International Journal of Environmental Science and Technology
https://doi.org/10.1007/s13762-022-04168-x

ORIGINAL PAPER

Designing long-term scenarios for Iranian electricity sector: a novel integrated scenario planning approach based on MCDM method

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Received: 29 July 2021 / Revised: 5 March 2022 / Accepted: 2 April 2022

Abstract
Today, the importance of the electricity industry as a major industry and its vital role in launching and exploiting other industries cannot be ignored. Therefore, long-term planning and forecasting are needed for its development. Therefore, in this study, a novel integrated scenario planning (SP) approach based on the multi-criteria decision-making (MCDM) method called I-MCDM-SP was presented. The proposed approach was applied in a case study to design scenarios for the Iranian electricity industry. In order to design the scenarios, different modes were considered for the two sectors of electricity generation and consumption. In this research, a SP method based on the cross-impact analysis and visualization methods was proposed, in which in order to design scenarios, key drivers (most important trends) should first be determined. Therefore, in this study, the analytic hierarchy process (AHP) model was used to select the most important trends. The results showed that for increasing, constant and decreasing modes of electricity consumption, "failure to correct the price of energy carriers," "laying down rules and regulations," and "improving the culture of energy consumption" with the weights of 0.337, 0.434, and 0.314 were selected as the best trends, respectively. To validate the proposed model, the AHP model was also compared with BWM and SWARA methods, which the results showed the accuracy of this model. Using this approach, four scenarios were designed that *improvement* and *energy management* scenarios were the most likely scenarios and *sustainable development* was the most optimistic scenario.

Keywords Renewable energy · Scenario planning · Multi-criteria decision-making · Cross-impact analysis · Visualization · Analytic hierarchy process

Introduction

Today, not only the development but also the advancement and continuation of life entails energy (Chaharsooghi and Rezaei 2016; Mollaei et al. 2019; Rezaei et al. 2020b). Currently, energy is provided through various carriers such as oil, gas, electricity, renewable energy. Energy supply in Iran enjoying vast geography and different physical locations such as altitude diversity, climate, social issues, and related matters requires careful and scientific planning (Razini et al. 2010). Lack of proper planning and mismanagement in the production, distribution, and consumption of energy will cause serious crises. One of the key solutions to these crises is to handle future problems properly. Developed countries have considered and designed solutions to solve this problem in the future, and underdeveloped countries perceive the future designed by others as their inevitable destiny (Karbassi et al. 2007).

The electricity industry, as an underlying backbone industry, plays an important role in economic development and society's welfare. Accordingly, a comprehensive study has been conducted or is being employed in this field, one of which is futurism in the electricity industry (Karbassi et al. 2007).

The scenario refers to a correct understanding of how the world might change in the future, how to recognize changes when they are happening, and what to do if they occur. The scenario planning (SP) approach has become popular among analysts because of its ability to make long-term predictions, especially when uncertainty surrounds the problem (Rezaei et al. 2020a). In such an approach, instead of imagining a specific future, several possible futures should be considered that are closer to reality; however, each of these futures has its initial assumptions (Chaharsooghi et al. 2015).

Editorial responsibility: Dai-Viet N. Vo.

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The future of the electricity industry in Iran depends on adopting a long-term strategy and planning to provide financial resources, solving the infrastructure problems of the industry, using modern tools and equipment for better control and management, paying attention to the environment, reducing the pollution impacts of power plants, empowering the human resources in the development and operation of the electricity industry, and monitoring the gradual reform of existing disorders. Such an issue makes it necessary to review the country's electricity production and consumption policies.

In this research, a novel integrated SP approach based on multi-criteria decision making (I-MCDM-SP) was presented. In this approach, for designing scenarios, the most important key drivers should first be selected, for which the MCDM method was used. This approach was applied in a case study to design Iran's electricity industry scenarios. In this study, firstly, according to the studies conducted in the field of electricity in the country and obtaining accurate information, the criteria for evaluating the production, distribution, and consumption of electricity in the country were weighted based on experts' opinions by the MCDM approach. Finally, comprehensive scenarios were presented as a solution for the production, optimal distribution of electricity, and improvement of the country's electricity consumption.

In this study, a review of similar research is first presented in "Literature review" section. Then, in "Materials and Methods" section, the methods used in this research are introduced, including the SP and MCDM methods. After that, in "Case study" section, the case study is described. The scenarios are then designed in "Results and discussion" section according to the MCDM method, and the results and discussion are described. Lastly, in "Limitations" and "Conclusion" sections, the limitations and conclusions are illustrated.

Literature review

In this section, previous studies that have combined the MCDM and SP approaches are reviewed. In some studies, first, some scenarios were developed, and then by multiple attribute decision-making (MADM) methods, the best scenarios were selected. In a study, Ribeiro et al. (2013) evaluated power generation scenarios by designing a mathematical model with two objective functions (reducing cost and carbon dioxide emissions) and creating several limitations for different scenarios. By adopting the optimization models in constructing scenarios, they ultimately ranked the scenarios. Sawicka & Zak (2014) ranked the scenarios related to distribution systems using a randomized MCDM method. They obtained the relationship between the options (scenarios) by the Bayesian classification method and finally prioritized the redesigned scenarios. Golfam et al. (2019) applied the analytic hierarchy process (AHP) and the technique for order performance by similarity to ideal solution (TOPSIS) methods to select the most suitable scenario related to climate change in agriculture for a region of Iran. Keyghobadi et al. (2020) developed three scenarios in shipbuilding industry for the merchant fleets future. These scenarios were ranked by the stepwise weight assessment ratio analysis (SWARA) and grey complex proportional assessment (G-COPRAS) methods.

In some studies, the SP method was applied for sensitivity analysis of the results of MADM methods. Supriyasilp et al. (2009) used the SP method to prioritize 64 potential locations for hydropower generation. In the first scenario, the criteria weights were assumed to be the same, and in the second one, they were weighted by the AHP method. Marzouk et al. (2013) examined the project's feasibility by defining a series of criteria through interviewing experts and weighed the criteria using the Simus method. They prioritized five projects using the MCDM method. Then, using the sensitivity analysis method and the scenario, they proved that the most important criteria are not necessarily the key criteria.

Streimikiene et al. (2017) ranked the different power plants. A series of criteria and sub-criteria were defined, and the alternatives were prioritized by the AHP-ARAS method. They used the SP method for sensitivity analysis to analyze the results of the new prioritization. In each of the different scenarios, the weights of one of the criteria were higher than the other similar criteria. Seiti et al. (2019) proposed a new MCDM approach for preventive maintenance planning. For validating this model, they applied it in a case study of a steel plant under different risk scenarios. Spyridonidou and Vagiona (2020) applied the MCDM and GIS methods to plan offshore wind farms in Greece. They used four scenarios for testing and assessing the reliability of the methodology.

SP was also used in some studies to make a different decision matrix. In this case, the criteria and alternatives for the scenarios are the same, but the weights of the criteria and the matrix numbers are different. Goodwin and Wright (2001) prioritized strategies for a national postal company under different scenarios. They designed two different scenarios, each with three different goals, and considered the same options (with different matrix numbers) for the scenarios. Kalbar et al. (2012) selected the appropriate technology for wastewater treatment. According to experts' opinions, they identified two types of decision matrices using a scenario based on the TOPSIS method. In the first type of this decision matrix, the criteria were the same, but with different weights, and in the second type, the same options with different matrix numbers were considered for the scenarios. Chung and Kim (2014) examined the locations of treated wastewater based on some climate change scenarios. Using the fuzzy TOPSIS method, they prioritized the alternatives under two modes of the same criteria and the same options. Witt et al. (2020) combined the SP and MCDM methods to evaluate future energy systems. The SP method helped design the scenarios of energy transparently and systematically.

The SP method can be applied to design different decision matrices. In this case, different criteria and options are considered for each scenario. Hashemkhani et al. (2016) proposed a new approach of combining the SP and MCDM methods. They considered some hypothetical scenarios in which the criteria and alternatives were different under the scenarios. They suggested an approach for final ranking the alternatives.

A summary of the studies that used the SP and MCDM methods is shown in Table 1, which can be divided into the following four categories:

- Ranking alternatives by the MCDM method and applying sensitivity analysis by the SP method (sensitivity analysis).
- Presenting scenarios as the options and ranking them by the MCDM method (scenarios as the options).
- Making a different decision matrix according to scenarios and ranking by the MCDM method (a different decision matrix).
- Constructing different decision matrices according to scenarios and ranking by the MCDM method (different decision matrices).

According to Table 1, in these studies, the SP and MCDM methods were combined in such a way that first, the scenarios were created and then they were prioritized by the MCDM method, or for considering the uncertainty of decision-making problems, the SP approach was used to construct different decision matrices. To our best knowledge, the use of the MCDM method to construct and design scenarios has not been addressed so far.

Table 2 indicates some of the studies that have predicted the consumption or generation of electricity. These prediction methods focus only on the most probable event and do not include all probable events. In fact, this prediction ultimately leads to a point estimate of the future. However, the SP approach presented in this research is a structured method for analyzing and evaluating uncertainties and possible future events. According to Table 2, in these studies, only one aspect of production and consumption has been considered, while in this research, these two factors are considered together, and their effects on each other are also considered.

Also, as shown in Table 2, in these prediction approaches, the variables considered influential factors in predicting electricity consumption or production are often limited and quantitative. But in the current research, various aspects and dimensions of sustainable development (economic, environmental, and social) were considered, and impressive qualitative variables were also included.

In this study, a novel integrated SP approach based on the MCDM method called I-MCDM-SP was presented. In this approach, in order to design scenarios, the most important key drivers should first be found, for which the MCDM method was applied. The proposed approach was implemented in a case study to design Iran's electricity scenarios.

Materials and methods

In this section, the methods used in this research are described in the following.

MCDM method

Decision-making science has a long history, and many methods are available in this field. Decision-making deals with the systematic modeling of decision makers' preferences for making choices among alternatives involving several often conflicting objectives (Kalbar et al. 2012). These methods make a certain

Table 1 Types of using the SP and MCDM methods

Refs.	Country	Subject	Type of using the SP and MCDM methods
Ribeiro et al. (2013)	Portugal	Evaluating the power generation scenarios	Scenarios as the options
Kalbar et al. (2013)	India	Selecting wastewater treatment options	A different decision matrix
Chung and Kim (2014)	Korea	Ranking treated wastewater locations	A different decision matrix
Štreimikienė et al. (2016)	Lithuania	Ranking the power generation technologies	Scenarios as the options
Hashemkhani Zolfani et al. (2016)	–	Ranking the alternatives of a hypothetical example under some hypothetical scenarios	Different decision matrices
Kylili et al. (2016)	Cyprus	Selecting the most suitable energy crops	Sensitivity analysis
Roozbahani et al. (2018)	Iran	Prioritization of groundwater management scenarios	Scenarios as the options
Chang et al. (2019)	Azerbaijan	Selection of smartphone alternatives and tariff plans for taxi service operators	Sensitivity analysis
Talebi et al. (2019)	Iran	Planning road networks for tourism development	Scenarios as the options
Spyridonidou and Vagiona (2020)	Greece	Ranking the suitable sites for offshore wind farms	Sensitivity analysis
Zamani et al. (2020)	Iran	Ranking the adaptation scenarios for climate change	Scenarios as the options
Witt et al. (2020)	Germany	Evaluation of energy scenarios	A different decision matrix

Table 2 Prediction of electricity consumption and generation

Refs.	Country	Variables	Methods	Goal
Bianco et al. (2009)	Italy	GDP, GDP per capita, Population	Multiple linear regression	Prediction of electricity consumption
Kavaklioglu (2011)	Turkey	Population, GNP, Imports, Exports	Support Vector Regression	Prediction of electricity consumption
Maliki et al. (2011)	Nigeria	Annual average load demand, Instantaneous annual peak load demand	Multiple linear regression, Artificial Neural Network	Prediction of electricity generation
Rahman and Esmailpour (2015)	The United States	Time	Artificial Neural Network	Prediction of electricity generation
Panklib et al. (2015)	Thailand	GDP, Population, Maximum ambient temperature, Peak electric power demand	Multiple linear regression, Artificial Neural Network	Prediction of electricity consumption
Sarkodie (2017)	Ghana	GDP, Population	ARIMA	Prediction of electricity consumption
Zheng et al. (2019)	The United States	Time	LSTM recurrent neural network	Prediction of electricity consumption
Banik et al. (2021)	India	Peak electric power demand	Random Forest and extreme gradient boosting	Prediction of electricity consumption

deeper conception of the multidimensionality of problems and promote the involvement of participants in the decision-making method, simplify group decisions and agreement decisions, and enable modeling of different scenarios and projection of outcomes (Štreimikienė et al. 2016). The decision-aiding techniques and decision support methodologies (DSMs) vary considering the qualitative and quantitative type of data, the degree of complexity, uncertainty, and fuzziness embedded in the dataset, the use of weightings for criteria, and the assurance and transparency of outcomes (Browne et al. 2010).

MCDM serves as one of the most well-known subdivisions of decision-making, which is divided into multi-objective decision making (MODM) and multi-attribute decision making (MADM) (Kalbar et al. 2012). There are several MCDM methods, such as the weighted product method (WPM), weighted sum method (WSM), elimination and choice translating reality (ELECTRE), preference ranking organization method for enrichment evaluation (PROMETHEE), technique for order preference by similarity to ideal solution (TOPSIS) and multi-attribute utility theory (MAUT). The MCDM method applied in this research is the analytic hierarchy process (AHP), developed by Saaty (1980).

AHP is the most popular method among MCDM methods, which is chosen because of its simplicity, flexibility, intuitive revision, and ability to handle both qualitative and quantitative criteria (Supriyasilp et al. 2009). The AHP not only helps with the analysis of arriving at the best decision but also provides a clear rationale direction to the made choices and involves the principles of analysis, pair-wise comparisons, generation, and combination of priority vectors (Zolfani et al. 2012). The steps of the AHP approach can be described as follows:

Step 1 Building a hierarchical model of decision-making.

Step 2 Comparing the decision elements in pairs. The scale for the pair-wise comparison is shown in Table 3.

Step 3 Estimating the relative weight of decision elements through matrix-based methods.

Step 4 Ranking the alternatives that contain the relative weighting of the decision elements to earn the final score of each alternative.

In the AHP method, assuming that A, B, and C are the influencing criteria to set goal, the matrix of pair-wise comparison is shown as:

$$\begin{bmatrix} \frac{A}{A} & \frac{A}{B} & \frac{A}{C} \\ \frac{B}{A} & \frac{B}{B} & \frac{B}{C} \\ \frac{C}{A} & \frac{C}{B} & \frac{C}{C} \end{bmatrix} \tag{1}$$

Consider

Table 3 Pair-wise comparison scales

Explanation	Intensity of importance
Equally important	1
Slightly important	3
Strongly important	5
Very strongly important	7
Extreme important	9
Intermediate points of important	2, 4, 6 and 8

$$\frac{A}{A} = C11, \quad \frac{A}{B} = C12, \quad \frac{A}{C} = C13 \tag{2}$$

Therefore, the matrix of the pair-wise element is obtained by Eq. (3):

$$\begin{bmatrix} C11 & C12 & C13 \\ C21 & C22 & C23 \\ C31 & C32 & C33 \end{bmatrix} \tag{3}$$

The normalized pair-wise matrix element is obtained by Eq. (4):

$$\mathrm{X}ij = \frac{Cij}{\sum_{j=1}^{n} cij} \tag{4}$$

in which n is attribute numbers. Therefore, the obtained normalized pair-wise element matrix is:

$$\begin{bmatrix} X11 & X12 & X13 \\ X21 & X22 & X23 \\ X31 & X32 & X33 \end{bmatrix} \tag{5}$$

The weight matrix element can be calculated by Eq. (6):

$$wjj = \frac{\sum_{j=1}^{n} cij}{n} \tag{6}$$

So, the priority matrix is shown by Eq. (7):

$$\begin{bmatrix} w11 \\ w21 \\ w31 \end{bmatrix} \tag{7}$$

In this step, the consistency of decision must be assessed by Eq. (8):

$$CR = \frac{CI}{RI} \tag{8}$$

where CI is the consistency index that can be calculated by Eq. (9).RI is an index of random consistency, which is the index of consistency for a randomly filled matrix as shown in Table 4.

$$CI = \frac{\lambda\max - n}{n - 1} \tag{9}$$

in which λmax is the eigenvector of the maximum value of eigen (Eq. 10):

$$\lambda = \sum_{j=1}^{n} Cvij \tag{10}$$

In Eq. 10, $Cvij$ is the consistency vector, and $Cv11$ is obtained by Eq. (11):

$$Cv11 = \frac{1}{Wij}[C11W11 + C12W12 + C13W13] \tag{11}$$

Other elements can be obtained similarly. The last normalized principle eigenvector is calculated by Eq. (12).

$$\begin{bmatrix} Cv11 \\ Cv21 \\ Cv31 \end{bmatrix} \tag{12}$$

If $CR \leq 0.1$, the inconsistency is acceptable; otherwise, if $CR > 0.1$, the revision of subjective judgment should be considered. Decision-makers are free to assign relative weights to the various elements of decision-making (Bhonsle and Junghare 2015).

Scenario planning method

Scenario planning (SP), a widely employed methodology for supporting strategic decision making, employs unreal future scenarios to help decision-makers think about the essential uncertainties they face and devise strategies to manage those uncertainties (Montibeller et al. 2006). Scenarios try to describe alternative futures based on the present. The matter is to recognize key elements of uncertainty in today's situation and consider how alternative futures may be generated, depending on how these key elements develop. The futures differ in the emphasis which they give to one element rather than another, or else in the way in which all the different elements interact (Brauers and Weber 1988).

The SP method has been defined as a method for determining several informed, plausible, and imagined alternative future environments in which decisions about the future may be played out to change current thinking, improve decision making, increase human and organizational learning, and improve efficiency (Chermack 2004). Future-oriented scenario methods should operate without making direct extrapolations from past situations and frameworks, and they need the attention of qualitative, subjective data (Oppenheimer 1990).

Electricity (electrical energy) has always been one of the factors driving and pushing the development of every country. Such energy is so important that it can be said that it is the mainstream of the world economic and political cycle. In recent decades, as a result of the excessive use of energy resources, this vitally

Table 4 Random consistency index

N	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

strategic element is stepping into a new crisis that necessitates long-term strategies for predicting its future. In scenario-based approaches, thanks to conceptualizing and predicting several future possibilities, one is becoming more flexible in the planning than the ever-changing future. Every year, large companies and organizations in the energy sector make huge budgets for collecting and updating reports that will be presented about the future of this energy. These large national and international institutions include the World Energy Council (WEC), the International Energy Agency (IEA), and Shell, which experience and invest enormous costs in preparing future energy scenarios (Chaharsooghi et al. 2015).

Cross-impact analysis

Cross-impact analysis (CIA) is a powerful tool for considering future events and examining the potential causal effects of each event on the others (Amer et al. 2013). The CIA is designed to calculate the fundamental impact of a political, social, or technological event on the likelihood of other events. The ability of this method to analyze complex fields with different interactions has made it one of the most common techniques used to generate scenarios. Another factor in the success of this approach is that it is a flexible method that can be combined with other techniques such as Delphi methods to enable the construction of a real participatory and the SP model by the groups.

Visualization

The most widely used approaches of the SP method are judgmental methods (Bishop et al. 2007). The purpose of this approach is to create predictions based on acceptable scenarios. In this method, scenarios are generated by considering all possible factors, their relative effects, the interactions between them, and the goals to be anticipated. Visualization is one of the most important kinds of judgmental techniques. Beyond conveying the expression of facts, knowledge transfer occurs in different ways to convey more insights, experiences, attitudes, values, expectations, views, opinions, and predictions using visualization. Visualization uses relaxation and meditation techniques to calm the analytical mind and allow more intuitive images of the future to be displayed.

SP based on MCDM method

In this study, a novel integrated SP approach based on MCDM, namely I-MCDM-SP, was presented. This approach is based on a combination of the SP and AHP methods. Finding the key variables is one of the most important challenges in designing scenarios. In this study, cross-impact analysis and visualization methods were used to design scenarios. In these methods, the most important possible trends for designing scenarios should be identified first. Therefore, the AHP method as a kind of MCDM approach was used in this research to identify them. This method was applied in a case study to design Iran's electricity scenarios.

Case study

Energy serves as one of the most important factors for development. On the other hand, fossil fuels are declining, and their resources will be depleted in the future. Fossil fuel consumption is also the most important cause of air pollution and climate change. Today, the significance of the electricity industry and its vital role in setting up and operating other sectors cannot be denied. The renewable sources application in electricity generation has a significant impact on making energy supply more economical. Nowadays, the electricity permeability in the world is so high that it is impossible even to imagine a world without electricity. Due to the ease of transmission and the ability to be converted to various types of energy, including thermal, optical, motor, and other forms, electricity is permeated among all consumers, including home, industrial, and agricultural sectors. Therefore, different countries pay special attention to production, distribution, and electricity consumption management (Raturi 2016).

Global electricity generation capacity has almost doubled between 2000 and 2011. Electricity generation from renewable energy is slowly increasing as many countries continue to augment fossil fuel capacity significantly. In 2019, the transfer from energy consumption and production based on non-renewable resources such as oil and natural gas, etc., to renewable and more efficient energy at the global level has slowed down, and its average annual growth has reached its lowest level compared to the last five years. Although developed economies have improved since 2019, they still face the challenge of paralleling economic growth and environmental sustainability (Frei et al. 2013). The best countries in electricity generation, using renewable resources, were China, the USA, India, Brazil, and Germany at the end of 2018 (Raturi 2016).

Iran's electricity industry has undergone a significant shift in the past two decades to meet growing domestic needs, industrialization, and exports increases. Despite the adverse effects of sanctions, lack of technology, mismanagement, and financial challenges, the electricity industry continues to respond to the country's growing demand. Over the past few years, the industry has gradually weakened under severe capital constraints and investors. The continuation of these problems has made the electricity industry one of the business challenges.

Electricity generation in Iran

The most important part of the electricity industry is electricity generation. Lack of production capacity of the country's power plants has the adverse effects of power outages, which sometimes cause severe damage to the economic, political, and social spheres of the country. Today, production is the economic and industrial engine, and production and productivity advancement has become a national priority in the economies of all countries. In general, such an engine (electricity) increases production and controls inflation, enhances economic competitiveness, improves per capita income, reduces costs and augments profitability, increases gross national product, and so on. What has always been of interest in the electricity industry is optimal operation and economic efficiency. Moreover, rising fuel prices, environmental concerns, energy sustainability issues, rapid population growth, and growing consumption intensity have added to such importance (Sadeghi et al. 2013).

Due to specific geographical conditions, Iran has great potential for electricity generation from hydropower, wind, solar, geothermal, and biomass sources, and if adequately invested, Iran can benefit from such a great blessing of God. Unlike non-renewable and fossil fuels, renewable energy can be recovered and recycled in nature and can be used without restriction. With the development of necessary technologies, Iran can supply a large part of its electricity consumption from renewable power plants and take various economic and environmental advantages. Furthermore, by establishing and constructing thermal power plants using a combination of several types of fuel to generate electricity, it not only brings more efficiency and production than power plants that use the same type of fuel, but also significantly reduces greenhouse gas emissions (Khosroshahi et al. 2009).

Figure 1 shows the production share of different power plants from 2018 to 2019. The total electricity generated in Iran sums up to about 309 billion kilowatt-hours, of which 304 billion kilowatt-hours were generated by the power plants of the Ministry of Energy and the private sectors, and the rest by large industries.

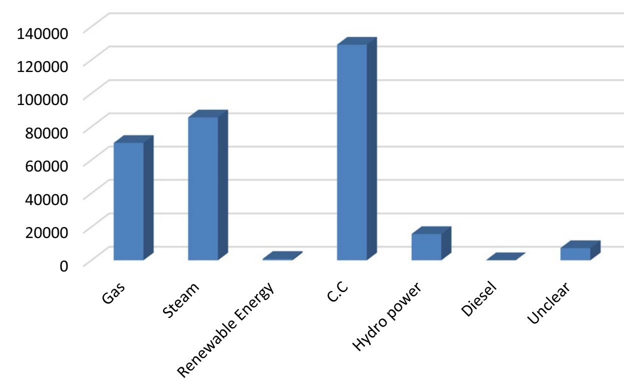

Fig. 1 Production share of different power plants in 2018–2019

Electricity consumption in Iran

Currently, electricity, as one of the energy carriers, has the largest share of the world's energy consumption basket after oil. As each country becomes more advanced, the electricity consumption also increases. In recent years, one of the main concerns of countries and their energy sector policymakers has been to respond to the growing demand for electricity and resources and provide appropriate solutions to meet this increasing need. Upon the introduction of environmental considerations, the implementation of energy-saving policies, and optimization strategies, although electricity consumption in the world has been controlled to some extent in recent years, it is still one of the most widely used end-energy sources.

In Iran, considering the population growth, development of metropolises and lifestyle changes, cheap energy prices, and low share of the total cost of household consumption that arises from the allocation of subsidies, lack of proper consumption culture and the use of low-efficiency household appliances in energy consumption are the main reasons for the increase in energy intensity in the home, public, and commercial sectors (Rezaei and Babazadeh 2021). The electricity consumption rate in the industrial, agricultural, and transportation sectors is constantly increasing. However, with the slowdown in economic growth, the increase in electricity consumption is also slower in this sector (Raturi 2016). The electricity sector receives large subsidies from the government, and most state-owned companies control the generation, distribution, and transmission of electricity (Aghahosseini et al. 2018).

Fluctuations in electricity consumption in the country show that various factors affect the amount of electricity consumption. On the other hand, the geographical extent of Iran, despite the different climatic regions, has caused different provinces to have different needs for electricity consumption, and its amount fluctuates in different seasons (Babaeian et al. 2017). The country's economic and industrial growth, the expansion of the distribution network related to the government's social policies, and the increase in household subscribers have led to a severe imbalance in electricity supply and demand. Therefore, despite increasing production capacity in this field, there is a fragile balance between consumption and supply, causing extensive and frequent shutdowns with a slight increase on demand or supply side, which can be destructive for the economic growth and social welfare because of the lack of sustainable energy.

Optimization of electricity use

Electricity consumption optimization is the selection of the patterns and application of methods and policies in the correct use of electricity which is desirable from the point of view of the national economy and ensures the continuity of energy and the survival of life. This proper use of energy not only provides the continuity of life and sustainable development of society but also leads to the survival of energy for future generations. It will also prevent the production and spread of environmental pollution due to improper energy consumption.

The construction of power generation facilities and power grids requires a lot of costs. The current and fixed annual costs of power plants sometimes are up to 20% of the initial investment.

In addition to these costs, the time required to build a plant is 3–to 8 years. Therefore, reducing electricity consumption is significantly effective in maintaining national capital. According to the savings potentials in the industrial sector, 670 billion Tomans can be saved annually in this sector. Also, in the home sector, it is possible to essentially prevent the loss of national capital by applying strategies for the optimal use of high-consumption home appliances.

Optimization of electricity production

Advances in technology and population growth have increased the demand for electricity, which has created a strong dependence on this energy carrier in various fields of economy, production, education, health, security, and industry. On the other hand, electrical energy is considered the first option among energy carriers due to its ease of access and the possibility of conversion to other forms. The basic requirements for a reliable and sustainable supply of electricity, considering the past experiences and the current state of the electricity economy, and the supply of primary energy sources in Iran, are stated in the following.

Improving the efficiency of power plants, reforming the electricity economy, developing renewable energy sources, managing consumption and improving energy intensity, optimal using of primary energy sources, taking into account environmental consequences, considering the capacity of production, transmission, and distribution facilities, upgrading of power plants, and considering strict measures in this regard can help significantly in optimizing electricity production.

Loss of electricity

In recent years, a large amount of electricity produced in the country has been lost during transmission and distribution. In Iran, the rate of electricity losses is at least three to four times the global average. There are many problems in managing and consuming electricity. For example, the power plants cannot be designed to turn off when power consumption is low and on when the power plants are busy. Because these power plants are generated based on efficiency, economic benefits, and revenue, it is not easy to turn them on or off at different consumption times. One of the major problems concerning the management of the country's electricity resources is that in the current situation, there is no standard and up-to-date transmission network in the country, and Iran's transmission networks are very old and worn out. This causes about 15% of daily electricity generation to be wasted due to burnout. Other problems with the management of electricity resources include the fact that in recent years, no serious measures have been taken to replace the old power plants and increase their efficiency.

Results and discussion

In this study, an approach based on a combination of the SP and MCDM methods was presented. The presented approach was applied in a real case study to design Iran's electricity scenarios, which is described in the following.

Selecting the most important trends by MCDM methods

To design the scenarios, two parameters of electricity generation and consumption were considered. Different modes of increasing, constant, and decreasing may occur for each of these parameters. Different trends may occur for each of these assumptions that are shown in the following tables. AHP method was applied to select the most important trend for each of these assumptions. The results were used as input to the SP method to design the scenarios.

There are many parameters that would lead to an increase in electricity consumption listed in Table 5. The values were the result of pair-wise comparisons of parameters related to the increase in electricity consumption, which were obtained by the experts' opinions.

The results of analyzing Table 5 using the AHP method and expert choices software are represented in Fig. 2. As shown in Fig. 2, "failure to correct the price of energy carriers" was the most important trend related to the increasing electricity consumption assumption.

Similarly, pair-wise comparisons were conducted for the different modes of constant electricity generation, reducing electricity generation, and constant electricity consumption. The results are summarized in Figs. 3, 4, and 5, respectively.

To evaluate the alternatives of increasing electricity generation and reducing electricity consumption, different criteria were considered. For each of these modes, the weight of the criteria should first be determined. For example, in the case of reducing electricity consumption, first, the criteria were compared in pairs. Then, the weights of these criteria were obtained using the AHP method and expert choice software, the results of which are shown in Table 6.

Then, considering the AHP method steps, the alternatives should be compared in pairs according to each criterion, and their priority should be determined based on the concept of normalization. For example, for the people's satisfaction criterion, the pair-wise comparison table, and finally, each option priority was described based on this criterion in Table 7.

Similarly, the pair-wise comparisons were made for the other criteria, and each option priority was obtained based on each criterion, shown in Table 8. In the last step, the final priority of the alternatives should be obtained. Each option score was calculated from the sum of each option priority multiplied by the criterion's weight based on the criterion "I," the results of which are shown in Fig. 6.

Moreover, for the mode of increasing electricity generation, pair-wise comparisons were made for all criteria, and the priority of each option was obtained based on each criterion, which is shown in Table 9. Then, the final priority of the alternatives, in this case, is summarized in Fig. 7.

According to the results of the tables and figures, the most important trend related to each mode was selected and used for designing scenarios, which is explained in the next section.

Comparison with other methods

In order to validate the proposed AHP model, in this section, the results of the AHP model are compared with some other

Table 5 Pair-wise comparisons of parameters related to increasing electricity consumption

	Improving people's lifestyle	Population increase	Economic growth	Improper implementation of subsidy reform plan	Failure to correct the price of energy carriers	Increase the country's military power
Improving people's lifestyle	–	1.73	0.48	0.49	0.71	1.82
Population increase	–	–	0.51	0.4	0.29	2.45
Economic growth	–	–	–	0.54	0.24	3
Improper implementation of subsidy reform plan	–	–	–	–	0.58	4.58
Failure to correct the price of energy carriers	–	–	–	–	–	4.24
Increase the country's military power	–	–	–	–	–	–

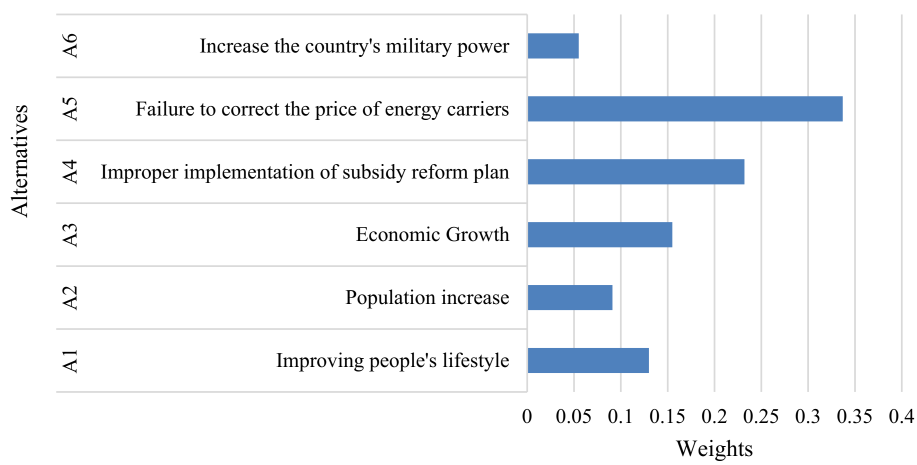

Fig. 2 Prioritization of possible trends related to increasing electricity consumption

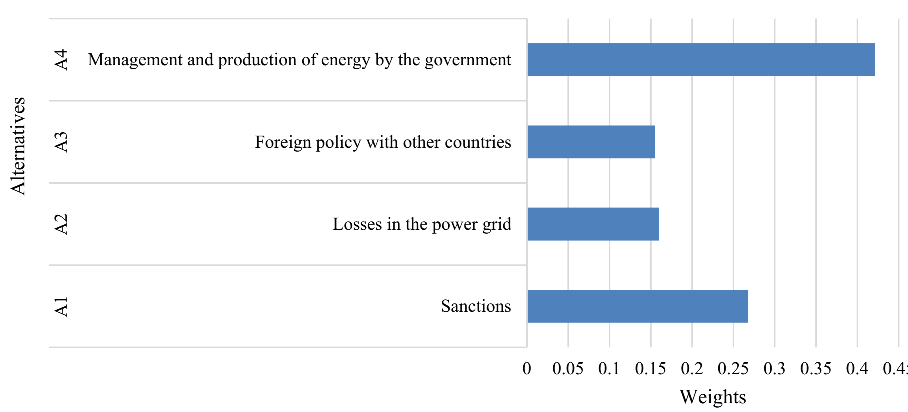

Fig. 3 Prioritization of possible trends related to constant electricity generation

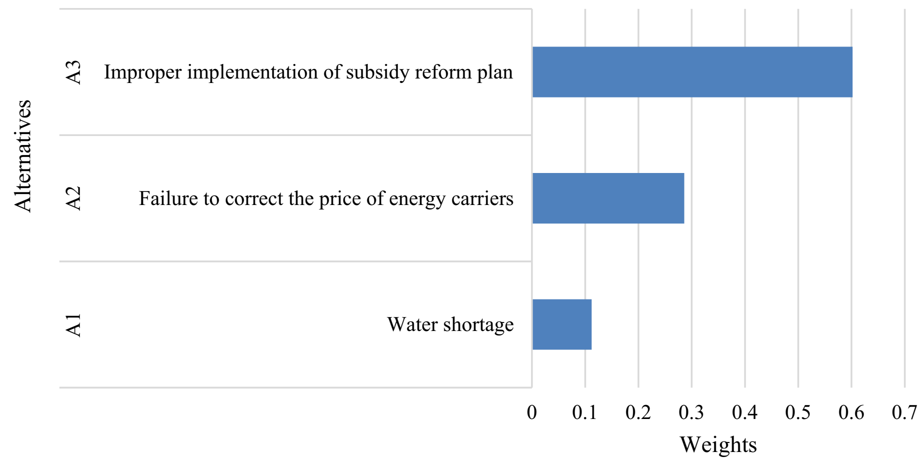

Fig. 4 Prioritization of possible trends related to reducing electricity generation

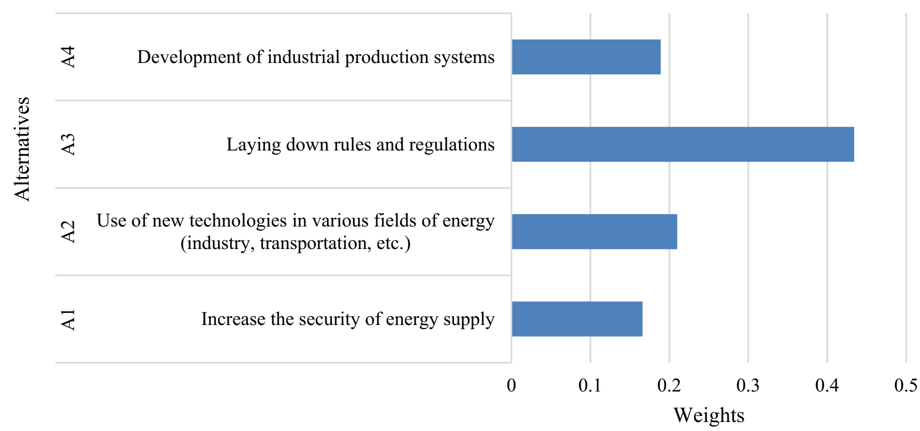

Fig. 5 Prioritization of possible trends related to constant electricity consumption

Table 6 Criteria weights in the mode of reducing electricity consumption

Criteria		Weights
C1	The satisfaction of people	0.302
C2	Attracting foreign capital	0.079
C3	Energy exports	0.113
C4	Environmental pollutions	0.185
C5	Inflation	0.199
C6	Risk of investing in electricity	0.122

prioritization methods in the literature, including stepwise weight assessment ratio analysis (SWARA) and best worst method (BWM). These methods have been compared, for example, for the reducing and constant modes of electricity generation. The results are shown in Figs. 8 and 9.

As shown in Fig. 8, in all three methods, "improper implementation of subsidy reform plan" was selected the best trend for reducing electricity generation. According to Fig. 9, in all three methods, "management and production of energy by the government" was the best option for the mode of constant electricity generation. As these figures show, the results obtained for the other alternatives were also close to each other, which indicates the accuracy of the proposed AHP model.

Designing scenarios based on the selected trends

To construct the scenarios, a combination of different modes of electricity production and consumption was used. For each of the factors of electricity production and consumption of the country, three modes of increase, decrease, and constant were considered. As stated in the previous sections, for each of these situations, the most important trend was obtained by MADM methods (as shown in Table 10).

By experts' opinions, the cross-impact matrix was obtained, which are shown in Table 11. These numbers were between −2 and +2, where positive numbers represent the positive effect of trends on each other.

Table 7 Pair-wise comparisons matrix based on people's satisfaction criterion in the case of reducing electricity consumption reduction

	Improving the culture of energy consumption	Reforming the pricing system of energy carriers	Proper implementation of subsidy reform plan	Improving the quality of supplied energy carriers	Option priorities
Improving the culture of energy consumption	–	4.47	1.55	0.87	0.355
Reforming the pricing system of energy carriers	–	–	0.49	0.42	0.105
Proper implementation of subsidy reform plan	–	–	–	0.63	0.213
Improving the quality of supplied energy carriers	–	–	–	–	0.327

Table 8 Options priority based on each criterion in the case of reducing electricity consumption

	Criterion	The satisfaction of the people	Attracting foreign capital	Energy exports	Environmental pollutions	Inflation	Risk of investing in electricity
Alternative		0.302	0.079	0.113	0.185	0.199	0.122
		C1	C2	C3	C4	C5	C6
		+	+	–	–	–	+
A1	Improving the culture of energy consumption	0.355	0.121	0.222	0.441	0.453	0.13
A2	Reforming the pricing system of energy carriers	0.105	0.304	0.183	0.166	0.113	0.242
A3	Proper implementation of subsidy reform plan	0.213	0.413	0.418	0.148	0.178	0.394
A4	Improving the quality of supplied energy carriers	0.327	0.163	0.177	0.245	0.257	0.233

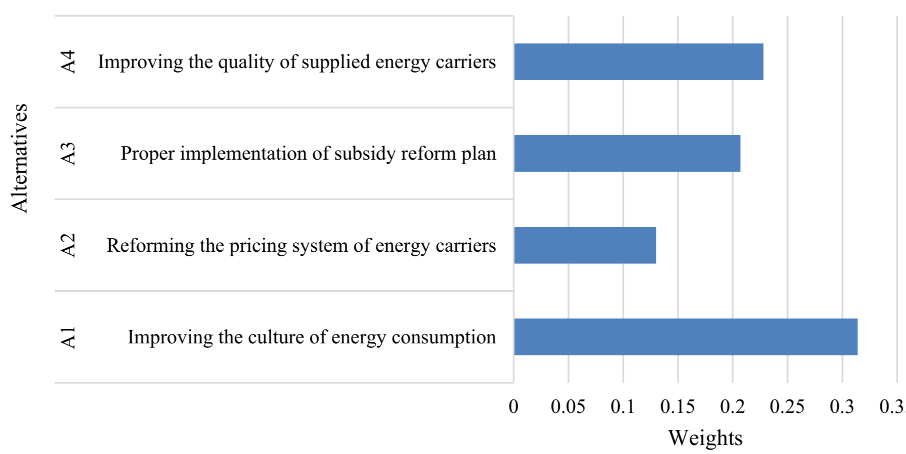

Fig. 6 Alternatives final priority in the case of reducing electricity consumption

By the use of Eq. 13, the probability matrix was obtained. The results are shown in Table 12.

$$P = 0.5 + \frac{SE \times CI}{4} \tag{13}$$

Table 9 Options priority based on each criterion in the case of increasing electricity generation

	Criterion	The satisfaction of the people	Attracting foreign capital	Energy exports	Environmental pollutions	Inflation	Risk of investing in electricity
Alternative		0.065	0.109	0.317	0.167	0.07	0.272
		C1	C2	C3	C4	C5	C6
		+	+	+	−	−	+
A1	Applying new technologies	0.12	0.127	0.043	0.098	0.091	0.041
A2	Targeting energy subsides	0.05	0.045	0.083	0.099	0.06	0.12
A3	Reforming the pricing system of energy carriers	0.049	0.049	0.07	0.133	0.05	0.078
A4	Private sector development	0.201	0.196	0.233	0.067	0.188	0.251
A5	Government financial and technical support	0.192	0.12	0.096	0.058	0.146	0.127
A6	Increasing the use of renewable energy (solar, wind, etc.)	0.077	0.077	0.149	0.247	0.11	0.064
A7	Fair purchase of renewable energy by the government	0.081	0.065	0.13	0.198	0.086	0.083
A8	Development of competition in the production of electricity and petroleum products	0.123	0.176	0.148	0.036	0.167	0.18
A9	Increasing the energy specialists	0.107	0.144	0.5	0.064	0.102	0.057

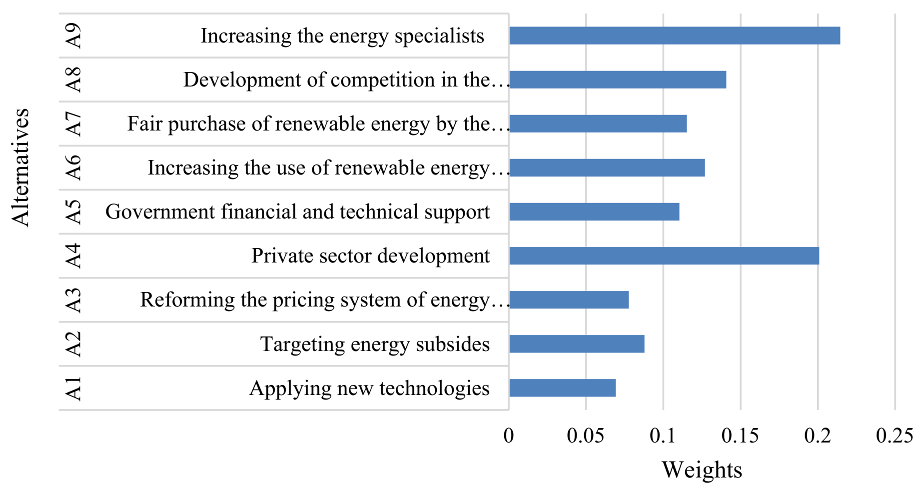

Fig. 7 Alternatives final priority in the case of increasing electricity generation

where *CI* represents the value of the cross-impact matrix, and *SE* indicates a sensitivity coefficient that was considered to be 0.75 on average.

In Table 12, the cells with the highest probability values were bolded and selected for designing the scenarios based on these trends, which are presented as follows:

Sustainable development

In this scenario, it was assumed that the government in the electricity industry, by improving the knowledge and productivity of specialized human resources, supporting research centers, developing new technologies in government and non-government sectors as a valuable asset, and also upgrading capabilities in generating electricity from a variety of sources, including new and renewable energy, will increase the electricity production with appropriate quality.

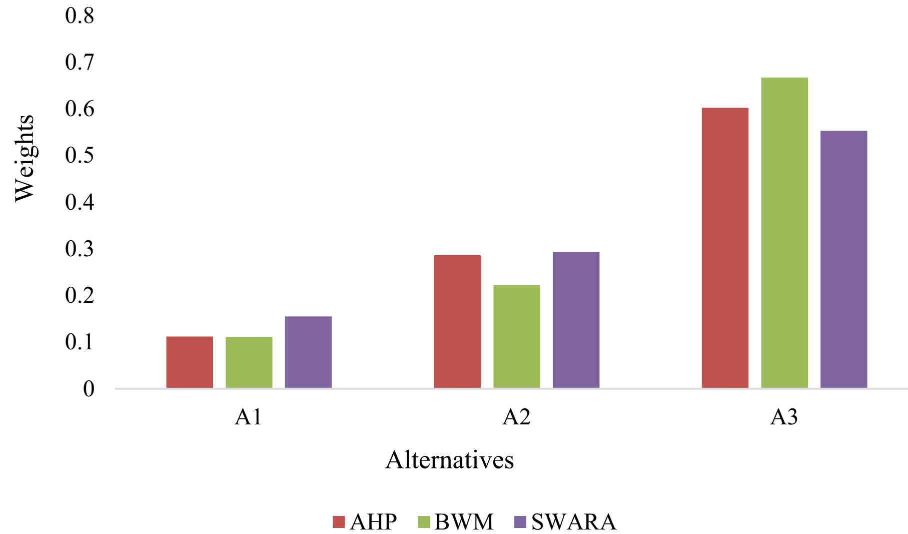

Fig. 8 Comparison of AHP, BWM, and SWARA methods in the case of reducing electricity generation

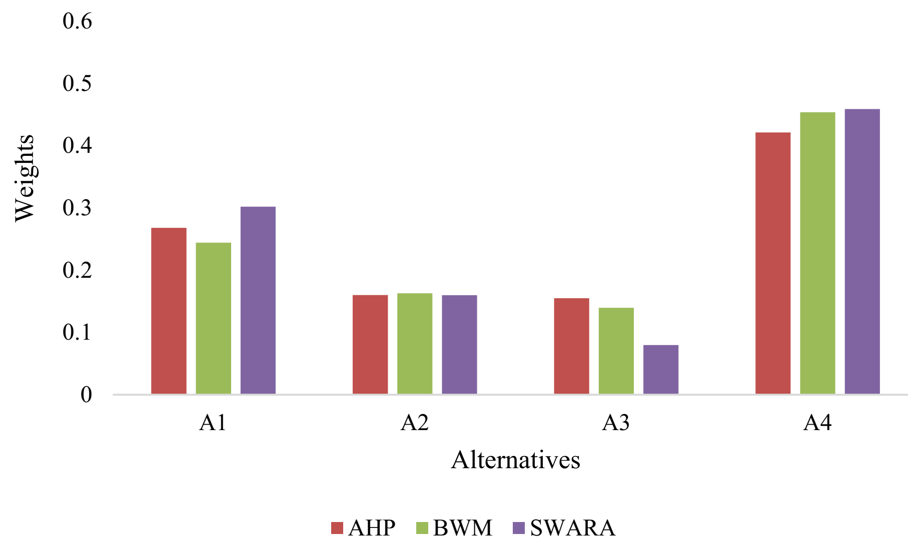

Fig. 9 Comparison of AHP, BWM, and SWARA methods in the case of constant electricity generation

Table 10 Assumptions and the most important trends in electricity production and consumption in Iran

Assumptions	Id	Trends
Electricity generation increases	T1	Increasing the energy specialists
Electricity generation remains constant	T2	Management and production of energy by the government
Electricity generation decreases	T3	Improper implementation of subsidy reform plan
Electricity consumption increases	T4	Failure to correct the price of energy carriers
Electricity consumption remains constant	T5	Laying down rules and regulations
Electricity consumption decreases	T6	Improving the culture of energy consumption

The government provides direct transactions between sellers (electricity suppliers) and people (buyers) by attracting participation of the people to increase social welfare, reform the pattern of energy consumption, raising public awareness, and by creating a suitable platform for developing communication. In fact, for people, the exact amount of electricity consumption of all electrical devices in electricity bills is determined so that people can calculate the average consumption and costs (this detail is important for suppliers) and compare the costs between several supplier companies to buy their electricity monthly. Of course, subscribers can use electricity generated from renewable energy resources to reduce environmental pollution. Also, if high-consumption systems are replaced, they can manage their electricity consumption

Table 11 Cross-impact matrix

	T1	T2	T3	T4	T5	T6
T1	–	− 1.2	− 1.6	− 1	1.4	1.6
T2	− 1.2	–	1.1	1.3	− 0.5	− 0.6
T3	− 1.6	1.1	–	1.8	− 1.2	− 1.55
T4	− 1	1.3	1.8	–	− 0.8	− 1.6
T5	1.4	− 0.5	− 1.2	− 0.8	–	1.2
T6	1.6	− 0.6	− 1.55	− 1.6	1.2	–

Table 12 Matrix of probabilities

	T1	T2	T3	T4	T5	T6
T1	–	0.275	0.2	0.313	**0.763**	**0.8**
T2	0.275	–	0.706	**0.744**	0.406	0.388
T3	0.2	0.706	–	**0.838**	0.275	0.209
T4	0.313	0.744	0.838	–	0.35	0.2
T5	0.763	0.406	0.275	0.35	–	0.725
T6	0.8	0.388	0.209	0.2	0.725	–

and reduce their costs. This requires informing the public that the government plays an essential role in this area. The government will increase electricity production and reduce its consumption by reforming the sales structure and developing the competitive market, and improving business processes in this area.

In this scenario, by reducing consumption and increasing electricity production, the government can take a major step toward sustainable development, self-reliance, and growth in global energy supply by exporting a large part of the country's electricity production.

Improvement

This scenario is designed based on the combination of power generation and sustainable consumption. In this scenario, it is assumed that the government enacting laws and regulations to save energy and formulate standards and making compliance with standards in buildings, industry, transportation, and sectors that use electricity, as well as providing financial and tax incentives to use savings facilities and tools, have led to savings in electricity consumption, which in turn keeps electricity consumption constant. The government not only plays an effective role in the employment of the country but also increases the electricity generation by creating the necessary conditions for applying the knowledge of creative and capable professionals, supporting educational and research centers, and improving the skills of human resources.

Energy management

This scenario is designed based on the combination of constant power generation mode and increased power consumption. According to this scenario, the management and production of electricity are done by the government. Since fossil energy has the largest share in the country's electricity supply, assuming no privatization in the country and no attention to electricity production using renewable energy, the government is content with the current trend of electricity generation, as a result of which electricity production in the country has remained almost constant and will not grow significantly. On the other hand, in the field of electricity consumption, not reforming the price of energy carriers and cheap energy in the country increases consumerism in various sectors, including household, industry, transportation, and agriculture, and also reduces investment in the energy sector; as a result, economic growth will decline.

Recession

In this scenario, it is assumed that Iran has not been able to simultaneously implement the targeted subsidy plan and the realization of energy carrier prices. Failure to properly implement the targeted subsidy plan and keep energy prices low will reduce economic growth and increase electricity consumption and social inequality.

Excessive energy consumption also increases global warming and accelerates the destruction of the environment. In addition, declining economic growth reduces competition, motivation, and private sector investment in energy, resulting in reduced electricity production. On the other hand, energy subsidies and low prices of energy carriers have caused the affluent segment of society with higher consumption than the low-income segment to use more energy subsidies. This contradicts the purpose of the targeted subsidy plan, which must pay attention to deserving people.

Limitations

Like most studies, there were some limitations in this study. Because the approach used in this research was more qualitative, in some cases, it was needed to collect the opinions of experts. Because this research was limited to a specific field of energy (electrical), the selection of experts to collect the initial data was very important. The basic knowledge of any expert could affect the evaluation of criteria and indicators. If any experts' knowledge was inconsistent with the subject of this study, it might sometimes lead to bias in the results and a negative impact on them. Also, for this research, a large sample size is needed to get more accurate results. With the efforts of the authors, these limitations were largely smoothed.

Conclusion

Activities related to planning and managing the production and consumption of electricity are considered as one of the main priorities of countries. Therefore, in this research, a new integrated approach was presented by combining the SP and MCDM methods (I-MCDM-SP). Moreover, four scenarios for the future of Iran's electricity industry were presented, which were designed by considering important sectors of electricity generation and consumption. The SP method used in this research was based on the cross-impact analysis and visualization methods. Different modes can be imagined for the country's electricity generation and consumption sectors. In the proposed SP method, it is necessary to consider the most important key drivers. Also, the AHP method was used as a type of MCDM to select key drivers from possible trends. The results of AHP models showed that for increasing, constant and decreasing modes of electricity generation, the trends of "increasing the energy specialists," "management and production of energy by the government," and "improper implementation of subsidy reform plan" with scores of 0.214, 0.421, and 0.602 were the best trends, respectively. Also, for increasing, constant, and decreasing modes of electricity consumption, the trends of "failure to correct the price of energy carriers," "laying down rules and regulations," and "improving the culture of energy consumption" with scores of 0.337, 0.434, and 0.314 were selected, respectively.

As pinpointed in the results of this study, in the sustainable development and improvement scenarios, the governments' role is highlighted and emphasized. The governments can increase production and reduce and keep consumption at a stable rate through using the experts' knowledge, attracting the people's participation, and enacting the relevant laws and regulations. The recession and new energy scenarios reveal that the government's lack of proper management and non-implementation of privatization and targeted subsidies will reduce (destabilize) production and increase consumerism. The designed scenarios can be used for a comprehensive policy to formulate macro-planning in the electricity industry. In fact, electricity consumption management is based on information, awareness, and planning. Scenarios and predictions made in this research can be used as a useful tool to perceive the future of the country's electricity situation. Researchers and decision-makers can use them to design strategies in the field of electricity generation and consumption management.

In future work, by dividing the country into smaller regions, it is possible to have a more accurate assessment and make better suggestions. It is suggested that the results of this study are compared with other quantitative or qualitative approaches. For example, the system dynamics method can be used for modeling the country's electricity consumption and generation. Machine learning methods can also be applied as quantitative methods to predict them. It is also suggested that the linguistic variables related to experts' opinions are analyzed by the fuzzy logic method. Finally, the proposed approach can be used in other case studies for designing appropriate scenarios.

Acknowledgements The authors thank Tavanir Company and Iran Ministry of Energy for provision of data and other relevant information.

Funding There is no funding for this research.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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