore, TIS is applied to HFCTIS to determine both structural and functional factors.

2.1. TIS structure

The structure of TIS includes a number of elements and the relations between them. They influence the formation of the technology through the direct or indirect impact of the performed activities in each element. In the TIS approach, "actors" and "institutions" are two main elements in the formation of technologies. They are described as follows:

- *Actors* include individuals or organizations that influence the formation of the technology through making and/or implementing decisions. Some examples are firms, research centers, governmental organizations, and financers.
- *Institutions* are the sets of rules that shape the behavior and affect the impact of activities performed by actors. Institutions are different from organizations, which are considered as "actors". Examples of institutions are standards, laws and regulations which are referred to as "hard institutions". "Soft institutions" include visions, norms, expectations and routines.

Some researchers add technologies to the structural elements of TIS [15,16]. Technologies include products, infrastructures or technological characteristics. Examples of technological characteristics are "cost", "safety", and "reliability".

Structural elements change slowly and provide a static image of TIS [15]. These elements and their relations create networks in the system. In this research, the structure of the HFCTIS in Iran is determined, using the "System Configuration Model (SCM)" [17–20]. The configuration consists of five components: *government structure*; *supply side*; *demand side*; *knowledge structure* and the *intermediary structure* (Fig. 1).

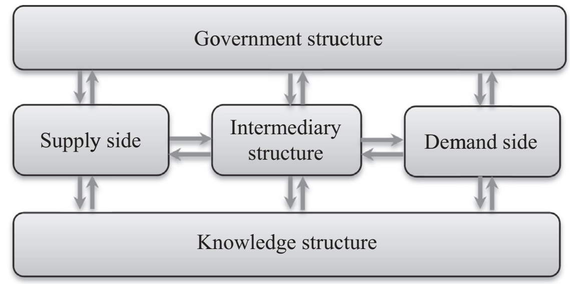

Fig. 1. TIS configuration of components [19].

Each component is a combination of actors, institutions, networks and technologies. The *supply side* contains elements that deal with the production and supply of the technological artifacts and knowledge. The elements of the *demand side* are related to the utilization of the technology. The *knowledge structure* consists of elements that support other subsystems through the creation, evaluation, and transfer of knowledge. Elements of the *governmental structure* are related to policy making, and the provision of regulations and facilities. These elements may enhance or hinder the formation of the technology. Finally, *intermediary structure* includes elements that support the interactions among other subsystems.

The performance of the system is evaluated based on SCM. The evaluation needs to consider the development of all components as well as the strength of their relations. Accordingly, the more developed are actors, institutions, technologies and networks of the system, the more strong is its structure. These elements support the diffusion and use of an emerging technology [17].

2.2. TIS functions

The structural elements provide a static picture of the socio-technical systems. As a result, the analysis of the structural elements does not help to comprehend technological changes, in general. Therefore the functions of the innovation system are also analyzed in the TIS approach. TIS functions are considered as main processes affecting the formation of the technology. Some sets of functions have been proposed to be used in the TIS approach (Table 2). Table 2 indicates the convergence of the sets of functions over the time period 1998–2012. The final set of functions is used in this research [15,16], cited in Table 1. Some indicators are also defined to evaluate the functions. A questionnaire has been designed based on the indicators and sent to the experts in the HFCT field. The fulfillment of functions is evaluated based on the rating of indicators by experts. The indicators and results of the ratings are presented in Section 4.

3. The structure of HFCTIS in Iran

The status of HFCTIS in Iran is analyzed by studying the structures of the components in TIS SCM (Fig. 1). They are *government structure*, *supply side*, *demand side*, *knowledge structure*, and the *intermediary structure*. The structural analysis helps to identify the process of the technology development and the existing barriers.

Table 1
TIS functions [16].

System function	Description	Event types associated
F1. Entrepreneurial activities	This process aims at the translation of existing knowledge into business opportunities and, ultimately, innovation.	Projects with commercial aims, demonstrations
F2. Knowledge development	This process aims at the increasing knowledge in the system.	Studies, laboratory trials, pilots
F3. Knowledge diffusion	This process aims at the knowledge sharing and dissemination among the actors of the system.	Conferences, workshops, alliances
F4. Guidance of the search	This process aims at the shaping the expectations and needs of actors and their decisions.	Expectations, promises, policy targets, standards, research outcomes
F5. Market formation	This process aims at building demand for the technological products in order to enhance their competitiveness with respect to the existing products.	Market regulations, tax exemptions
F6. Resource mobilization	This process aims at allocating the (financial, human and materials and equipment) resources to system actors.	Subsidies, investments
F7. Support from advocacy coalitions	This process aims at overcoming the resistance to the development of the technology.	Lobbies, advice

Table 2
Sets of functions chronically proposed by authors.

References	**Functions**							
[21]	Experimentation by entrepreneurs	Knowledge development	Knowledge diffusion	Guidance of the search	Market formation	Resource mobilization	Legitimacy creation	
[22]	Entrepreneurial experimentation	Knowledge development	Diffusion of knowledge about the innovation	Influence on the direction of the search	Market formation	Resource mobilization	Creation of legitimacy	Development of positive externalities
[15,16,23,24]	Entrepreneurial activities	Knowledge development	Knowledge diffusion	Guidance of the search	Market formation	Resource mobilization	Support from advocacy coalitions	
[25]	Entrepreneurial activities	Knowledge development	Knowledge diffusion	Guidance of the search	Market formation	Resource mobilization	Creation of legitimacy	
[26]	Entrepreneurial activities	Knowledge creation	Knowledge diffusion	Guidance	Market creation	Resource mobilization	Legitimization	
[27,28]	Entrepreneurial experimentation	Knowledge development and diffusion		Influence on the direction of search	Market formation	Resource mobilization	Legitimation	Development of positive externalities
[17,29,30]	Entrepreneurial activities	Knowledge development	Knowledge diffusion through networks	Guidance of the search	Market formation	Resource mobilization	Creation of legitimacy/ counteract resistance to change	
[31]	Entrepreneurial activities	Knowledge development	Knowledge diffusion through networks	Guidance of the search	Market formation	Resource mobilization	Support from advocacy coalitions	
[32]		Provision of research and development Competence building Provision of consultancy service	Networking	Articulation of quality requirements Creating and changing organizations Creating and changing institutions	Formation of new product markets	Financing of innovation process Incubating activities		
[33]		To create “new” knowledge		To guide the direction of the search process	To facilitate the formation of markets	To supply resources		To facilitate the creation of positive external economies
[34]	Implementation	Research	Linkage		End-use	Education		
[35]	To create and diffuse products To create and diffuse technological opportunities	To market and partner research	To enhance networking	To direct technology	To create markets and diffuse market knowledge	To create human capital To incubate To facilitate financing To create a labor market	To legitimize technology and firms	
[36]			Facilitate the exchange of information and knowledge	Reduce social uncertainty Guide the direction of search Recognize the potential for growth	Stimulate/create markets Supply incentives for companies	Supply resources	Counteract the resistance to change	

Table 3
The performance indicators of the “knowledge development” (KD) function.

Dimension	Code	Indicators	Code
Projects size	K1	Number and size of research projects about fuel cells (including stack and balance of plants)	KD1
		Number and size of research projects about fuel processing and the related components	KD2
		Number and size of joint research projects which were done with the participation of researchers from foreign countries	KD3
		Number of feasibility, economic, and market studies	KD4
Projects quality	K2	Quality of research projects about fuel cells (including stack and balance of plants)	KD5
		Quality of research projects about fuel processing and related components	KD6
		Match between the knowledge created by research centers and the demand in the industry	KD7
Scientific outputs	K3	Number of publications as international articles, dissertations, and academic books	KD8
		Number of innovations and national and international patents	KD9

3.1. *Supply side*

The *supply side* contains the elements related to the supply of technological products. The HFCTIS of Iran is in its early phases of growth. Therefore, few actors can be identified in this subsystem. Most of the products used in the HFCTIS have been purchased from foreign firms. The *supply side* includes Pillar Energy Company, Isfahan Engineering Research Center, Parsian Poya Polymer Company, E4 Research Center, Poshesh Fanavaran Sat’h Company, and Ghods Niro Company.

“The national strategy to develop fuel cell technology” was approved in 2007 [37]. It contains the main institutions of the HFCTIS in Iran. The “national program”[1] was developed and detailed in three 5-year operational programs [38]. According to these operational programs, fuel cell samples are to be developed in the first two 5-year periods.

3.2. *Demand side*

On the *demand side* the utilization of technological products is of concern. The main demanding actors are ranked as the government, firms and even individuals. This sequence depends on the maturity of the innovation. HFCT is emerging in Iran and the only demanding actor is the “Hydrogen and Fuel Cell Office” (HFCO) of the “Renewable Energy Organization of Iran” (SUNA). Based on the national plan, this office is in charge of promoting HFCT and managing the purchase, installation, and operation of the prototypes of fuel cell systems in Taleghan site. On the other hand, the Saba-Battery and Iran-Khodro companies are the potential customers of the products; both companies have also implemented similar projects.

There is an interactive relation between supply and demand in HFCT. Since the technology is emerging in Iran, the *demand side* is still underdeveloped; only a few institutions exist that have a demand for this technology. One of the goals of the national plan is to promote the demanding actors in the first five-year period. Thus, purchasing 20 fuel cell systems from domestic producers has been approved by Fuel Cell Steering Committee (FCSC) in 2011.

3.3. *Knowledge structure*

Knowledge structure includes those actors and institutions related to the production, evaluation, and transfer of knowledge. In Iran, this structure is a relatively more developed subsystem of HFCTIS. These actors are leading in the development of HFCT in Iran. In addition to universities, several main actors and institutions are involved in the *knowledge structure*. They include Isfahan Engineering Research Center, Green Research Institute of Iran University of Science and Technology, Shomal Science and Technology Research Institute, Rafsanjan Industrial Complex, Polymer and Petrochemical Research Institute of Iran, Materials and Energy Research Institute, Petroleum Industry Research Institute, Niroo Research Institute, and Iran Research Organization for Science and Technology. In addition to these actors, the first 5-year plan has programs to promote research and knowledge-oriented projects in this field.

3.4. *Government structure*

Government structure includes those actors and institutions related to policy making, regulating and facilitating the development of HFCT. In Iran, these actors are grouped in “system level” and “decision level”.

The “system level” group includes organizations with entities mainly depending on HFCT. This group includes the HFCO of SUNA, and two active networks of the actors, called the Fuel Cell Technology Development Council (FCTDC) and FCSC.

The “decision level” group includes the organizations whose decisions significantly influence the development of HFTC technology. This group comprises the Expediency Discernment Council, the parliament, the Supreme Council of Science, Research and Technology, Ministry of Energy, Ministry of Petroleum, Ministry of Industries and Mines, Ministry of Science, Research and Technology, Tavanir Company, SUNA, Power Development Organization, Environmental Protection Organization, Deputy President of Strategic Planning and Control, the Presidential Office of Technological Cooperation, and the Supreme Council of Cultural Revolution.

Finally, the national program has devised policies for directing the system as a whole. These policies mainly belong to the *governmental structure*.

3.5. *Intermediary structure*

Intermediary structure supports the relationships and interactions among other subsystems. This structure includes FCSC, the HFCO of SUNA, the Renewable Energy Initiative Council and the Technical Committee for Fuel Cell Technologies. This technical committee was established under the supervision of the National Committee for Electricity and Electronics. The committee is obligated to prepare the needed standards for production, installation, safety, and efficiency of fuel cells.

An important decision is the establishment of Fuel Cell Technology Development Center. This center can play an important role in enhancing interactions among other parties. However, this center has not been established yet. Other institutions in this structure are plans that contribute for creating relevant associations and Non-Governmental Organizations (NGOs). These entities can support the development of fuel cell technology, the

[1] Later in this paper, “national program” indicates “the national strategy document to develop fuel cell technology”.

Table 4
The performance indicators of “knowledge diffusion” (KDi) function.

Indicators	Code
The influence of joint research projects on the knowledge of the actors	KDi1
The formation of networks of actors from government, academia, and industry	KDi2
The number of conferences, seminars, and workshops held	KDi3
The communications among organizations in terms of knowledge and experts transfer	KDi4

Table 5
The performance indicators of “entrepreneurial activities” (EA) functions.

Indicators	Code
The rate of entrance of companies into the technology application areas	EA1
The rate of entrance of governmental and the public organizations into the technology application areas	EA2
The rate of emergence of startup companies in the incubators and technology parks	EA3
The number and size of projects for prototyping technological products	EA4
The cooperation with foreign companies or organizations for importing and installing technological products	EA5

Table 6
The performance indicators of “guidance of the search” (GS) function.

Dimension	Code	Indicators	Code
Goal setting	G1	The awareness of researchers and technology developers about governmental goals and strategies	GS1
		The success of government in implementing development strategies of the technology	GS2
Laws and regulations	G2	The variety of supportive laws and regulations	GS3
		The effectiveness of supportive laws and regulations	GS4
Coordination of system components	G3	The convergence of the researches towards a dominant design of technological products	GS5
		The coordination among activities at the national level	GS6
		The degree of precipitancy of decisions made by the government	GS7

Table 7
The performance indicators of “resource mobilization” (RM) function.

Indicators	Code
The availability of experts	RM1
The number of implemented training programs and provided technical assistance by foreign experts	RM2
The volume of investment in the technology by the government	RM3
The volume of investment in technology by private sector investors	RM4
The availability of required infrastructure, raw materials and supplementary assets	RM5

Table 8
The performance indicators of “support from advocacy coalitions” (SAC) function.

Indicators	Code
The support condition for the technology provided by laws and regulations at the energy sector level	SAC1
The support condition for the technology provided by the decision makers in the energy sector	SAC2
The number of implemented demonstration projects and promotional activities	SAC3
The degree of social acceptance of renewable energy	SAC4

Table 9
The performance indicators of “technology development” (TD) function.

Dimension	Code	Indicators	Code
Quantitative development of the system	T1	The number of fuel cells and the related equipment prototypes produced in Iran	TD1
		The number of fuel processing system prototypes produced in Iran	TD2
		The number of job opportunities for professionals in the field of fuel cell technology in Iran	TD3
		The rate of growth of utilization of fuel cell technology and its products in Iran	TD4
Qualitative development of the system	T2	The variety of fuel cell technology applications in Iran	TD5
		The quality of fuel cell technology product samples which are produced in Iran	TD6

Table 10
The performance hydrogen and fuel cell innovation system in Iran.

Function	Indicator	Mean	Standard deviation	Function	Indicator	Mean	Standard deviation	Function	Indicator	Mean	Standard deviation
Knowledge development	KD1	3.12	1.12	**Guidance of the search**	GS1	3.48	1.49	**Resource mobilization**	RM1	3.53	1.44
	KD2	2.68	1.22		GS2	2.68	1.15		RM2	1.92	1.00
	KD3	1.71	1.01		GS3	2.65	1.31		RM3	2.81	1.22
	KD4	2.55	1.20		GS4	2.74	1.27		RM4	1.54	0.83
	KD5	3.39	1.25		GS5	2.66	1.28		RM5	2.60	1.23
	KD6	2.96	1.23		GS6	2.40	1.39	**Support from advocacy coalitions**	SAC1	2.67	1.26
	KD7	2.51	1.35		GS7	4.24	1.66		SAC2	2.68	1.17
	KD8	4.23	1.41	**Technology development**	TD1	2.74	1.23		SAC3	2.66	1.35
	KD9	2.55	1.29		TD2	2.15	0.94		SAC4	2.33	1.35
Knowledge diffusion	KDi1	3.62	1.31		TD3	2.20	1.10	**Entrepreneurial activities**	EA1	2.08	0.98
	KDi2	2.72	1.20		TD4	2.33	1.17		EA2	1.95	1.06
	KDi3	3.56	1.20		TD5	2.52	1.18		EA3	2.66	1.15
	KDi4	2.43	1.05		TD6	3.31	1.39		EA4	2.87	1.17
									EA5	2.12	1.09

promotion of an information center, and publishing bulletins to cover global and local news about fuel cell technology.

4. Functions of HFCTIS in Iran

A number of indicators were defined to evaluate the fulfillment of the HFCTIS functions in Iran. This required determining the current optimal level of HFCT development. Therefore, a model is used to assess the commercial maturity of the technologies [39]. This model divides any "technology development" into five phases, as follows [39]:

- *Basic and applied research and development*. This includes doing research activities by researchers from industry and/or universities.
- *Demonstration*. In this phase, full-scale working prototypes and even products are manufactured. A few (even one) products are installed for the first time and funded by research budgets.
- *Pre-commercial*. For the first time, a large number of samples, made in the previous phase, are installed or some units are put together for much larger-scale installation. Larger players manage to enter in the technology development as a business or spin-off. Hence the investment risk is very high in this phase.
- *Supported commercial*. In this phase, some laws and regulations are formulated to support emerging technology to enhance the competitiveness of the technology products.
- *Commercial*. Finally, in this phase, the products of the technology can compete with other products on the same ground.

The maturity of this technology in leading countries is the proper benchmark. Since the technology is in the *pre-commercial* phase in leading countries, this phase of the technology is the current desired level in Iran. Accordingly, an increase of the demand for fuel cells in different applications is desirable. This increases the competitive capability of both the technology and the products, under supportive conditions.

A set of questions was formulated to evaluate the fulfillment of the HFCTIS functions. The questions were turned into some indicators and then presented in a questionnaire (Tables 3–10). For any function of HFCTIS, the higher scores indicate a higher level of fulfillment. The "market formation" function was not included in the questionnaire, because no significant relevant action yet exists in Iran.

The questionnaire was sent to the stakeholders and they were asked to score all indicators. The scores 1 and 7 show the lowest and the highest levels of fulfillment for every function respectively. Indicator GS7 is an exception where scores 1 and 7 show the highest and lowest fulfillment of the GS function.

Of the 150 stakeholders of HFCTIS in Iran who received the questionnaire, 132 (88 percent) responded. About 10 percent of the respondents were in the governmental sector, 10 percent in the industry sector, and the rest in academia. The results of evaluations by the respondents are presented in Table 10.

5. Discussion

The current desired level of maturity for HFCT in Iran is the *pre-commercial* phase which is the achieved maturity level in leading countries. This phase is highlighted with some features. First, a large number of sample products are produced and installed for the first time. Second, a number of large-scale units are installed and operated. Third, larger players manage to enter the system or spin-off. Based on the results of the evaluations, the score of HFCT's development is 2.54, which shows a gap with the desired level. From stakeholders' point of view, this means that Iran is far less successful in the development of this technology in comparison to the leading countries. The main causes for this gap will be investigated, using the results of Sections 3 and 4.

According to the desired level, a large number of samples or some large units have to be installed for the first time in Iran. It is required to fulfill the "entrepreneurial activities" function. Also by ratifying supportive legislations, the competitiveness of the technological products should be improved. The products are *supported commercially* in the next phase. This will drive the "market formation" function at the end of the *pre-commercial* phase. In other words, a number of niche markets should be created for the technological products during the *pre-commercial* phase. In the national program, a set of plans have been formulated for the fulfillment of the "market formation" function. Additionally, FCSC has decided to order the development of 20 units of fuel cell systems. However, no significant activity related to the "market formation" function has been implemented in Iran yet [24].

The "entrepreneurial activities" function has an important role in passing through the *demonstration* phase and starting the *pre-commercial* phase. Based on the evaluations, the "entrepreneurial activities" function scored 2.34. All indicators of this function obtained low scores. The reasons are the small number of established firms in technical areas, few implemented projects and the low rate of incoming firms in fuel cell industry. In addition, no considerable cooperation with foreign companies was identified. The incomplete fulfillment of the "entrepreneurial activities", and to a lesser degree, the "market formation" function caused

HFCTIS to get stuck in the *demonstration* phase. Moreover, the fulfillment of the "market formation" and "entrepreneurial activities" functions were interdependent. Due to the weak fulfillment of the "entrepreneurial activities" function, a small number of technological products were available. Therefore, the gap between the desired and the current status of HFCT in Iran were explained in terms of the implementation of entrepreneurial activities. The authors have discussed various factors that affect the fulfillment of this function at different analytical levels, some of them existing on the landscape and regime levels in [24]. This paper provides a complementary view of the influential factors at the niche level. Both structural and functional factors affect "entrepreneurial activities" at the niche level. These factors are discussed briefly in the rest of this section.

5.1. Structural causes

5.1.1. Prolonged demonstration phase

Knowledge structure is the most developed component of the HFCT innovation system of Iran. On the contrary, few players have entered into the *supply side* and only one actor has attempted to provide fuel cell systems. No relatively large enterprise has entered into this structural component yet. Also, no significant plan to facilitate the formation of the *supply side* is included in the first 5 year plan of the national program. The first 5 year plan has focused on "knowledge development", "guidance of the search" and "support from advocacy coalitions". Due to the long delays in the formulation and approval of the national program, its first 5 year period lasted for 3 more years, i.e., up to 2012. This delay was mainly due to the sluggish provision and approval of the national program. It could have been completed earlier, and also drive the mobilization of the resources and the coordination of the activities earlier. As a result of the delays, the technology in Iran remained in the *demonstration* phase until 2012. Only a small number of the samples were made and the whole technological system was operated in small units. The production and operation of these units were also dependent on the research grants.

5.1.2. Weak networks of actors

There is no effective mechanism for interactions among actors in the government, industry and academia. This structural weakness of HFCTIS influences "knowledge diffusion" and "guidance of searches". The problem is also reflected in the results of questionnaire and by low scores of indicators KDi2 and KDi4. Despite the existence of a formal national program in support of HFCT, the researchers and technology developers are not very well aware of the government's goals and strategies as it is shown by a medium score in GS1. This indicates that the *intermediary structure* of HFCTIS is not successful in pursuing its mission. The problem is also pervasive at the national level [40,41]. It leads to low levels of awareness of actors of the capabilities, activities and goals of other actors. The unawareness eventually results in weak coordination among actors and waste of resources. The relatively higher score for indicator KDi3, compared to KDi2 and KDi4, reflects more utilization of informal ways of interactions among the actors of HFCTIS in Iran. However, these mechanisms are less capable to solve the problems due to their non-continuous nature.

5.1.3. Low power of active actors

HFCO of SUNA is the main active custodian of HFCT development and the sole active actor in the *government structure* of HFCTIS. However, this enactor of the system does not have a correspondingly strong position in the structure of the energy sector in Iran. Thus, limited resources are assigned to HFCO. The establishment of the FCTDC could somewhat improve the situation by incorporating top-level actors of the energy system. However, due to low commitment of the members of the council to HFCT, the opportunity of leveraging the resource mobilization capability of the system with the members' position is missed.

5.2. Functional causes

5.2.1. Lack of continuous planning mechanisms

The prolonged provision and approval of the national program has caused the *demonstration* phase to extend. Moreover, this program has not been revised for more than six years after the approval of the first version. Due to the rapid changes in the environmental factors of HFCTIS, there is a crucial need for mechanisms to develop continuous planning. This will result in the formation of the required supportive institutions. However, this is partly dependent on the emergence of such mechanisms at the level of the renewable energy sector, which is lacking [24,42].

5.2.2. Weak mobilization of resources

The highest score for the indicators of the "resource mobilization" functions belongs to the capabilities of human resources. The accumulation of the experience of researchers for more than a decade and the repatriation of Iranian professionals and technicians in the field [24] are the main reasons for high score. However, evaluations show that even the current active researchers are not enough to achieve the desired phase. Indicators also reflect a relatively small amount of investment by the government and private sector. The current *demonstration* phase of HFCTIS hinders the private sector from investing considerably in the technology. To thrust the technology, the government should pave the way with early investments. As a result, the main characteristics of this phase are the implementation of the research projects funded by grants and inviting experts from leading countries for training. Meanwhile, the provision of equipment and materials are fundamental measures. These preparations require financial resources. Therefore, governmental financing is panacea in this phase. As discussed in Section 5.1, the weak authority of the active actors has been one of the barriers. Based on this evaluation, the system has not successfully supplied the required resources.

5.2.3. Lobbying with little success

On the one hand, enactors of the system do not have enough financial resources to facilitate the development of HFCT. On the other hand, resources are mainly allocated with lobby [24,43]. Lobbying with more powerful actors is an alternative to obtain the required finance for the projects. Meanwhile, evaluations indicate that HFCTIS in Iran suffers from a legitimacy problem. This has led to deficiencies in the allocation of resources for knowledge development and diffusion, and entrepreneurial activities [24].

6. Conclusion

The evaluation and analysis of the structure and functions of the HFCTIS clarified that HFCT has not successfully met the desired level of development in Iran. The structural analysis revealed that the actors of the system focus on the endogenous development of HFCT. The *knowledge structure* is the most developed component of the system. However, the system suffers from numerous delays in planning, the lack of strong ties among actors, the weak authority of the active actors, the lack of continuous planning mechanisms, and the shortage of resources. These problems prevent the system to form a strong knowledge and technology basis. This is required for the transition of the system to the next phase of development. Therefore, companies are confronted with high risk, and so no desire to get involved in the system. The main sponsor of the technology could afford only small research projects. As a result, few technological products were developed, the implementation of large-scale projects was avoided and HFCT has been developing at a low pace.

There exist some reasons for the inadequate financial resources of the projects. First, the allocation of the required resources to the projects defined in the national program has not been taken seriously. This impedes the research and entrepreneurial activities in the field. The second reason is the poor organizational authority of SUNA in the energy sector of Iran. SUNA does not have the proper authority to provide necessary resources for the development of renewable energies. Furthermore, SUNA focused on “wind energy” which obtained a significant share of the total limited budget devoted for renewable energy. To solve the problem, the national program chose a number of powerful actors to participate in the FCTDC, but the actors did not intend to take part in the council. Finally, the top and middle level managers of the energy sector do not envisage a promising horizon for HFCT in Iran. They have been reluctant to allocate necessary resources, and the lobbies have failed to attract their support.

Improving the status of HFCT to the *pre-commercial* phase requires much more resources. Unless the dominant actors understand the importance of this technology, the resources will not be mobilized. Further progress of the leading countries and remarkable products will most probably affect the key decision makers in Iran. This will stimulate the development of HFCT. Therefore, the fulfillment of the “support from advocacy coalitions” function will affect the technology development in the case of Iran. Some measures such as formulating necessary supportive laws and regulations to support the HFCT, lobbying with some powerful actors outside the energy sector and doing more promotional activities can further fulfill “support from advocacy coalitions” function.

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