Mapping of a science and technology policy network based on social network analysis

Esmaeel Kalantari[1], Gholamali Montazer[2], Sepehr Ghazinoory[3]

Abstract

PURPOSE: *The main purpose of this paper is to define a science and technology policy network in the form of a social network, from the perspective of policy documents, and then analyze it using the social networks analysis (SNA) method.* ***METHODOLOGY:*** *As a case study, the science and technology policymaking network in Iran is analyzed using the suggested framework in this research. The data used in this study were collected through the content analysis of 25 policy documents and an interview with 20 Iranian science and technology policy elites, before being interpreted using the social network analysis method and software such as NetDraw and UCINet.*

FINDINGS: *The most pivotal science and technology policymaking institutions in Iran and the interactions between them were determined from the network viewpoint. This was achieved by performing a two-dimensional core-periphery analysis, identifying the cut points and blocks, and measuring the structural power of each institution using the degree centrality, closeness centrality, and betweenness centrality methods.* ***IMPLICATIONS FOR THEORY AND PRACTICE:*** *The most important practical implications of this research are: the integration of a number of policymaking institutions, the division of clear and precise work between policy institutions, the design of vertical and horizontal coordination mechanisms between institutions, the elimination of interferences of some institutions in the tasks of the others, the design of complementary mechanisms to control the role of cutting points, and paying attention to the important activities in the margins of the network.*

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Received 27 October 2020; Revised 4 January 2021, 18 January 2021; Accepted 25 March 2021.

ORIGINALITY AND VALUE: *The most important contribution of this research is to develop a framework for studying science and technology policy and then to develop a method for studying science and technology policy based on SNA. Therefore, the framework for studying science and technology policy in a cycle consists of three stages: 1- Agenda setting and prioritization (at two levels of mega policies and meta policies); 2- Design and implementation or executive policies (in three parts: demand-side policies, supply-side policies, and networking and interconnection infrastructure policies); 3- evaluation and policy learning.*
Keywords: *science and technology policy, policy network, social network analysis, SNA, structural power, Iran*

INTRODUCTION

Since the 1960s, results of science and technology studies have been gradually applied to science and technology policy, and this has been seriously addressed by policy makers entering the third millennium (Ahlqvist et al., 2012). The participation of different actors in science, technology and innovation policy is one of the essential features of this system (Wojnicka-Sycz, 2020). The "institutions" and "institutional interactions" are the concepts that gradually emerged during the maturity period of science and technology policy studies through the works of a number of scientists (Martin, 2012). Therefore, institutional mapping is used, analyzed and studied to investigate the national innovation system in some countries (Organization for Economic Co-operation and Development (OECD), 1999; Capron & Cincera, 2001; Bikar et al., 2009). The evolution of the innovation models from the linear model of science, technology, and innovation to the systematic model (innovation system) (Edquist & Hommen, 1999), as well as the establishment of the policy networks concept in public policy studies, have created a growing emphasis on the importance of institutions and the interactions between them, especially from a network perspective (Kalantari et al., 2021; Blanco et al., 2011; Wasserman & Faust, 1999). Thus, the importance of policymaking institutions, and especially the interactions between them from the perspective of innovation literature and policymaking literature, is also emphasized. Moreover, the concept of systematic failure (affected by the viewpoints of evolutionary economics) signifies that any lack or deficiency in structures, institutions, and rules affecting the availability and production of the required knowledge is due to economic failure. This is due to the lack or inefficiency of the required relationships between the institutions in the innovative system. Furthermore, it is indicative of insufficient rules, lack of presence or a limited number of key players, weak harmony among sectors, and lack of knowledge progress (Niosi, 2002; Teubal, 1993). From another point of view, it emphasizes the necessity and importance of the science and technology policymaking institutional network.

In this paper, by reviewing relevant articles, a framework for the network analysis of science and technology policymaking institutions is designed. Thus, in the first phase, a framework is formulated for a science and technology policymaking process and then, in the next phase, another framework is formulated to divide the labor between science and technology policymaking institutions. Third, analyzing the method of social networks and the way of establishing the science and technology policymaking network is discussed. Afterward, the analysis of the science and technology policymaking network in Iran is discussed as a case study. Lastly, the paper is finalized with a discussion, conclusion, and some suggestions about the reformation of the science and technology policymaking network in Iran.

LITERATURE REVIEW

Mapping of the policy networks with the social network analysis (SNA)

Various studies have been conducted by other researchers, in which policy networks in different policy fields have been mapped using the SNA method (Kalantari et al., 2021). Normann (2017) uses the SNA method and the concept of policy networks to study stakeholders and actors in energy and climate policy in Norway. Two fields of carbon capture and storage, and offshore wind plant have been investigated in this study as case studies. The data of this study were collected through existing empirical studies and semi-structured interviews with 42 policymakers, civil activists, industry representatives, research organizations and other stakeholders. In this research, first, the policy network in the field of carbon capture and storage in three consecutive time periods has been drawn and analyzed. Then, the policy network of power plants is drawn and analyzed in two consecutive time periods; and then these networks were compared with each other.

In another study, Rogelja and Shannon (2017) used SNA to describe the network of actors involved in the Serbian anti-corruption forest policy network. The Serbian Anti-Corruption Policy Network consists of 16 actors (organizations), of which only five have a strong and reciprocal involvement in anti-corruption activities. Most of the central actors are state-owned enterprises and public companies, which themselves form a sub-network. The data collection method is semi-structured interview and the sampling method is the snowball method, which is done in three steps. In this research, in addition to drawing a policy network, a number of network characteristics, including network density and network degree, have also been calculated. In addition, Browne et al. (2017) describe the network structure of influential organizations in the field of health policy in the Torres Islands. In this policy network, 61 influential organizations have been identified. In this research, in addition to drawing the network with the SNA method, indicators of the network, including network density and average degree have been calculated.

In addition, another study (Mikulsliene & Pitrenaite-Zileniene, 2013) was conducted to evaluate the education and science policy network in Lithuania and to identify barriers to collaborative management in this network. This study is based on a case study in decision-making groups within the Ministry of Education and Science in Lithuania from 2007 to 2010. In this study, the education and science policy network in Lithuania has been mapped using the SNA method. Also, in a study conducted by Mohammadi Kangarani and Rafsanjani Nezhad (2015), the power structure in the water policy and management network in the Islamic Republic of Iran has been mapped and analyzed. In order to achieve the purpose of this study, the SNA method is used to draw a network of the legal tasks and powers of institutions, determine the centers of power, and establish how the power is distributed among the institutions of this network. Using the SNA method, we can first describe the dependencies and relationships between institutions involved in water policy, secondly, we can determine the degree and importance of an institution or a set of institutions and show the distribution of power among different institutions, and third, we can show the sensitivity of the water policy network structure in the absence of certain institutions.

Despite the mentioned research and other research that has used the SNA method to map the policy networks in various fields of policy, so far, no suitable research has been done to map the science and technology policy network by the method of social network analysis. Therefore, in this study, the researcher's goal is to map the science and technology policy network in Iran by the SNA method and then analyze this network with the help of SNA indicators. For this purpose, and before analyzing this network, we are looking for a framework for mapping this network. Therefore, in the continuation of this section, by reviewing the literature of science and technology policies, an attempt is made to establish a framework for mapping the science and technology policy network in Iran.

Science and technology policymaking process

Science, technology and innovation policymaking consists of three main activities including (OECD, 2005; Hjelt et al., 2005; Polt, 2005) "agenda setting and prioritization," "design and implementation" and "evaluation and policy learning." In terms of policymaking levels, Dror (1971) divides such policies into two categories:

A) Mega policies consisting of postures, assumptions, strategies, and main guidelines special policies must obey. The mega policies are the same as master or umbrella policies showing the purposes and priorities of a country. Even though they are few in number, from the perspective of scope and time horizon, they are very large and lengthy. They are the main guidance framework for the activities of governments and are usually sources for secondary policies, as well as the establishment basis for performing policy instruments (Akinsanya & Ayoade, 2013).
B) Meta policies formulate the state of policymaking structure to reach considered policies (Dror, 1971). On the other hand, they focus on the policymaking structure and procedure. The main subject of meta policies is the improvement of the methods, techniques, and tools of designing policies and policymaking processes in governmental firms (Akinsanya & Ayoade, 2013). The meta policies are strategic policies explaining the performance of main policies.

The purpose of these phases is to design and manage the policymaking system as a whole as well as to set overall principles and rules for policymaking based on the concepts of meta and mega policies. Miyakawa (1999) suggests the following frameworks for policymaking:

A) Preliminary, comprehensive policymaking (mega policies and meta policies).
B) Detailed specialized policymaking: (operational policies).

Therefore, general and executive policies have specific characteristics detailed in Table 1.

After defining policies and priorities at the first level of science and technology policymaking (studied in two levels of mega and meta policies), at the second level, there are institutions that design and implement executive policies or plans. The plans are practical designs and implementation aspects of executive policies formulated and set for a specific period. In each policy plan, beside setting goals and priorities (previously done at the first level), other issues should also be taken into consideration (Bartzokas & Teubal, 2002): main groups or institutions of purpose, administrators and their approaches, time period, necessary sources and expected outputs of the plan, and the plan's relative situation regarding other plans.

Table1. The Difference between General and Executive policies

Row	Features	General Policymaking		Executive Policymaking
		Mega Policies	**Meta Policies**	**Operational Policies or Plans**
1	Definition	Mega policies contain standards, theories, strategies, and main instructions that operational policies must obey.	Meta policies formulate the state of methods and the structure of policymaking to reach the considered policies.	Operational policies contain the formulation and implementation of small and operational actions based on the method and structure of the formulated policy to reach political purposes.
2	Main Emphasis	Policy main purposes	Policy methods and structures	Operational policy instruments
3	Main Question(s)	What?	Who? How?	How?
4	Main Actions	Selection of the general political purposes	Selection of methods and administrative structures for formulating and performing operational policies. Evaluation of feedback information sent by operational policymakers and consideration of retesting general political purposes.	Selection of operational actions (such as formulation and performing policies) based on the chosen methods and structures. Giving feedback to general policymakers about the feasibility of general political purposes, impacts, and outputs of policy operation.
5	Policymaking Level	Macro	Macro	Micro
6	The Volume of Policies	Small	Small	large
7	Policymaking Scope	Large	Large	Small
8	Policies time horizon	Long-term	Long-term	Short-term

Source: Research findings.

Lastly, after setting the policies and priorities at the first level, and designing and implementing them at the second level, the evaluation of policies and the political learning are performed at the third level. The "policy evaluation" is a systematic, programmed and purposeful process, which involves the collection of data on the question and problems of society in general, and policies and plans in particular. The evaluation is a knowledge strengthening and decision making process; whether these are decisions to improve or reform a plan or policy, or to continue and expand it, there are some aspects of judgment about merit, value and worth of the subject under evaluation in each of these decisions (Preskill & Russ-Eft, 2005).

Different kinds of science and technology policies

The study of the science, technology, and innovation policymaking field shows that the researchers divide science and technology policy into three groups (Leith et al., 2018; Edler & Yeow, 2016; OECD, 2012; UNCTAD, 2011; Taylor, 2008; Sarewitz & Pielke, 2007; Clark & Guy, 1998; Kim & Dahlman, 1992) of supply-side policies, demand-side policies, and networking and interconnection infrastructure policies. The supply-side policies are those that support innovation offerings in companies (European Commission, 2015). These policies, which are also referred to as "technology push policies" (Hansen et al., 2015; Mowery et al., 2010), seek to identify and resolve failures in the market (Elder et al., 2013). The supply-side policies are related to the linear model of innovation and support the linear processes of innovation (Edquist, 2001). The supply-side policies can be considered as the first generation of science, technology, and innovation policies. Gradually, with the advent of interactive innovation models, another broader set of policies in science, technology, and innovation was formed, which became known as demand-side policies (Edquist, 2001). Such policies, which appear as the second generation of science, technology, and innovation policies, seek to shape the context in which companies innovate (European Commission, 2015). These policies usually try to make demand and use innovation through the determination and removal of defects in the ability and willingness of the potential users (Elder et al., 2013).

Recently, several scholars have emphasized the necessity of the existence of policies linking supply and demand in the national innovation system, and have proposed a third group of science, technology, and innovation policies. In an interesting interpretation, Sarewitz and Pielke (2007) and Leith et al. (2008) expressed the reconciling of supply and demand for science as the "neglected heart" of the science policy. Elder et al. (2013) divides science, technology, and innovation into three groups:

A) The policies that are strictly on the supply side including fiscal incentives for R&D, direct support to R&D and innovation in firms, access to finance, publicly supported venture capital and loan guarantees, policies on training and skills to improve innovation capabilities in firms, human resources migration and employment protection, support measures for exploiting intellectual property, policy, technical services, and device, cluster policy on innovation, policies to support collaboration for R&D and innovation, and innovation network policies.
B) The policies that are strictly on the demand side including measures to stimulate private demand for innovation and public procurement policies.

C) The policies existing on both sides of supply and demand sectors including pre-commercial procurement, innovation inducement prizes, standardization and standards, regulation, and technology foresight.

Tailor (2008) divides technology policies into three groups of "upstream investment policies" (supply-side policies), "market creation policies" (demand-side policies), and "interface improvement policies." In the case of upstream policies, the supply of new knowledge in specific technologies is supported by the government through policymaking in R&D and the procurement of initial investment. Moreover, in market creation policies, the government provides specific technologies to new customers. Lastly, in interface improvement policies, the government promotes the innovative function of players who are between the technology creator and final users in the innovation chain. Clark and Guy (1998) divide innovative policies into three groups:

A) Supply-side policies: the policies stimulating the technology supply.
B) Demand-side policies: the policies that stimulate the demand for technology.
C) Networking and developing research infrastructure policies: the policies related to the improvement of information through the development of networks or national infrastructures.

The OECD (2012) categorizes innovative policies into three groups: A. The supply-side innovation policies; B. The demand-side innovation policies; C. The cohesive supply and demand-side policies.

Moreover, based on the studies conducted by other scholars, the science, technology, and innovation policies are grouped into three categories as follows:

A) Supply-side policies: The policies creating technological and scientific knowledge supply.
B) Demand-side policies: Such policies facilitate the use of technological and scientific knowledge.
C) Networking and interconnection infrastructure policies: The policies that seek to provide an appropriate infrastructure to establish a link between different players of the innovation system (suppliers and demanders).

Table 2 shows the division of science, technology and innovation policies based on the supply-side, demand-side and infrastructure policies.

This division can be used as the basis for the Division of labor between the science and technology policymaking institutions.

Table 2. The Division of science, technology, and innovation policies

Kinds	Row	Science, Technology and Innovation Policies	Description	Source
Supply-side Policies	1	Higher education promotion	Investment in higher education to develop human resources	Edler et al. (2013); OECD (2012)
	2	Training promotion	Investment in training to develop human resources	Roolaht (2011); Edler et al. (2013); OECD (2012)
	3	Direct support via public R&D	Financial support of public sector R&D; e.g. tax reduction on public firms in proportion to the budget spent on R&D	Hansen et al. (2015); Mowery et al. (2010); Edler et al. (2013); Roolaht (2011); OECD (2012)
	4	Direct support via private R&D	Financial support of the private sector; e.g. tax reduction or facilitating the availability of financial validity for private firms in proportion to the R&D cost	Mowery et al. (2010); Hansen et al. (2015); Edler et al. (2013); Roolaht (2011); Clark & Guy (1998); OECD (2012)
	5	Facilitate access to venture capital, loan guarantees, and other financing approaches	Public support to facilitate the accessibility of firms to finance approaches, and to provide necessary financial resources to firms for creating technology and innovation	OECD (2012); Edler et al. (2013)
	6	Entrepreneurship policies	Actions encouraging economic and social activities that are carried out by individuals	Edler et al. (2013)
	7	Cluster policies	Actions such as aiming and choosing geographical regions and specific technological activities	Clark & Guy (1998); Edler et al. (2013)
	8	Strengthening intellectual property rights	Supportive actions to benefit intellectual property rights and invention	Edler et al. (2013); Roolaht (2011); Clark & Guy (1998); OECD (2012)
Demand-side Policies	9	Public procurement	Public procurement of technology and innovation products, and R&D services	Tsipouri (2013); Hansen et al. (2015); Mowery et al. (2010); Edler et al. (2013); Roolaht (2011); Clark & Guy (1998); OECD (2012)
	10	Stimulating the private sector demand	Actions to simulate the private sector innovation	Roolaht (2011) ; Edler et al. (2013); Tsipouri (2013); Clark & Guy (1998)
	11	Regulation	A regulation that inclines demand to use the substituting technologies	Hansen et al. (2015); Mowery et al. (2010); Edler et al. (2013); Roolaht (2011) ; Tsipouri (2013); OECD (2012)
	12	Standardization	Actions leading to the confirmation of regulations and instructions to gain the best degree of regularity in a specific field	Clark & Guy (1998); Edler et al. (2013); Roolaht (2011); OECD (2012)

Kinds	Row	Science, Technology and Innovation Policies	Description	Source
Networking and interconnection infrastructure Policies	13	Network policies	Actions including facilitating the adjustment of relationships between knowledge suppliers and demanders, and co-operative activities between them such as skill training, technological development, production design, marketing, skills sharing, facility sharing and co-research plans	Mowery et al. (2010); Hansen et al. (2015); Edler et al. (2013); Roolaht (2011); Clark & Guy (1998); OECD (2012)
	14	Offering technical and consulting services	Technological and innovation consulting services such as information, technical aid, consulting, education, and other supportive services helping the firms in the adaption and implementation of new technology and innovative commercialization	Edler et al. (2013); Roolaht (2011); Clark & Guy (1998)
	15	Technology demonstration	Technological and innovation exhibitions and technology trial implementation	Hansen et al. (2015); Mowery et al. (2010)
	16	Innovation prize awarding	Stimulate the creation and use of innovation through technology awareness and innovation prizes	Hansen et al. (2015); Mowery et al. (2010); Edler et al. (2013)
	17	Creating the innovation culture	Measures to promote the culture of creation and the use of technology and innovation	Roolaht (2011)
	18	Science and technology foresight	Science and technology foresight that not only does play the role of news transmission but also has a creative role	Edler et al. (2013)
	19	The improvement of university-industry relation	Promotion of mutual co-operation between university and industry	Clark & Guy (1998)

Source: Research findings.

Theoretical framework of science and technology policymaking

Based on the three-step model of science and technology policymaking proposed by the OECD, the general and executive policymaking levels and the three-step division of science, technology and innovation policymaking extracted from the literature, the following framework is suggested (Figure 1).

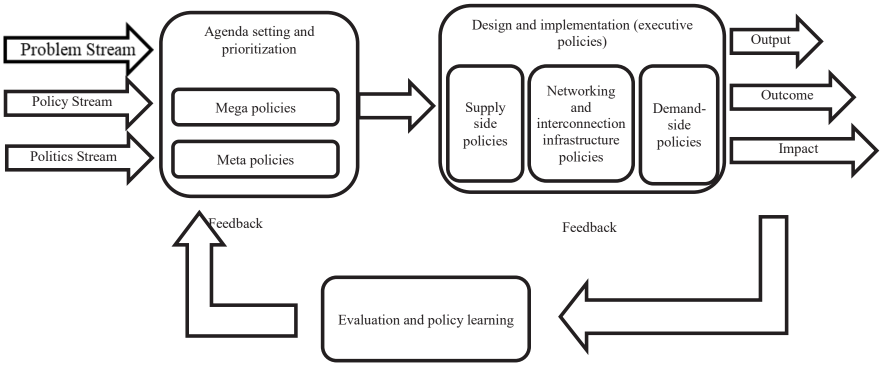

Figure 1. Suggested framework of science and technology policy

Source: Research findings.

As shown in Figure 1, the policies result from the merging of three streams:

A) Problem stream: Along this stream, after the problem is raised, the policymaker tries to focus their attention to find the cause and the definition of the problem.
B) Policy stream: In this stream, different solutions to which the policy should obey are determined. Researchers, specialists, masters, and professional groups have an important role in this stream.
C) Politics stream: In this stream, a list of problems for which the policymakers should find solutions is arranged and formulated by officials and politicians.

Figure 1 shows that when policies and priorities are determined in two policy levels of meta and mega, they must be delivered to executive institutions to be implemented. In this phase, the policymaking is commenced in three groups of supply-side policies, demand-side policies, and networking and interconnection infrastructure policies. Each policy has outputs at three levels; "outputs" that are tangible and intangible policy interventions, "outcomes" that are short-term and medium-term policy intervention outputs, and "impacts" that are long-term positive/negative, primary/secondary, direct/indirect, intentional/unintentional policy intervention outputs. The evaluation of the outputs for each policy at the above-mentioned levels provides feedbacks to the policy determination phase and, subsequently, the cycle of policymaking repeats.

Thus, by reviewing the literature, a framework for science and technology policy was designed. Based on this framework, science and technology policymaking is done in three stages: 1) agenda setting and prioritization (including two sub-stages of formulating mega policies and formulating meta policies); 2) Design and implementation of executive policies (including 19 types of policies in three categories of supply-side policies, demand-side policies, and networking and interconnection infrastructure policies); 3) Evaluation and policy learning (at three levels of outputs, outcomes, and effects). This framework, including 24 policy levels or activities (two levels of policy formulation in the first phase, 19 types of policy in the second phase, and three levels of policy evaluation in the third phase), is the basis for mapping the science and technology policy network. Therefore, by mapping the science and technology policy institutions in Iran in each of these 24 cases, the science and technology policy network in Iran is mapped. In the following section, after explaining the methodology considerations, the science and technology policy network in Iran is mapped. Then, based on a number of indicators and methods of social network analysis (SNA), the science and technology policy network in Iran is analyzed.

METHODOLOGY

Based on the research onion model of Saunders et al. (2012), the methodology of this study is formulated at six levels. Its philosophy paradigm is based on interpretivism, and its rational approach is based on induction. The methodology of this study is based on a mixed method. Its strategy follows a case that focuses on the analysis of science and technology policymaking in Iran in 2018. According to Yin's (1994) typology, this research is an exploratory case study. Thus, the purpose of this study is to discover new perspectives on the science and technology policy network in Iran and to construct new meanings and new insights about science and technology policymaking institutions in Iran and the interactions between them. This study tries to answer the main question of "how is the science and technology policymaking network in Iran?" Other questions discussed in this study are as follows:

A) What are the main players in the science and technology policy network in Iran, from the perspective of policy documents?
B) What are the interactions between the main players of Iran's science and technology policy network, from the perspective of policy documents?
C) Which of the players have more structural power in the science and technology policy network in Iran, from the perspective of policy documents?

The methodology of social network analysis (SNA) was used for this study. The SNA method is an appropriate method for analyzing policy networks that are used in many studies (Yun et al., 2014). It is based on the basis of "network theory" and "graph theory" (Hanneman & Riddel, 2005). The most important feature of network theory is to change the focus from actors and their features to each pairing of them and their relations (Parkhe et al., 2006; Wellman & Berkowitz, 1998). The graph theory is also a summary of the structural aspect of any model, and simulates the network mathematically (Brandes & Erlebach, 2005). The key assumption in social network analysis is that the relationships between actors have considering characteristics (Wellman & Berkowitz, 1998). Hence, the theoretical framework of studies in social network analysis should be based on the relationships between actors; moreover, for collecting relational data, experimental actions should be designed. In this research, a number of SNA tools are used in accordance with the research questions. Thus, to answer the first question, core-periphery analysis is used. Also, to answer the second question, a network is drawn (with NetDraw); and to answer the third question, the centrality index (degree centrality, closeness centrality, and betweenness centrality) is used. The network analysis studies are validated via a structural assessment in which the collection of evidence is achieved through multiple sources such as questionnaires, interviews, observations, documents, and others. It is also possible to consult with the experts in the field to examine the accuracy of the results and data sources (Helms et al., 2010). Denzin and Lincoln (2003) also suggest different types of triangulation methods to increase the credibility of qualitative research, in which a data triangulation method has been used. This means that multiple sources of data (policy documents, semi-structured interviews, national and international reports such as the UNCTAD (2016) report, and researcher observations of the interactions of science and technology policy institutions in Iran) have been used.

The science and technology policymaking organizational network in Iran is the network this study focuses on. Moreover, the science and technology policymaking organizations of Iran are the nodes of the network under study. The nodes are the building blocks and representatives for the entities in the network (Estrada, 2013). Furthermore, the communicational relations or the relationships in the network are those along which the messages and information are exchanged between the actors (Knoke & Kuklinski, 1990). The scope of the analysis in this network covers the whole network. To determine the network boundary, the nominal approach is used based on the research purpose (Wasserman & Faust, 1999). In this study, 25 science and technology policy documents of the Islamic Republic of Iran were identified, including the constitution, general policies announced by the Supreme Leader, laws approved by the parliament, approvals of the Supreme Council of the Cultural Revolution, and approvals of the cabinet. A list of these documents is provided in Appendix. In order to validate the collected data, an open interview with 20 science and technology policymaking experts in Iran was conducted. The experts were chosen based on the snowball sampling method with eight of them having a theoretical specialty in science and technology policymaking and the rest having professional experience in science and technology policymaking in Iran. More precisely, the combination of experts was: three from previous ministers of science, research and technology, one of the previous health ministers, eight university professors with expertise in science and technology policies (from University of Tehran, Tarbiat Modares University, Allameh Tabatabaei University, Sharif University of Technology, Amir Kabir University of Technology and University of Shiraz), six heads of large universities (University of Tehran, Tarbiat Modares University, Sharif University of Technology, Amir Kabir University of Technology, University of Teachers and University of Islamic Education), one of the members of parliament and a member of the Supreme Council of the Cultural Revolution. The main purpose of interviewing experts was to validate data analysis that was extracted from policy documents. Thus, since the main purpose of this research is the mapping of the science and technology network in Iran, the questions raised from experts around the two main axes were; what are the most important actors of Iran's science and technology policy and, second, what are their interactions with each other? In this way, the ambiguities of policy documents were resolved and modified with the help of experts. The interviews performed were also semi-structured. Furthermore, to analyze data, a social network analysis method using UCINet and NetDraw software was used.

The list of science and technology policymaking organizations in Iran was extracted based on the study of 25 science and technology policy documents in Iran. Using this list and the research's conceptual framework (i.e., 24 policy levels or activities according to Figure 1 and Table 2), the organization-task matrix for science and technology policymaking in Iran was designed. This matrix consists of 19 rows (according to the number of science and technology policy organizations in Iran) and 24 columns (according to the number of levels and activities of science and technology policy in Iran). Thus, in this matrix, each corresponding organization is considered with a row and each corresponding task with a column. The matrix cells are filled with the numbers 0 or 1. In this study, by studying and analyzing the above-mentioned 25 policy documents, proportionate to the conceptual framework of the research, 86 nodes were recognized. Each node is proportionate to a task that is described for an organization in the science and technology policy documents of Iran. The cell value in the organization-task matrix is 1 when the institution mentioned in the science and technology policy documents is required to do the corresponding task; otherwise, the cell value is 0. Upon entering this matrix into the UCINet software, by applying appropriate commands to the software, a two-mode, core-periphery analysis and calculation related to centrality (degree, closeness, and betweenness) was performed. Also, Iran's science and technology policy network was drawn with the help of NetDraw software, which is a software add-on.

RESULTS

Using the data from the matrix, the organization-task network of science and technology in Iran was plotted in Figure 2.

As demonstrated in Figure 2, this is a two-mode network that consists of nodes representing institutions and tasks. The red circular nodes are science and technology policymaking organizations in Iran, while the blue squared ones denote the levels and activities of science and technology policymaking based on the conceptual framework of the study. According to this figure, and what has been previously mentioned, some levels and activities of science and technology policymaking are performed by various institutions. Moreover, some of the policymaking institutions contribute to different levels and activities of science and technology policymaking in Iran.

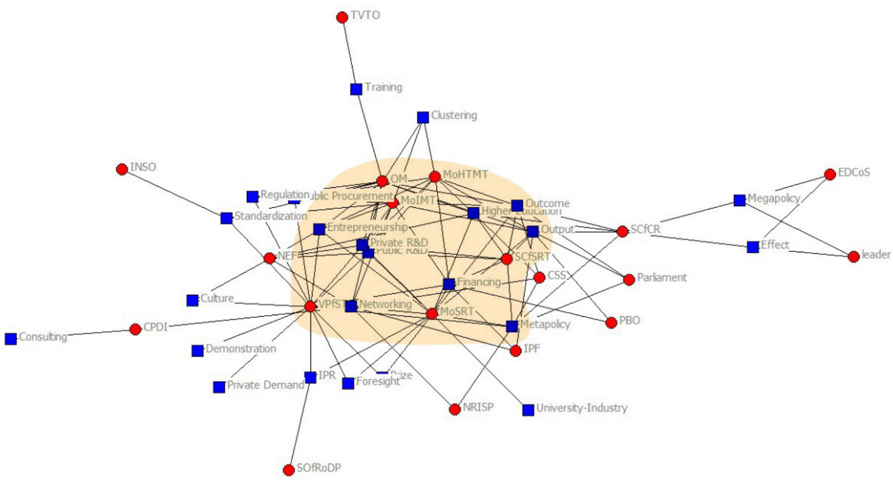

Figure 2. Organization-task network for the science and technology policymaking organizations in Iran

Source: Research findings.

The two-mode, core-periphery analysis simultaneously categorizes the players and the tasks into two groups (Hanneman & Riddel, 2005):

A) "Core": this includes a group of players who have a close relationship with each task, as well as a group of tasks that have a close relationship with the core. Thus, the core is a cluster of players and tasks, often interacting with one another simultaneously;
B) "Periphery": this includes a group of players who do not meet in the same task, as well as tasks that are not related to each other, as they do not have a common player.

From the viewpoint of documents, and based on the two-dimensional core-periphery analysis, six institutions such as the ministry of industry and mines, ministry of health, ministry of science, research and technology (MoSRT), other related ministries, the supreme council of science, research and technology, and the vice presidency for science and technology (VPfST), have the highest co-ordination capability in policymaking levels. These levels include 1- formulating meta policies, 2- designing and implementing plans such as higher education activities, supporting public and private R&D, facilitating financing, entrepreneurship and network policies, and 3- outcomes and outputs evaluation. The density matrix index of the core block is 0.784. This is a large value; thus, these six institutions form the core of the science and technology policymaking network in Iran. However, the coordination capability between other science and technology policymaking institutions is significantly poor, especially at policymaking levels 1-mega policies formulation, 2-designing and implementing plans such as training, cluster policies, intellectual property rights, technical and consulting services, technology demonstration, university–industry relationship, public procurement, stimulating private demand, regulation and standardization, and 3-the evaluation of policy impacts. The density matrix index for the periphery block is the small value of 0.054. In Figure 2, the core of the science and technology policymaking network is illustrated with an orange background.

The two-mode, organization-task matrix is converted to a one-dimensional, organization-organization matrix using the cross-products method. Figure 3 shows the science and technology policymaking interactions in Iran.

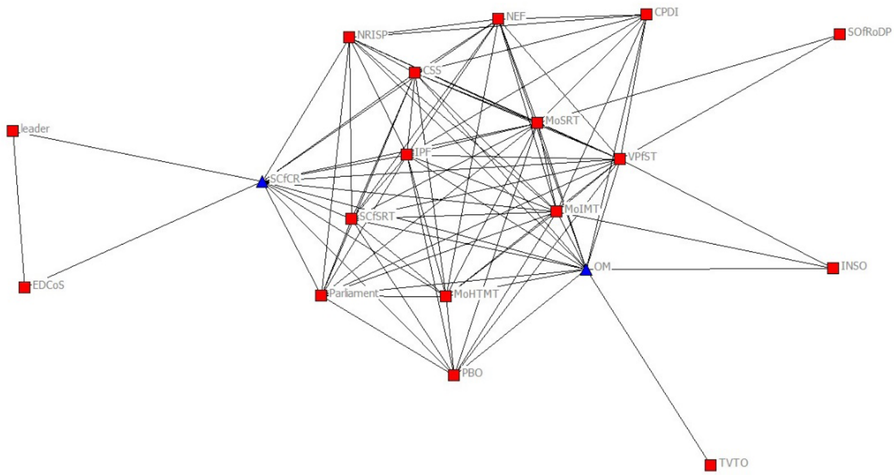

Figure 3. Interactions network for the science and technology policymaking organizations in Iran

Source: Research findings.

The size of this network is 19, meaning that there are 19 institutions with a serious effect on science and technology policymaking in Iran. There are 180 edges in this network. Each edge is a representative for a relationship between two institutions (Hogan, 2007). Furthermore, each institution, on average, has 9.47 relationships with others. As shown in Figure 3, in order to accomplish its tasks, each institution should have a relation to another. In each network, the density is the sum of relationships existing in the network (Hansen et al., 2011). The density of the science and technology policymaking network in Iran is 0.526. Therefore, 52.6% of all possible relationships are predicted in the policy documents.

In the analysis of social networks, the "cut point" is the actor whose deletion leads to the division of the whole network structure into several distinct substructures called the "block" (Wasserman & Faust, 1990; Hanneman & Riddle, 2005). As illustrated in Figure 3, the science and technology policymaking network in Iran has two cut points that divide it into three distinct blocks. The "supreme council of the cultural revolution," as the first cut point of science and technology policymaking, connects the supreme leader and the expediency discernment council of the system (EDCoS) to the network. The "other related ministries" as another cut point forms the connection between the Iran technical and vocational training organization (TVTO) and the network. In Figure 3, the cut points are shown by blue triangles connecting the left block (the supreme leader and EDCoS), the bottom block (TVTO), and the right block (other policymaking policies) to one another.

Using three approaches, the strength of Iranian science and technology policymaking institutions are compared with each other. According to the degree centrality index of the Bonacich's approach, the centrality of each actor is a function of its relationships number and also that of its adjacent actors (Hanneman & Riddle, 2005). In Table 3, the degree centrality of each actor is calculated based on Bonacich's approach. As seen in Table 3, the highest Bonacich power values are respectively related to MoSRT (with a value of 14820), other related ministries (with a value of 14139), and ministry of industry, mines, and commerce (with a value of 13902). In this table, the related degree centrality of these three institutions is shown in bold.

The closeness centrality is another power index for each actor in the network (Hanneman, 2001; Brandes & Erlebach, 2005). The closeness centrality of each actor is calculated using the Eigenvector method. Finding the most central actors with regard to the general structure of the network is the purpose of this method. Moreover, it applies less importance to patterns with a more local concentration (Hanneman & Riddle, 2005). In Table 3, the closeness centrality of the science and technology policymaking institutions of Iran is shown using the Eigenvector method. As shown, the highest amounts of closeness centrality belong to MoSRT (with a value of 0.423), other related ministries (with a value of 0.404), and ministry of industry and mines (with a value of 0.397). In Table 3, the related amounts of closeness centrality of these three institutions are shown in bold. The closeness centrality results of science and technology policymaking in Iran are in close concordance with those of Bonacich's approach.

Another approach for evaluating an actor's power is the betweenness centrality. In this approach, an actor is in an ideal condition from the viewpoint of power when the shortest, geodesic distance connects other pairs of actors in the network. In other words, the more individuals depend on an actor for establishing relationships with others, the more power that actor possesses (Hanneman 2001; Hanneman & Riddle, 2005). Table 3 shows the betweenness centrality of the actors in the science and technology policymaking network of Iran using the Freeman method (Hanneman & Riddle, 2005). As Table 3 shows, the largest amounts of betweenness centrality respectively belong to the Supreme Council of the Cultural Revolution (with a value of 32), other related ministries (with a value of 22), and the vice presidency for science and technology (with a value of 14). The betweenness centrality of these three organizations is shown in bold in Table 3. The results of the betweenness centrality for the Iranian science and technology policymaking differ from those resulting from using other approaches to degree and closeness centrality.

The Supreme Council of the Cultural Revolution (SCfCR), with a remarkable difference, has the most power from the viewpoint of betweenness centrality. This shows that a lot of actors depend on SCfCR for connecting to others. This is rational as SCfCR has an important role in connecting the supreme leader and EDCoS (active at the macro policymaking level) with other organizations (active at the operational policymaking level, plan design, and implementation). The key role of SCfCR is appreciated for linking the institutions with regard to the place of SCfCR as a cut point in the network.

Table 3. Centrality of science and technology policymaking institutions in Iran based on different methods

Row	Institution Name	Symbol	Power		
			Degree Centrality	Closeness Centrality	Betweenness Centrality
1	The Supreme Leader	Leader	234	0.007	0
2	Expediency Discernment Council of the System	EDCoS	234	0.007	0
3	The Supreme Council of the Cultural Revolution	SCfCR	5654	0.161	32.5
4	The Supreme Council for Science, Research and Technology	SCfSRT	10020	0.286	0.56
5	Parliament	Parliament	4104	0.117	0.33
6	Vice Presidency for Science and Technology	VPfST	13690	0.391	14.3
7	Iran's National Elites Foundation	NEF	7878	0.225	0.74
8	Ministry of Science, Research and Technology	MoSRT	14820	0.423	9.0
9	Ministry of Health	MoHTMT	12166	0.348	0.33
10	Ministry of Industry, Mine and Trading	MoIMT	13902	0.397	5.8
11	Other ministries like Ministry of Information and Communication Technology; Ministry of Defense; ...	OM	14139	0.404	22.8
12	Iran Technical and Vocational Training Organization	TVTO	271	0.008	0

Row	Institution Name	Symbol	Power		
			Degree Centrality	Closeness Centrality	Betweenness Centrality
13	Plan and Budget Organization	PBO	2892	0.083	0
14	Innovation and Prosperity Fund	IPF	4361	0.124	1.5
15	Center for Progress and Development of Iran	CPDI	1498	0.043	0
16	Center for Strategic Studies	CSS	5347	0.153	0.98
17	Nation Research Institute for Science Policy of Iran	NRISP	2525	0.072	0.74
18	Iran National Standard Organization	INSO	798	0.023	0
19	Iran Registration of Documents and Real Estate Organization	SOfRoDP	545	0.016	0

Source: Research findings.

Lastly, in order to compare the power of policymaking institutions, the average of the above-mentioned index was calculated and the final power of the institution was determined. Therefore, before calculating the mean power of each organization, based on a Likert scale (very high, above average, average, below average, very low), the power of each organization in each power index was organized. Table 4 indicates the power of each organization.

Table 4. Structural power of science and technology policymaking institutions

Row	Institution Name	Power			Final Power
		Degree Centrality (Bonacich)	Closeness Centrality (Eigenvector)	Betweenness Centrality	
1	The Supreme Leader	Very low	Very low	Very low	**1**
2	Expediency Discernment Council of the System	Very low	Very low	Very low	**1**
3	The Supreme Council of the Cultural Revolution	Below average	Below average	Very high	**3**
4	The Supreme Council for Science, Research and Technology	Above average	Above average	Very low	**3**
5	Parliament	Below average	Below average	Very low	**1.67**
6	Vice Presidency for Science and Technology	Very high	Very high	Average	**4.33**

Row	Institution Name	Power			Final Power
		Degree Centrality (Bonacich)	Closeness Centrality (Eigenvector)	Betweenness Centrality	
7	Iran's National Elites Foundation	Average	Average	Very low	**2.33**
8	Ministry of Science, Research and Technology	Very high	Very high	Below average	**4**
9	Ministry of Health	Very high	Very high	Very low	**3.67**
10	Ministry of Industry, Mine and Trading	Very high	Very high	Very low	**3.67**
11	Other Ministries Like Ministry of Information and Communication Technology; Ministry of Defense;	Very high	Very high	Above average	**4.67**
12	Iran Technical and Vocational Training Organization	Very low	Very low	Very low	**1**
13	Plan and Budget Organization	Very low	Very low	Very low	**1**
14	Innovation and Prosperity Fund	Below average	Below average	Very low	**1.67**
15	Center for Progress and Development of Iran	Very low	Very low	Very low	**1**
16	Center for Strategic Studies	Below average	Below average	Very low	**1.67**
17	Nation Research Institute for Science Policy of Iran	Very low	Very low	Very low	**1**
18	Iran National Standard Organization	Very low	Very low	Very low	**1**
19	Iran Registration of Documents and Real Estate Organization	Very low	Very low	Very low	**1**

Source: Research findings.

As shown in Table 4, other related ministries within science and technology, including the ministry of information and communication technology, ministry of power, ministry of petroleum, and others, by achieving 4.67 out of 5 have the largest structural power in Iran. Following them, VPfST and MoSRT respectively, with scores of 4.33 and 4 have more structural power in comparison to the other institutions.

DISCUSSION, CONCLUSION, AND POLICY RECOMMENDATIONS

In spite of Iran's rising trend in science and technology, which has been mentioned in numerous international reports (Montazer & Kalantari, 2019; Nourizadeh et al., 2018; Cornell University et al., 2018; NUCTAD, 2016;

Kalantari et al., 2015; Kalantari & Charkhtab Moghadam, 2015; INSEAD et al., 2011), serious institutional problems exist in science and technology policymaking in Iran. This research's findings address two basic problems in science and technology policymaking in Iran (Kalantari et al., 2019; Montazer et al., 2019). The first one is the multiplicity of policymaking institutions in the field. Even though the large number of players had previously been considered as a serious problem in science and technology policymaking by researchers, the existence of 19 institutions that play a role in different levels of science and technology policymaking in Iran has caused some problems for the division of labor among them. The large number of decision-maker institutions in science and technology policymaking (Soofi, 2017), the existence of numerous players in science, technology and innovation policymaking (UNCTAD, 2016), the existence of different institutions in science and technology policymaking (UNESCO, 2010), the existence of different attendants in science and technology policymaking (Soltani et al., 2017), the multiplicity and overlapping of policymaking institutions and the weakness of policymaking institutions (Soltanzadeh et al., 2017), the existence of parallel institutions in science and technology policymaking (Zaker Salehi, 2012), the numerous effective organizations on science, technology and innovation system (Danaeifard, 2004), are all the evidence that other researchers have alluded to, implying there are numerous problems with the science and technology policymaking organizations in Iran.

The lack of interaction mechanisms among policymaking institutions in the science and technology field of Iran is the other problem. Despite the association of a number of institutions in some tasks, interaction mechanisms among them have not been predicted in policy documents, and most of the times, despite the prediction, they are not performed correctly. There are several studies in the literature referring to such cases. Different and complicated vertical and horizontal relations (UNCTAD, 2016), the necessity of complicated mechanisms of co-ordination and division of labor (UNESCO, 2010), recommendations for the improvement of co-ordination and coherence in innovation policymaking institutions (Soltani et al., 2017), lack of scientific, industrial and technological networks (Norouzi et al., 2016), island, disorganized, inconsistent structures devoid of purposeful relations, fragmented decision-making and policymaking centers, lack of coherence and unity (Zaker Salehi,2012), little communication among different players, the important role of government in policymaking without involving different interested parties (Haji Hosseini et al., 2011), lack of co-ordination and macro and national policymaking (Ghazinoory & Ghazinoori, 2008), lack of communication and mutuality of policymaking centers, lack of effective interaction between policymakers and scientists (Manteghi et al., 2010), lack of communication among science and technology policymaking institutions, lack of techniques in this field (Tabatabaeian and Bagheri, 2003), are all evidence that other researchers have pointed to, indicating the lack of relation and co-ordination among the different players involved in science and technology policymaking in Iran.

In addition to the two main mentioned problems, other institutional problems are also considered in science and technology policymaking in Iran. First, some activities in the core-periphery analysis that are grouped as periphery activities can pose a serious threat to science and technology policymaking in Iran. For example, “the determination of mega policies” and “the evaluation of the policy impacts,” which have an important role in determining meta and operational policies and are based on policy documents from EDCoS, are put into the periphery of the network. The inattention to the policy impacts and relying only on the evaluation outputs and the policy outcomes (which is usually performed by the parliament and public ministries) can gradually lead to mere attention to a quantitative output index and, consequently, a deviation from the policies. Second, the implication of some tasks by several institutions without designing the necessary coordinating mechanisms among them causes parallel work, neutralizes policies and wastes resources. For example, based on document policy, the public ministries, VPfST, and SCfSRT are in charge of supporting private R&D. However, there is no clarification available on the role and task of each organization. Another example is the financial resources support for the science and technology field, which, in addition to the public ministries, is done by a plan and budget organization and an innovation and prosperity fund.

Third, according to the policy documents, there is a very high interaction density among some of the science and technology policymaking institutions, especially those having roles in the planning and implementation levels. This interaction density leads to the complications and complexity of interactions leading to a serious weakness in the division of labor among the institutions. Consequently, even using relationship-analyzing software such as UCINet would fail to identify institutions and would partition them into groups with more interactions in certain tasks. Thus, the serious interferences among the tasks of these institutions and the consequent disorders are considered as a major threat. Fourth, SCfCR as a supreme institution that plays an important role in the policymaking level and determination of national priorities and policy impacts evaluation, have an active role in planning and plan implementation levels. Therefore, the presence of an institution in all three-fold levels of policymaking causes an overlap in its activities with those of many other institutions, especially the ones responsible for planning. Fifth, the existence of two cut points in the network increases the possibility of vulnerability in the network. SCfCR, as the cut point for the supreme leader and the EDCoS with other institutions, connects the policymaking level and national priorities with the level of planning and implementation of plans. Moreover, other related institutions such as the ministry of information and communication technology of Iran, the ministry of defense and armed force logistics, and the ministry of power, are the cut points for TVTO with other organizations connecting the training with other tasks. If the mentioned interactions are disconnected for various reasons, such as the weakness of the organizations acting as cut points in the network, the science and technology policymaking network will fall into a fragmentation process. To overcome the mentioned problems, the following policy recommendations are suggested:

A) The institutions with considerable overlap in their tasks should gradually, over the medium term (for example, one or two five-year programs), merge into one another. If, based on the experts' opinion, the merging of these institutions would face a lot of institutional resistance and have a vast negative result, the tasks of each institution must be clearly and accurately defined through the accurate and clear division of labor among them.

B) The interaction and coordination mechanisms among institutions should be determined clearly and accurately especially for 1- institutions which are in various vertical levels (for example, the interaction mechanisms among institutions determining the policy formulation and national priorities with the institutions playing roles in the planning level and implementation of executive programs); 2- institutions which are active in a certain task (for example, interaction among institutions, such as EDCoS and SCfCR, that formulate mega policies).

C) A mechanism should be designed to transfer the key activities of the science and technology field from the periphery to closer to the network core. For example, two activities of "the determination of mega policies" and "the policy impact evaluation," which determine the main direction of science and technology policies, are in the periphery of the network and have little effect on the overall course of the science and technology policies. Hence, designing a mechanism to place these two activities in a more central region of the network is of great necessity.

D) The redundant interaction mechanisms predicted in policy documents must be omitted. Such mechanisms are mostly caused by the interference of some institutions in the tasks of others. Consequently, they lead to a decrease in the effectiveness and efficiency of policies. For example, the intricate relationships among policymaking institutions in the field of higher education cause a weakness in the efficiency and effectiveness of the policies. Therefore, it is necessary to eliminate the redundant interaction mechanisms by the accurate division of labor between institutions.

E) The interaction mechanism among institutions connected to the network only through cut points should be strengthened. The existence of cut points in the network decreases the risk of vulnerability in the network and in some cases, could cause a deviation in policies. Hence, it is necessary to design complementary mechanisms in the network in a way that limits the role of cut points in the network.

The findings and results of this research are based on the analysis of science and technology policy documents in Iran. Since, sometimes, policy documents are different from what is happening in reality, one of the limitations of this research is the analysis of the science and technology policy network in Iran from the perspective of policy documents. Therefore, in future research, it is recommended that researchers map the science and technology policy network in Iran in reality, for example, based on mere interviews with experts, and compare and analyze the differences between that network and the document-based network.

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Appendix: List of science and technology policy documents in Iran

#	Name of the policy document in the field of science and technology	approving body	year of approval
1	Constitution of the Islamic Republic of Iran	Assembly of Constitutional Experts	approved in 1979 and amended in 1989
2	Position, goals and tasks of the Supreme Council of the Cultural Revolution	The Supreme Council of the Cultural Revolution	1997
3	Leadership rulings in determining of the members of the seventh period of the Expediency Discernment Council of the System	The Supreme Leader	2017
4	Detailed Description of Tasks and Powers of the Supreme Council of Science, Research and Technology	Cabinet	2004
5	Rules of Procedure of the Parliament	Parliament	2016
6	Basic Goals and Tasks of the Vice Presidency for Science and Technology	Vice Presidency for Science and Technology	2017
7	Articles of Association of the National Elite Foundation	The Supreme Council of the Cultural Revolution	2005
8	Law on Removing Barriers to Competitive Production and Improving the National Financial System	Parliament	2015
9	Law on Maximum Use of Production and Service Capacity in Meeting the Needs of the Country and Strengthening in Export and Amending Article 104 of the Law on Direct Taxes	Parliament	2012
10	Law on Tasks and Powers of the Ministry of Oil	Parliament	2012

#	Name of the policy document in the field of science and technology	approving body	year of approval
11	Law on Goals, Tasks and Organization of the Ministry of Science, Research and Technology	Parliament	2004
12	Law on Organization and Tasks of the Ministry of Health, Treatment and Medical Education	Parliament	1998
13	Articles of Association of the Technical and Vocational Training Organization	Cabinet	-
14	Law on Concentration of Industry and Mining and Establishment of the Ministry of Industries and Mines	Parliament	2000
15	Separation of the Program and Budget Organization and the Administrative and Employment Organization	Supreme Administrative Council	2016
16	Articles of Association of the Innovation and Prosperity Fund	Cabinet	2017
17	Tasks of the Center for Progress and Development	Not approved	-
18	Articles of Association of the Center for Strategic Studies	Not approved	-
19	Articles of Association of the Nation Research Institute for Science Policy of Iran	Ministry of Science, Research and Technology	2012
20	Law on Amending the Laws and Regulations of the Institute of Standards and Industrial Research of Iran	Parliament	1992
21	Tasks of the Iran Registration of Documents and Real Estate Organization	Not approved	-
22	Law on Support of Knowledge-Based Companies and Institutions and Commercialization of Innovations and Inventions	Parliament	2010
23	Law on Tasks and Powers of the Ministry of Communications and Information Technology	Parliament	2003
24	Law on the Establishment of the Ministry of Defense and Support of the Armed Forces	Parliament	1989
25	Law establishing the Ministry of Power	Parliament	1974

Source: Research findings.

Abstrakt

CEL: *Głównym celem tego artykułu jest zdefiniowanie sieci polityki naukowej i technologicznej w postaci sieci społecznej z perspektywy dokumentów politycznych, a następnie jej analiza metodą analizy sieci społecznych (SNA).* ***METODYKA:*** *Jako studium przypadku, sieć polityki naukowej i technologicznej w Iranie jest analizowana przy użyciu sugerowanych ram w tym badaniu. Dane wykorzystane w tym badaniu zostały zebrane poprzez analizę treści 25 dokumentów politycznych i wywiadów z 20 przedstawicielami irańskich elit polityki naukowej i technologicznej, zanim zostały zinterpretowane przy użyciu metody analizy sieci społecznej i oprogramowania, takiego jak NetDraw i UCINET.* ***WYNIKI:*** *Najważniejsze instytucje kształtujące politykę naukową i technologiczną w Iranie oraz interakcje między nimi zostały określone z punktu widzenia sieci. Udało się to osiągnąć poprzez przeprowadzenie dwuwymiarowej analizy rdzeń-peryferia, zidentyfikowanie punktów cięcia i bloków oraz pomiar siły strukturalnej każdej instytucji przy użyciu stopnia centralności, centralności bliskości i centralności pośredniczącej.* ***IMPLIKACJE DLA TEORII I PRAKTYKI:*** *Najważniejszymi praktycznymi implikacjami tych badań są: integracja szeregu instytucji tworzących politykę, podział wyraźnej i precyzyjnej pracy pomiędzy instytucje polityczne, projektowanie mechanizmów koordynacji pionowej i poziomej między instytucjami, eliminacja ingerencji jednych instytucji w zadania innych, projektowanie komplementarnych mechanizmów kontroli roli punktów cięcia oraz zwracanie uwagi na ważne działania na marginesach sieci.* ***ORYGINALNOŚĆ I WARTOŚĆ:*** *Najważniejszym wkładem tych badań jest opracowanie ram badania polityki naukowej i technologicznej, a następnie opracowanie metody badania polityki naukowej i technologicznej opartej na SNA. W związku z tym ramy badania polityki naukowej i technologicznej w cyklu składają się z trzech etapów: 1- Ustalanie agendy i ustalanie priorytetów (na dwóch poziomach megapolityki i metapolityki); 2- Projektowanie i wdrażanie lub polityki wykonawcze (w trzech częściach: polityka po stronie popytu, polityka po stronie podaży oraz polityka dotycząca infrastruktury sieciowej i wzajemnych połączeń); 3- ewaluacja i nauka polityki.*

Słowa kluczowe: *polityka naukowo-technologiczna, sieć polityczna, analiza sieci społecznych SNA, władza strukturalna, Iran*

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Conflicts of interest

The authors declare no conflict of interest.

Citation

Kalantari, E., Montazer, G., & Ghazinoory, S. (2021)l. Mapping of a science and technology policy network based on social network analysis. *Journal of Entrepreneurship, Management and Innovation*, *17*(3), 115-147. https://doi.org/10.7341/20211734