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Case Study

DPSIR framework to evaluate and analyze Iran's energy security

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Abstract
Energy security has become an increasing concern for many countries, policymakers, and decision-makers. Beyond the environmental challenges of fossil energy sources, energy security remains a prominent concern for economic development. Therefore, evaluating energy security can be a valuable tool for policy formulation. This article models the energy security of Iran using the DPSIR framework (driving forces, pressures, states, impacts, and responses). The period under study is from 2012 to 2021. The dimensions of this framework include five aspects: driving forces, pressures, status, impacts, and responses. The TOPSIS model with entropy weighting is used to calculate the weights of indices and ultimately determine the final energy security. The research findings indicate that throughout the examined period, there have been fluctuations in the trend. However, Iran's energy security has been bullish and has reached 0.61 in 2021 from 0.38 in 2012. The indicators of driving forces and impacts have enhanced energy security threats. International sanctions, population growth, urbanization, reliance on fossil fuel consumption, and the emission of environmental pollutants were the most influential factors contributing to decreased energy security. Iran requires the implementation of suitable strategies for long-term control of these factors.

Article Highlights

- Designing DPSIR framework for energy security evaluation
- Using TOPSIS and entropy methods for weighting sub-indices
- Evaluation of energy security and its prioritization from 2012 to 2021

Keywords Energy policy · Complex systems · Entropy weight · TOPSIS model · Case study

1 Introduction

In today's society, energy plays a significant role in bolstering economic and social development. So, energy security directly affects keeping finances safe, national safety, and social stability [1]. The history of energy security has been shaped by geopolitical, economic, environmental, and technological factors. It has developed from concentrating solely on conventional energy sources to adopting a more comprehensive approach that includes sustainability, diversity, resilience, and worldwide collaboration in fulfilling countries' energy requirement [2]. During the early 1900s, energy

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security essentially centered on furnishing military oil to governments worldwide [3]. However, the expansion of energy security research gained particular importance and further growth following the oil crises in the 1970s [4, 5].

1980s economic sanctions against Iran challenged the country's energy security. After severing relations with many oil-exporting countries, Iran sought ways to ensure its energy security. Since then, Iran has sought to ensure its energy security by increasing domestic energy production and expanding the oil and gas industry. Furthermore, Iran has tried to use the plentiful resources within its land and establish friendly partnerships with other nations [6]. However, at the United Nations Climate Change Conference 2015, Iran pledged to reduce greenhouse gas emissions by 4% between 2021 and 2030. Iran has also stated its intention to reduce the emissions of greenhouse gases by 12% in case the sanctions are lifted [7, 8]. Increasing the share of non-hydrocarbon resources, improving energy efficiency, and controlling long-term socio-economic factors lead to a reduction in CO2 emissions and a decrease in energy imports. Sound policies and structural reforms aimed at reducing dependency on fossil fuels can limit CO2 emissions and contribute to improving energy security [9].

Energy security is a multi-dimensional measure that depends on various sub-indicators. Comparing the sub-indicators of energy security in Iran with regional countries can provide an overview of its overall energy security situation. In the Middle East, Iran is a strategic country for energy supply, having access to resources in the Caspian Sea to the north and the Persian Gulf to the south. Iran possesses the second-largest oil reserves after Saudi Arabia and leads in natural gas reserves, followed by Saudi Arabia and Turkmenistan. In terms of population, Iran has the third-largest population after Pakistan and Turkey, ranking ninth in population growth in the region. Iran's gross domestic product (GDP) is not particularly favorable in the region, ranking tenth. Kuwait, the United Arab Emirates, and Saudi Arabia have the highest GDP. Iran has the second-highest energy consumption among regional countries after Pakistan. Similar to many other countries in the region, such as Saudi Arabia, Turkey, and the United Arab Emirates, nearly 100% of the Iranian population has access to electricity. The majority of electricity production from renewable sources is in Turkey, Pakistan, and Azerbaijan, with Iran ranking sixth. Iran has been ranked fourth in terms of the amount of carbon dioxide (CO2) emissions per capita. The countries that are ahead of Iran in this ranking are Kuwait, the United Arab Emirates, and Saudi Arabia. However, when it comes to the total quantity of pollutant emissions, Iran is in the first position among the countries in the region. Table 1 shows Iran's situation compared to the world average [10].

Evaluating the energy security status of a region and understanding its trends can help policymakers refine past strategies. On the other hand, energy security depends on different measures, and evaluating it requires thorough examinations. In previous research, various approaches have been employed to evaluate energy security. Brodny and Tutak [11] used the Multi-Criteria Decision Making (MCDM) approach to evaluate the energy security level of the European Union. In this study, they employed methods such as the criterion importance through inter-criteria correlation (CRITIC) and standard deviation (SD) to determine the weights of indicators. They also used graph theory and matrix approach (GRA) and technique for order of preference by similarity to ideal solution (TOPSIS). Solangi and colleagues [12] used an integrated AHP and fuzzy TOPSIS approach to assess and overcome obstacles to renewable energy for sustainable development in Pakistan. They identified seven main obstacles to renewable energy and twenty-nine sub-obstacles. Subsequently, they proposed various strategies to overcome these obstacles to renewable energy. Ali shah and colleagues [13] conducted a study examining alternative strategies for waste-to-energy (WtE) to enhance green economic recovery (GER) during the post-COVID-19 period. To assess these strategies, they developed a decision support framework focused on the

Table 1 Comparison of Energy Security sub-indicators between Iran and the World

Item	Unit	Iran, Islamic Rep	World
Oil reserves	% of total	9.5	100
Natural gas reserves	% of total	17.3	100
Population growth	annual %	0.71	0.79
GDP per capita	current US$	4,670	12,744
GDP per unit of energy use	$ per kg of oil	4.90	8.33
Fossil fuel energy consumption	% of total	98	81
Electric power consumption	kWh per capita	2928	3105
Electricity production from renewable sources	% of total	0.08	6.76
Access to electricity	% of population	100	91
CO2 emissions	metric tons per capita	7.06	4.29

energy trilemma, utilizing multi-criteria decision-making (MCDM) methods. In another study, Bamisile and colleagues [14] analyzed the dynamics of the energy security index of 30 provinces in China using comprehensive functional data analysis (FDA) techniques for modeling and analysis. The analysis indicated that from 2004 to 2017, despite increased investment in the energy sector of these provinces, an overall decrease in ESI occurred in most regions. Functional regression models indicate that energy sector investment had its most significant positive impact from 2010 to 2014. Kisel and colleagues [15] evaluated energy security indicators in short-term and long-term periods in Estonia. In this study, researchers presented a new energy security matrix. This matrix considered technical flexibility, vulnerability, economic dependency, and political susceptibility for the electricity, heating, and transportation fuel sectors. Wang and colleagues [16] focused on selecting renewable energy sources strategically using the SWOT-Fuzzy AHP approach for Pakistan. In this study, they assessed four main criteria: economic, environmental, technical, and socio-political, along with seventeen sub-criteria, and three renewable energy sources (solar, wind, and biomass) as alternatives in the decision-making model. Huang and colleagues [17] proposed a hybrid model to examine the energy security performance of 30 provinces in China from 2008 to 2017. This model integrates the best and worst fuzzy methods, data envelopment analysis, and guaranteed regions. The dynamic trend of energy security performance in these provinces during this period was also analyzed using the Malmquist Efficiency Index. Wang and colleagues [18] aim to overcome the limitations of conventional energy security indices in their study. They achieve this by introducing a method for functional performance analysis in constructing the Energy Security Index (ESI) and developing a Dynamic Energy Security Index (DESI) model. DESI extends the conventional ESI with a dynamic weighting mechanism over continuous periods. In the DESI model, every normalized indicator within three dimensions—energy supply, energy consumption and environmental—is smoothed into a continuous curve, and the changes in its importance are reflected objectively by functional information entropy weights with dynamic information updating. Madžarević and colleagues [19] conducted a study examining natural gas's energy security for the Republic of Serbiaa. They employed a Fuzzy-AHP synthesis model for measuring energy security. This model uses an asymmetric fuzzy reasoning approach to obtain results from situations involving asymmetric conditions of fuzzy sets. Considering the energy security characteristics in a specific region of China, Jian Hu and colleagues [20] developed an evaluation model using a fuzzy integral. They used this model to address energy security crises in the region. In a study, Kumar [21] focused on determining India's energy security criteria and indicators. This study examines five perspectives: energy flow risk, operational risk, financial risk, strategic risk, and environmental risk. Furthermore, it utilized the integrated fuzzy set method and the regret theory to evaluate and select energy security indicators.

As observed, researchers have employed various conceptual frameworks for analyzing energy security indicators. One of the methods used in security and risk analysis is the DPSIR approach, which can effectively represent both the present and the future [22]. This framework was initially introduced by the Organization for Economic Cooperation and Development (OECD) in 1994 under the name PSR (pressures, states, and responses) and has since been widely used [23, 24]. The United Nations Commission on Sustainable Development has introduced the "driving force-status-response" rating system (DSR). Additionally, the European Environment Agency has incorporated the "driving force" and "impact" indices into the DPSIR rating system, which builds on the PSR framework [25, 26]. The DPSIR framework assumes a chain of causal relationships that begin with driving forces (D) and lead to pressures (P) affecting the state (S) of the environment. These relationships, in turn, result in impacts (I) on society and the economy, ultimately necessitating a response (R) to mitigate or adapt to those impacts [27–29].

The DPSIR framework examines the causal relationship between energy security problems, their origins, and their outcomes. This framework identifies long-term drivers, including social, economic, population growth, and environmental protection requirements. These factors exert pressure on the energy security system and result in changes in its state. This results in various impacts on resources, the environment, the economy, and society. These effects lead the government and relevant research institutions to respond to the energy security situation. Such responses directly affect the pressure and status of the regional energy security system and influence the subsystem or composite system of economy, society, population, resources, and environment. Considering this, the DPSIR framework can be an approach for policymakers, energy companies, and other stakeholders to enhance their understanding and better manage energy security issues.

In the past, researchers have used the DPSIR framework in studies to evaluate energy security. Zhang and Shen [27] used the DPSIR framework to establish a comprehensive evaluation system for regional energy security along the eastern coast of China. In this study, they used factor analysis for quantitative assessments. In a study, Dalei [30] used the outputs of the DPSIR framework to propose policies for developing renewable energy sources. By utilizing this framework, the analysis focused on examining drivers, pressures, states, impacts, and policy responses. They identified and evaluated the key drivers of climate change. Also, Yang and colleagues [31] modeled China's energy security in the DPSIR framework. They evaluated energy security from 2010 to 2019 using entropy weighting and the TOPSIS model. In a study, Xiao [32]

and colleagues analyzed China's energy situation from 2000 to 2017 regarding energy consumption by fuel types, energy flow, and energy production. This analysis provided a better understanding of China's energy demand and supply situation. They used 21 indicators for evaluation based on the DPSIR framework.

In Iran, the evaluation and analysis of energy security is limited and mainly focused on the perspective of energy supply security and energy consumption security. Environmental indicators need to be given more attention. In this research, using the DPSIR framework, an attempt was made to solve this gap effectively. This framework has not been used to evaluate energy security in Iran and this research has provided a new evaluation.

This article intends to construct an indicator system through the DPSIR model and utilize the TOPSIS model with entropy weighting for a comprehensive evaluation of the indicator system to better understand energy security in Iran. In the end, it provides appropriate recommendations for its improvement. Initially, a questionnaire is designed through field research to establish the DPSIR framework. In the subsequent stage, data is collected, standardized, and a matrix is determined for the framework using entropy weighting. Finally, the TOPSIS method is employed to determine the energy security level for the examined period.

2 Materials and methods

This study employs the DPSIR framework to assess energy security, which consists of five layers: driving forces, pressures, states, impacts, and responses. The variables required for the index layer are selected based on each criteria layer. The "driving force" refers to factors that cause changes in the system and can be divided into environmental and socio-economic driving forces. "pressure" refers to the pressures exerted on regional energy security by energy production and consumption and primarily includes environmental and resource constraints, economic and social pressures, and energy system pressures. This article emphasizes the establishment of energy supply security and the security of energy utilization to identify the "status" of regional energy security. "Impact" reflects the influence of regional energy security status on the environment, resources, economy, and society. The "response" involves combining economic, legal, technological, commercial, foreign policies, and other tools, to reduce pressure on regional energy [27, 31, 33]. Figure 1 shows the DPSIR evaluation framework.

A combination of documentary and field data collection methods was employed for designing the DPSIR framework, utilizing a questionnaire as the research tool. The stages of conducting this research are depicted in Fig. 2.

Combining past sources, research studies, and brainstorming sessions with experts, a questionnaire was designed to determine the sub-indicators of each DPSIR factor. There were 36 agreed elements to form the initial framework, which were included in the questionnaire. Likert scale was used to weight the questionnaire. Content validity was employed to establish the questionnaire's credibility. Following the initial questionnaire design, a survey was conducted with 18 experts in the energy consumption management field, and the content validity of the questionnaire was confirmed. The expert selection was accomplished using the snowball sampling technique [34]. This sequential purposive sampling method is suitable for multi-criteria decision-making contexts. In this method, after identifying experts and gathering information from them, requests that those introduce other knowledgeable individuals. In total, 26 experts in the energy security field participated in formulating the DPSIR framework. All the interviews with experts to answer the questionnaires were conducted in person. Finally, the elements that overlap with each other or have little effect on the main factors of the framework were removed and the DPSIR framework was compiled according to Table 2.

The evaluation period of 2012–2021 was chosen due to the availability of data and relevant resources. Socio-economic statistical data was extracted from the Statistical Yearbook of Iran [35] and the World Bank [10], and energy data were taken from the energy balance sheet of Iran [36]. After collecting statistical information, the data was normalized using the following relationships.

1. To standardization of original data.

$$\text{Positive indicators} : R_{ij} = \frac{\left(x_{ij} - min_j\right)}{\left(Max_j - min_j\right)} \tag{1}$$

$$\text{Negative indicators} : R_{ij} = \frac{\left(Max_j - x_{ij}\right)}{\left(Max_j - min_j\right)} \tag{2}$$

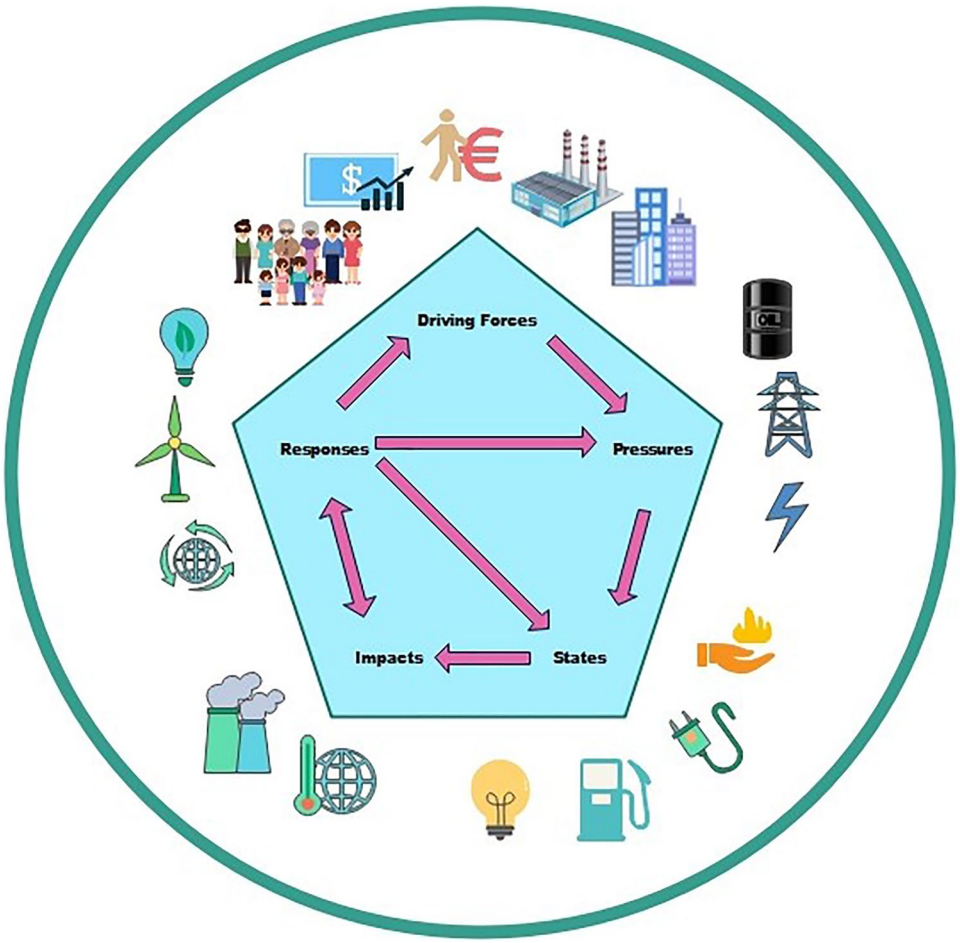

Fig. 1 The DPSIR assessment framework

where R_{ij} is the standardized value of each index, $R_{ij} \in [0, 1]$; x_{ij} is the valuation index; min_j is the minimum value of the index; and Max_j is the maximum value of the index.

There are various methods for weighing the indicators of an evaluation system. However, this study prioritizes ease of comprehension and straightforward application, employing the entropy weighting method. The relationships for this method are provided below.

2. Calculate the entropy of the indicator E_j.

$$P_{ij} = \frac{R_{ij}}{\sum_{i=1}^{m} R_{ij}} \tag{3}$$

$$E_j = -k \sum_{i}^{m} p_{ij} \ln\left(p_{ij}\right) \tag{4}$$

where P_{ij} is the proportion of the ith evaluation index of the jth evaluation factor, E_j is the entropy value; k is the constant term, $k = 1/1\mathrm{n}m$ is the proportion of the index value of element j of i.

$$g_j = 1 - E_j \tag{5}$$

3. Calculate the weight of evaluation index w_j:

$$w_j = \frac{g_j}{\sum_{j=1}^{n} \left(1 - E_j\right)}$$

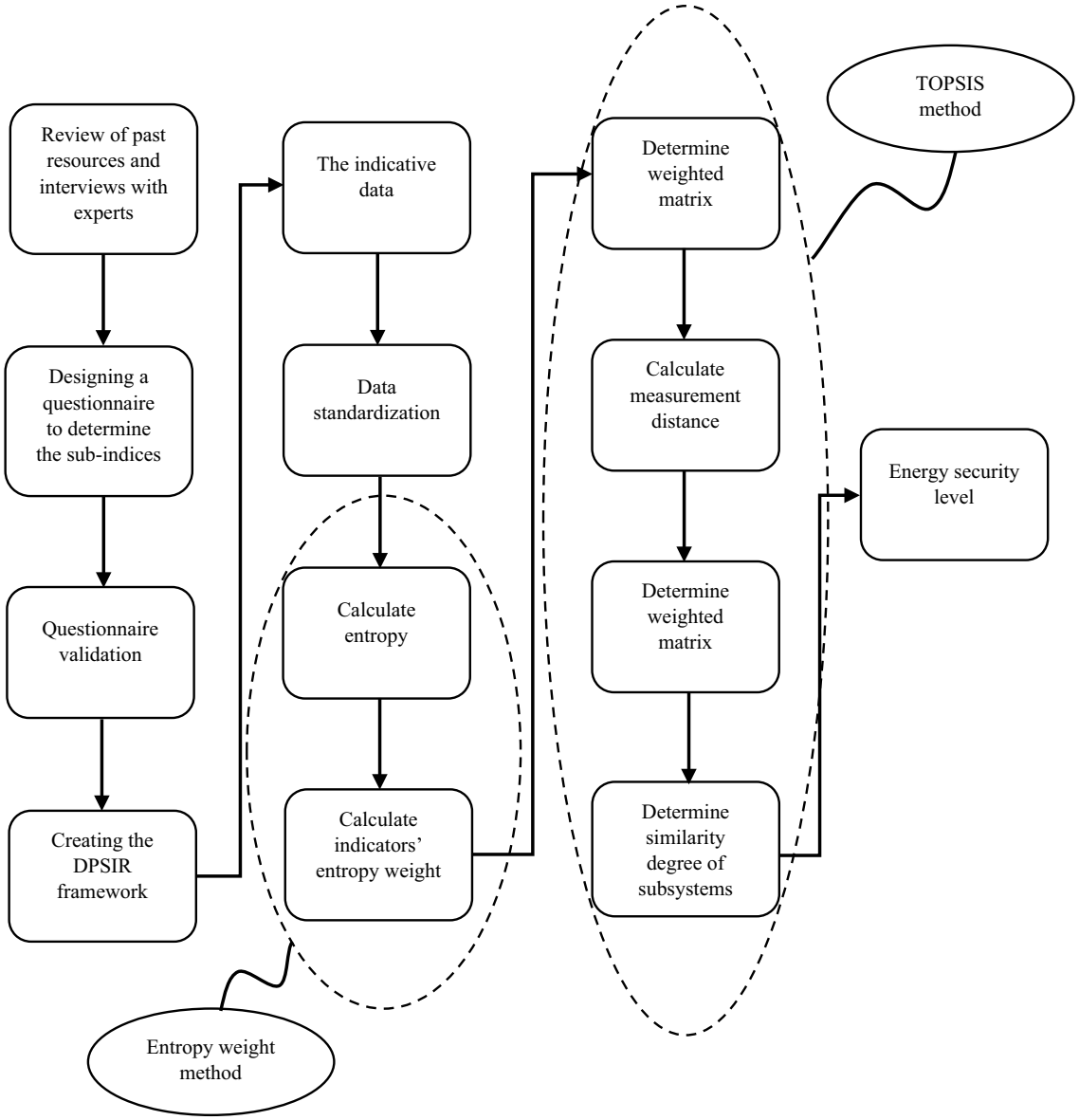

Fig. 2 Energy security evaluation steps

According to past studies, several methods can be used to weight the indicators of the evaluation index system. In this research, according to the simplicity of the TOPSIS model and its appropriate speed, it has been used to process many options and criteria. TOPSIS (technique for order of preference by similarity to ideal solution) operates on the foundational principle that the optimal solution possesses the minimum distance from the positive-ideal solution and the maximum distance from the negative-ideal counterpart. The ranking of alternatives is determined by computing an overall index derived from the disparities with the ideal solutions [37]. This method measures the alternative's proximity to the ideal best and worst values, favoring the shortest distance to the best and the longest to the worst [38]. Also, the system's output is quantitative and in addition to determining the best option, the ranking of other options is expressed numerically. Therefore, in this article, for analyzing and comparing results of energy security, the TOPSIS model has been used, and its formulas are indicated below.

4. To establish a standardized decision matrix V:

Table 2 Assessment index system of energy security in Iran based on DPSIR framework

Target layer	Criterion layer	Index layer	Unit
Energy security	Driving forces	Total population	People
		GNP	USD
		Manufacturing output	USD
		Urbanization level	%
		GDP Per capita	USD
	Pressures	Per capita energy consumption	GJ
		Per capita power consumption	kWh
		Energy intensity level of primary energy	MJ
		Energy consumption	kWh
	States	GDP per unit of energy use	USD per kg
		Electricity access	%
		The total supply of primary energy	GJ
		Electricity production	kWh
		Hydrocarbon reserves	Million Barrels
	Impacts	CO2 emission	kt
		CO2 intensity	unit
		CO2 emissions intensity of GDP	kt per USD
		Sulfur dioxide emissions	kt
		Nitrogen oxide emissions	kt
	Responses	Electric power transmission and distribution losses	%
		Percentage electricity production from renewable sources	%
		Research and development expenditure	% of GDP

$$V = R_{ij} \times w_j = \begin{bmatrix} R_{11}w_1 & R_{12}w_2 & \cdots & R_{1j}w_n \\ R_{21}w_1 & R_{22}w_2 & \cdots & R_{2j}w_n \\ \vdots & \vdots & \ddots & \vdots \\ R_{i1}w_1 & R_{i2}w_2 & \cdots & R_{ij}w_n \end{bmatrix} \tag{7}$$

5. Determine positive ideal solution and negative ideal solution.
Positive indicators

$$\text{Positive ideal solution} : V^+ = \left\{ Max_j V_{ij} \mid i = 1, 2, \cdots n; j = 1, 2, \cdots m \right\} \tag{8}$$

$$\text{Negative ideal solution} : V^- = \left\{ \min V_{ij} \mid i = 1, 2, \cdots n; j = 1, 2, \cdots m \right\} \tag{9}$$

Negative indicators

$$\text{Positive ideal solution} : V^- = \left\{ min_j V_{ij} \mid i = 1, 2, \cdots n; j = 1, 2, \cdots m \right\} \tag{10}$$

$$\text{Negative ideal solution} : V^+ = \left\{ \text{Max} V_{ij} \mid i = 1, 2, \cdots n; j = 1, 2, \cdots m \right\} \tag{11}$$

6. Calculate the distance from the evaluation object to the ideal solution and the negative solution.

$$D_i^+ = \left\{ \sum_i^n \left(V_{ij} - V_j^+ \right) \right\}^{1/2} \tag{12}$$

$$D_i^- = \left\{ \sum_i^n \left(V_{ij} - V_j^- \right) \right\}^{1/2} \tag{13}$$

where D_i^+ and D_i^- are the distances of the positive and negative ideal solutions, respectively.

7. To calculate the score of comprehensive evaluation:

$$Y_i = \frac{D_i^-}{\left(D_i^+ + D_i^- \right)} \tag{14}$$

where Y_i is the closeness of the evaluated target. The larger Y_i is, the better the evaluation result.

3 Results

This study examines Iran's energy security by considering five dimensions: driving forces, pressures, state, impacts, and responses. This analysis sheds light on the interaction between economic, environmental, social, and energy security indicators and contributes to a more comprehensive understanding of energy security dynamics. Entropy equations were used to determine the weighting of each index to assess energy security, and the results are shown in Table 3.

Table 3 indicates that the sub-indices of "percentage electricity generation from renewable sources (8.79%)" for responses and "the total supply of primary energy (6.82%)" for States have the highest weightings. The lowest weightings are for the sub-indices of "manufacturing output (2.35%)" and "per capita GDP (2.72%)" belonging to the Driving forces and "electricity access (2.99%)" belonging to the States index. The results show the percentage weightings in descending order for the indices: impacts, driving forces, states, responses, and pressures, with respective values of 23.9%, 21.97%, 21.9%, 18.79%, and 13.44%. The impact index has the highest weight, while the pressures index has the lowest. The weightings for Driving forces and States are nearly equal.

Table 3 Weight of each indicator

Criterion layer	Indicators	E_j	g_j	$w_j(\%)$
Driving forces	Total population	0.8523	0.1477	5.88
	GNP	0.8551	0.1449	5.76
	Manufacturing output	0.9409	0.0591	2.35
	Urbanization level	0.8678	0.1322	5.26
	Per capita GDP	0.9317	0.0683	2.72
Pressures	Per capita energy consumption	0.9165	0.0835	3.32
	Per capita power consumption	0.9025	0.0975	3.88
	Energy intensity level of primary energy	0.9230	0.0770	3.06
	Energy consumption	0.9200	0.0800	3.18
States	Unit GDP energy consumption	0.8998	0.1002	3.99
	Electricity Access	0.9248	0.0752	2.99
	The total supply of primary energy	0.8286	0.1714	6.82
	Electricity generation	0.8932	0.1068	4.25
	Hydrocarbon reserves	0.9031	0.0969	3.85
Impacts	CO2 Emission	0.8927	0.1073	4.27
	CO2 intensity	0.8832	0.1168	4.65
	CO2 emissions intensity of GDP	0.8533	0.1467	5.84
	Sulfur dioxide emissions	0.8639	0.1361	5.41
	Nitrogen oxide emissions	0.9063	0.0937	3.73
Responses	Electric power transmission and distribution losses	0.8699	0.1301	5.18
	Percentage electricity generation from renewable sources	0.7790	0.2210	8.79
	Research and development expenditure	0.8787	0.1213	4.82

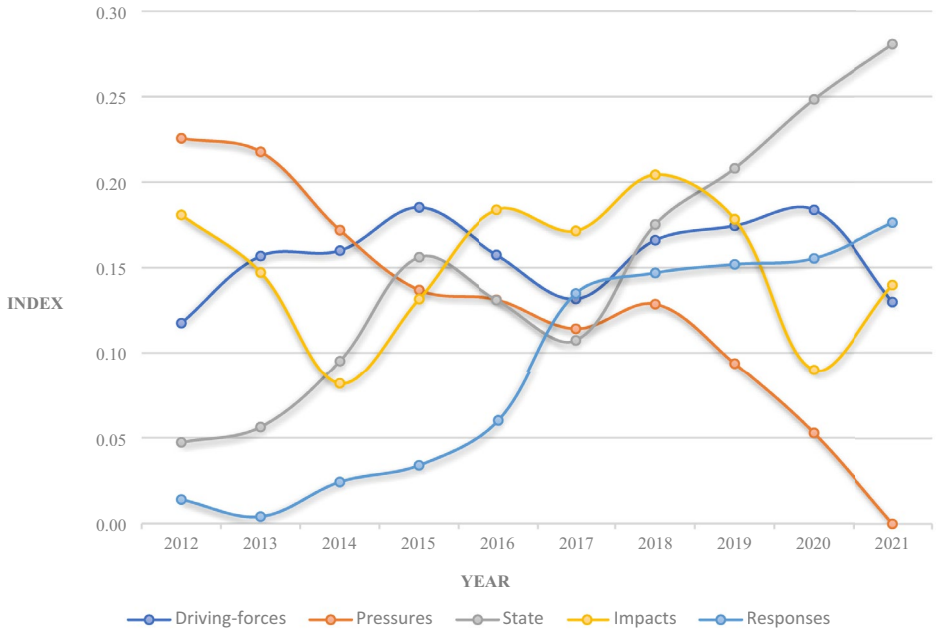

Fig. 3 Energy security criterion layer index in Iran

Table 4 Target layers' relative proximity

Year	D+	D–	C	Rank
2012	0.218	0.134	0.380	10
2013	0.210	0.131	0.384	9
2014	0.166	0.154	0.482	6
2015	0.163	0.145	0.469	7
2016	0.172	0.136	0.441	8
2017	0.153	0.159	0.510	5
2018	0.155	0.168	0.520	4
2019	0.150	0.170	0.531	3
2020	0.136	0.204	0.600	2
2021	0.139	0.220	0.612	1

According to Fig. 3, the driving forces index fluctuated from 2012 to 2021. It experienced an upward trend from 2012 to 2015, followed by a decline until 2017. It then increased again from 2018 to 2020 and decreased in 2021. The pressures index showed a declining trend during the period under investigation, negatively impacting Iran's energy security. This index had a slight increase only in 2018 compared to the previous year, and after that, it showed a decreasing trend. The states index demonstrated an upward trend. From 2012 to 2015, we observed an increase, followed by a downward trend in 2017 and a continuous rise from 2018 to 2021. Similar to the driving forces index, the Impacts index fluctuated. It decreased from 2012 to 2014 and increased from 2015 to 2018. It declined from 2019 to 2020 and had an upward trend again in 2021. The responses index had an upward trend and has consistently increased from 2013 to 2021.

In this study, the proximity degree has been used to demonstrate energy security in the region. Table 4 illustrates the relative proximity of target layers to Iran's energy security from 2012 to 2022 using the TOPSIS entropy model. This index is directly correlated with the level of energy security, and its increase indicates a relative improvement in energy security. As the table illustrates, in 2012 and 2013, Iran's energy security index remained relatively constant at a value of 0.38. A higher level of energy insecurity marks these two years. In 2014, there was a significant leap in energy security, reaching a level of 0.48. However, in 2015 and 2016, a downward trend appeared, leading energy security to reach a level of 0.44. Since 2017, an upward trend can be seen in energy security, which reached its highest level of 0.61 in 2021. The highest evaluation of energy security in the reviewed period was for this year. Overall, the energy security trend has shown positivity and has been on an ascending trajectory.

Figure 4 displays the linear graph evaluating Iran's energy security index during the examined period. The lowest level of energy security was in 2012 with a value of 0.380, and the highest was in 2021 with a value of 0.612. As observed, Iran's overall energy security trend is ascending from 2012 to 2021.

4 Analysis

Based on the obtained results, the higher weighting coefficient in the Impacts index compared to other indices indicates that the adverse environmental effects of energy resources are the most influential factor on Iran's energy security. This index is an environmental indicator and a hindering factor for sustainable development in Iran. The index has shown fluctuations over, and considering global warnings about pollution control and the Paris Agreement, significant changes have yet to be made. Iran uses fossil fuels extensively in its thermal power plants, mainly mazut and natural gas. The efficiency of these power plants is, on average, 38.56%, a considerable amount. However, about 91% of the country's electricity needs are met by thermal power plants, which involve high consumption of fossil fuels. Approximately 60 million liters of mazut are consumed daily, emitting significant pollutants.

Additionally, Iran consumes around 100 million liters of gasoline and 57 million liters of diesel daily in the domestic transportation sector, a significant contributor to pollutant emissions. Iran's transportation systems fall short of international standards, causing significant pollutant emissions attributed to the outdated transportation system. Furthermore, an examination of Iran's development path over the ten years has shown that energy policymakers in Iran have yet to show significant inclination towards utilizing renewable energy sources, which has, in turn, hindered the advancement of energy security in this sector.

The high weighting coefficient of the driving forces factor indicates that the continuous increase in energy demand resulting from economic and social development significantly impacts energy security. Over the ten years, this index has shown fluctuations and has remained almost without a consistent trend. The increase in population, especially the urban population, and the improvement in society's well-being are factors driving energy consumption and significantly affecting energy expenditures. In Iran, the urban population has reached approximately 73% during this period, which is 20% higher than the global average. On the other hand, Iran has experienced a decrease in per capita gross domestic product (GDP) during these ten years, primarily due to the global sanctions against Iran, negatively impacting the production and national income. The reduction in production and industrialization has led to decreased energy consumption.

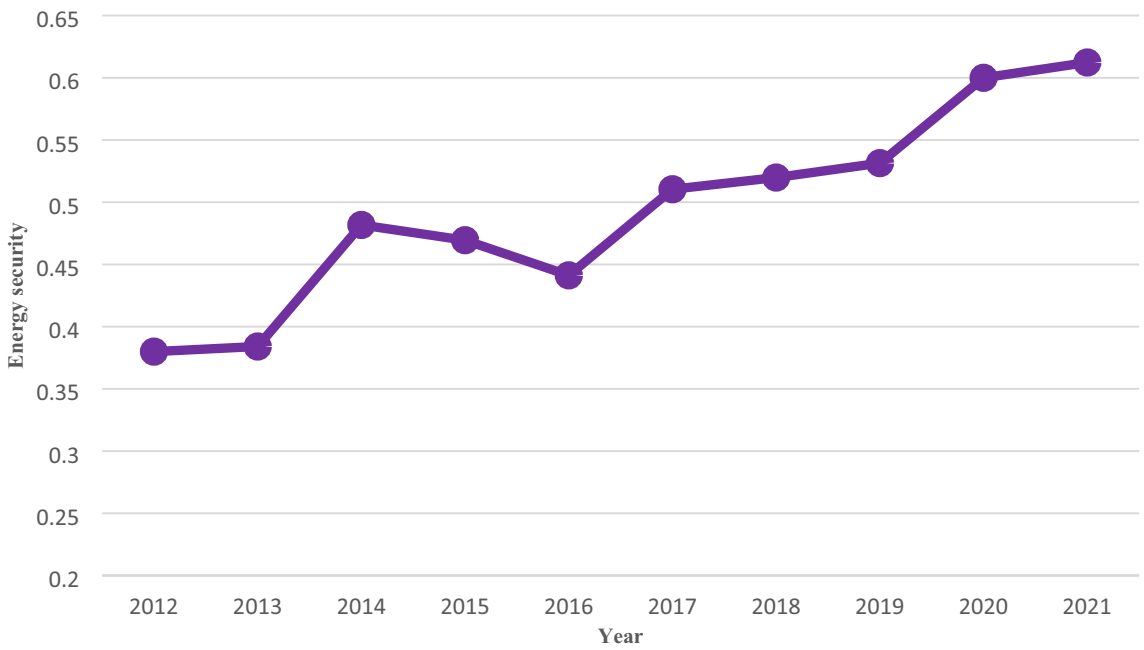

Fig. 4 Target layers' relative proximity ranking

Like driving forces, the state index has allocated a significant weighting coefficient. The state index is based on the supply. From 2012 to 2021, this index had an upward trend and has consistently been growing. The growth of this index is related to energy resources, reserves, and access to them. Access to electrical energy in Iran has significantly expanded during these ten years. More than 99% of rural communities have access to power transmission lines. Additionally, Iran has always had extensive hydrocarbon resources, and recent discoveries have significantly influenced the State index. By the end of 2021, Iran's hydrocarbon reserves had reached approximately 1.2 trillion barrels of crude oil.

The responses index has allocated a lower weighting coefficient than the three previous indices, indicating a relatively lesser impact on Iran's energy security. The responses index is developmental and has shown an upward trend in these ten years, contributing positively to Iran's energy security. One of the factors influencing energy security in Iran in this index is the reduction of losses in power transmission lines. Although losses in power transmission lines showed a decreasing trend during these ten years, by the end of 2021, they reached approximately 12%, still about 4% higher than the global average. Furthermore, Iran has yet to show significant growth in developing renewable energy power plants and has had a declining trend for some years. The share of renewable energy in Iran has been minimal, and in the best years, it only produced 5% of its energy from renewable sources. Another factor contributing to the growth of this index is the research and development pathway, which has consistently been on an upward trajectory.

The lowest weighting coefficient compared to other indices was calculated for the pressures index. The pressures index is a demand and consumption index, and from 2012 to 2021, its trend has consistently been decreasing, which has had a negative impact on Iran's energy security. Iran has been one of the highest energy consumers in the consumption sector. Throughout the examined period, per capita energy consumption has consistently increased. By the end of this period, the per capita consumption averaged 39,000 kilowatt-hours for each Iranian, which is approximately 75% higher than the global average. Final energy consumption has also seen an increasing trend, reaching approximately 226 million barrels of crude oil in Iran by the end of the period.

The evaluation of energy security in Iran shows an upward trend from 2012 to 2021. In 2021 and 2020, Iran had the highest energy security, while the lowest was observed in 2012 and 2013. The most significant upward leap occurred in 2014, followed by a downward trend until 2016. From 2017 onwards, an upward trajectory has continued until 2021. This evaluation signifies a positive outlook for energy security in Iran and despite the growth of negative factors like pressures, energy security in Iran is on the rise. One of the key factors contributing positively to this evaluation is the availability of potential fossil fuel resources, the expansion of power transmission lines, and improved access to energy. Additionally, the reduction in production capacity due to international sanctions against Iran significantly impacted energy consumption in the production sector.

5 Conclusions

This study created a criterion to evaluate Iran's energy security from 2012 to 2021. For this purpose, a framework called DPSIR and a method called TOPSIS with entropy weighting were used. The objective of this study was to evaluate Iran's energy security, considering economic, social, environmental, and energy resource factors, with the effects of these factors incorporated into the model through sub-indices.

The results showed that in the DPSIR framework, the highest weighting coefficient was assigned to the impacts index (23.9%), followed by the driving forces (21.97%) and States (21.97%) indices with almost equal weighting coefficients. The responses (18.79%) and pressures (13.44%) indices were assigned the lowest weighting coefficients. The analysis of DPSIR indices showed that the highest growth was for the States index, followed by the responses index. From 2012 to 2021, the states index increased from 0.05 to 0.28, and the responses index increased from 0.01 to 0.18. The impacts and driving forces indices showed fluctuations, and no significant trend was observed during the period, while the pressures index exhibited a downward trend and reached its lowest level in 2021.

In evaluating energy security, the lowest level was observed in 2012 and the highest in 2021. In 2012, the energy security index increased from 0.380 to 0.612 in 2021. Between 2014 and 2016, a downward trend was observed, which, after a sudden growth in 2017, again turned into an upward trend and continued until the end of 2021. Overall, energy security in Iran was positively evaluated from 2012 to 2021.

Despite improving Iran's energy security, examining the sub-indices showed the need for enhancements in impacts and driving forces of energy security. Improving these two factors is a highly effective solution that can further enhance Iran's energy security and reduce its negative impacts. Analysis of the impacts index indicates that Iran needs to accelerate the replacement of fossil fuels with renewable energies to reduce pollutant emissions. In this regard, various regions

of Iran should focus on developing renewable energy resources such as hydro, wind, and solar based on their specific local conditions.

Improving Iran's domestic transportation system in line with global standards also significantly reduces pollutants and energy consumption, positively affecting both the impacts and pressures indices. According to the driving forces index, Iran's continuous urban population growth has further strained energy reserves, necessitating long-term planning and control. Additionally, integrating optimal and innovative technologies and upgrading power transmission systems will significantly reduce primary and final energy consumption.

The noticeable difference between Iran's energy efficiency and global benchmarks underscores the necessity of enhancing energy efficiency in Iran. Supporting energy-saving approaches to increase energy efficiency requires more effective policies and actions.

In conclusion, despite the growth in energy security, Iran faces a complex interplay of economic, geopolitical, and environmental factors in its energy outlook. Striking a balance between using fossil fuels and renewable energy, addressing economic challenges in fuel pricing, and implementing effective measures to combat air pollution are key considerations for the country's sustainable development. The Iranian government has historically provided subsidies on fuel prices to support the people. However, the subsidy system has faced challenges due to its impact on the national budget. Efforts to reform fuel pricing have encountered public resistance. On the other hand, global fluctuations in oil prices directly affect Iran's fuel prices. Economic sanctions and geopolitical factors have added further complexity to the dynamics of pricing. Economic factors such as inflation and exchange rates also play a crucial role in determining fuel prices. Achieving a balance between affordable prices for the population and economic stability is an ongoing challenge that Iran is constantly working to manage. The widespread use of fossil fuels, especially in transportation and industry, has intensified air pollution. Rapid expansion of urbanization and the increase in the number of vehicles have led to traffic congestion, particularly in large cities. This has significantly caused air pollution and affected public health. The Iranian government has taken measures to address air pollution, including improving public transportation, introducing emission standards, and investing in cleaner technologies. But it seems that these efforts are not enough considering the amount of pollutant production. On the other hand, increasing public awareness of the environmental effects of individual and industrial activities is crucial. Involving people in sustainable actions and garnering their support for anti-pollution measures require continuous efforts.

Considering the conducted research and the obtained results, the authors have formulated recommendations for practical application:

- Promoting and increasing public awareness to aid carbon reduction in the country and controlling energy consumption.
- Increasing and improving energy efficiency and enhancing energy networks to reduce losses associated with energy conversion and distribution.
- Monitoring obstacles to the development of renewable energy and increasing its share in the country's energy supply.
- Developing and implementing crisis management for an appropriate response to energy security threats in a timely and location-specific manner.
- Utilizing new technologies in fossil fuel power plants and improving the efficiency of energy production systems from fossil sources.
- Developing carbon–neutral industries to increase domestic production and importing new and efficient technologies to enhance high-consumption industries.
- Expanding research and development units in the field of renewable energy and controlling the consumption of fossil fuels.
- Improving urban and interurban transportation systems.

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Declarations

Competing interests The authors declare no competing interests.

References

1. The Energy and Agriculture Nexus. 2000. https://www.fao.org/3/X8054E/X8054E00.htm.
2. Sovacool BK, Brown MA. Competing dimensions of energy security: an international perspective. Annu Rev Environ Resour. 2010;35(1):77–108. https://doi.org/10.1146/annurev-environ-042509-143035.
3. Achieving Energy Security. 2021. https://www.api.org/news-policy-and-issues/safety-and-system-integrity/achieving-energy-security.
4. Bösch, F. Reacting to anticipations: energy crises and energy policy in the 1970s; an introduction. Hist Soc Res/Historische Sozialforschung 2014; 7–21. https://nbn-resolving.org/urn:nbn:de:0168-ssoar-406587.
5. Jasiūnas J, Lund PD, Mikkola J. Energy system resilience—a review. Renew Sustain Energy Rev. 2021;150: 111476. https://doi.org/10.1016/j.rser.2021.111476.
6. Bahgat, G. Iran's role in Europe's energy security: an assessment. Iranian Studies 2010; 333–347. http://www.jstor.org/stable/27919920.
7. Report of the conference of the parties on its twenty-first session, held in Paris from 30 November to 13 December 2015. United Nations 2016 2016. https://unfccc.int/documents/9096.
8. The carbon brief profile: Iran. 2023. https://www.carbonbrief.org/the-carbon-brief-profile-iran/.
9. Cevik, S. Climate change and energy security: The dilemma or opportunity of the century? International Monetary Fund 2022; 20. https://www.imf.org/en/Publications/WP/Issues/2022/09/08/Climate-Change-and-Energy-Security-The-Dilemma-or-Opportunity-of-the-Century-523249.
10. World Development Indicators database. 2022. https://datatopics.worldbank.org/.
11. Brodny J, Tutak M. Assessing the energy security of European Union countries from two perspectives—a new integrated approach based on MCDM methods. Appl Energy. 2023;347: 121443. https://doi.org/10.1016/j.apenergy.2023.121443.
12. Solangi YA, Longsheng C, Shah SAA. Assessing and overcoming the renewable energy barriers for sustainable development in Pakistan: an integrated AHP and fuzzy TOPSIS approach. Renew Energy. 2021;173:209–22. https://doi.org/10.1016/j.renene.2021.03.141.
13. Ali Shah SA, et al. Energy trilemma based prioritization of waste-to-energy technologies: implications for post-COVID-19 green economic recovery in Pakistan. J Clean Prod. 2021;284: 124729. https://doi.org/10.1016/j.jclepro.2020.124729.
14. Bamisile O, et al. Comprehensive functional data analysis of China's dynamic energy security index. Energy Rep. 2021;7:6246–59. https://doi.org/10.1016/j.egyr.2021.09.018.
15. Kisel E, et al. Concept for energy security matrix. Energy Policy. 2016;95:1–9. https://doi.org/10.1016/j.enpol.2016.04.034.
16. Wang Y, Xu L, Solangi YA. Strategic renewable energy resources selection for Pakistan: based on SWOT-Fuzzy AHP approach. Sustain Cities Soc. 2020;52: 101861. https://doi.org/10.1016/j.scs.2019.101861.
17. Huang B, et al. Multi-criteria decision analysis of China's energy security from 2008 to 2017 based on fuzzy BWM-DEA-AR model and Malmquist productivity Index. Energy. 2021;228: 120481. https://doi.org/10.1016/j.energy.2021.120481.
18. Wang D, et al. A functional index model for dynamically evaluating China's energy security. Energy Policy. 2020;147: 111706. https://doi.org/10.1016/j.enpol.2020.111706.
19. Madžarević AR, et al. The fuzzy–AHP synthesis model for energy security assessment of the Serbian natural gas sector. Symmetry. 2020. https://doi.org/10.3390/sym12060908.
20. Hu J, Sun J, Yan JM, Liu Z, Shi YR. Regional energy security evaluation in China based on fuzzy integral method. Adv Mater Res. 2012;608–609:1487–91. https://doi.org/10.4028/www.scientific.net/AMR.608-609.1487.
21. Kumar S. Evaluation and analysis of India's energy security: a policy perspective. Energy. 2023;278: 127993. https://doi.org/10.1016/j.energy.2023.127993.
22. Ang BW, Choong WL, Ng TS. A framework for evaluating Singapore's energy security. Appl Energy. 2015;148:314–25. https://doi.org/10.1016/j.apenergy.2015.03.088.
23. Linster, M. OECD environmental indicators, development, measurement and use. Reference Paper 2003. https://www.oecd.org/.
24. Lan Huong TT, et al. Disaster risk management system in Vietnam: progress and challenges. Heliyon. 2022;8(10): e10701. https://doi.org/10.1016/j.heliyon.2022.e10701.
25. Waheed B, Khan F, Veitch B (2009) Linkage-based frameworks for sustainability assessment: making a case for driving force-pressure-state-exposure-effect-action (DPSEEA) frameworks. Sustainability 2009; pp 441–463. https://www.mdpi.com/2071-1050/1/3/441.
26. Wang B, et al. A SEEC model based on the DPSIR framework approach for watershed ecological security risk assessment: a case study in Northwest China. Water. 2022. https://doi.org/10.3390/w14010106.
27. Zhang Y, Shen L. Evaluation of regional energy security in eastern coastal China based on the DPSIR model. J Coal Sci Eng (China). 2012;18(3):285–90. https://doi.org/10.1007/s12404-012-0311-9.
28. Brunhara JPC, et al. A driving force-pressure-state-impact-response (DPSIR) tool to help waste pickers' cooperatives self-evaluate their environmental and economic performance. Hyg Environ Health Adv. 2023;6: 100054. https://doi.org/10.1016/j.heha.2023.100054.

29. Kristensen, P. The DPSIR framework. European Topic Centre on Water, European Environment Agency 2004; pp 27–29. https://fis.freshwatertools.eu/.
30. Dalei NN. Renewable energy policy responses to observed impact of climate change: evidence from DPSIR framework. Econ Policy Energy Environ Sustain. 2022. https://doi.org/10.1007/978-981-19-5061-2_2.
31. Yang B, et al. Evaluation and analysis of energy security in China based on the DPSIR model. Energy Rep. 2022;8:607–15. https://doi.org/10.1016/j.egyr.2022.01.229.
32. Xiao H, et al. Evaluating energy security in China: a subnational analysis. China's Energy Secur. 2020. https://doi.org/10.1142/9781786349224_0005.
33. Cheng C, et al. Study of SEA indicators system of urban green electricity power based on fuzzy AHP and DPSIR model. Energy Procedia. 2011;12:155–62. https://doi.org/10.1016/j.egypro.2011.10.022.
34. Babbie ER. The basics of social research. 4th ed. Belmont: Wadsworth Thomson Learning; 2008. ISBN: 0-495-10233-4.
35. Iran Statistical Yearbook. 2022: Statistical Centre of Iran, ISBN: 978–600–409–342–2.
36. Hydrocarbon country's balance sheet in 1397. 2022; https://isn.moe.gov.ir.
37. Chakraborty S. TOPSIS and Modified TOPSIS: a comparative analysis. Decis Anal J. 2022;2: 100021. https://doi.org/10.1016/j.dajour.2021.100021.
38. Sahabuddin M, Khan I. Multi-criteria decision analysis methods for energy sector's sustainability assessment: robustness analysis through criteria weight change. Sustain Energy Technol Assess. 2021;47: 101380. https://doi.org/10.1016/j.seta.2021.101380.