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Potentials for energy-saving and efficiency capacities in Iran: An interpretive structural model to prioritize future national policies

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ABSTRACT

Energy drives national economies with a positive correlation. Global environmental concerns, growth of the world population, and emerging of developing economies with more need for energy resources, would change the future of energy markets and human lives. To manage energy shortage and energy-related environmental threats, decision-makers have to decide between three potential solutions [1], to develop supply value [2], to suppress energy (all types) demands, or [3] to adopt a hybrid strategy. This paper is aimed to uncover potential saving capacities to fill the supply-demand gap based on efficiency improvements for the case of Iran as a developing economy with increasing energy needs. The methodology has been designed based on energy balance calculations which have been evaluated and validated through 47 expert panels under 9 major themes. Then, policy sets have been determined and to map how defined policies were interacting in the living energy, a system interpretive structural model was performed to determine direct and indirect relationships among policies. As a result, policymakers can prioritize and set a roadmap to approach the desired future. Findings showed for the case of supply-side Iranian energy management [1] maximizing electricity transmission and distribution efficiency [2], upgrading the consumption standard in equipment and processes (in the terms of energy production, conversion, and transmission), and [3] online monitoring of distribution networks are most basic and top priority policies. While for the case of demand-side "targeting energy subsidies" is the most crucial policy to support the Iranian energy efficiency improvement targets.

1. Introduction

In the modern era, energy plays a key role in the socio-economic development of different countries. Therefore, management and optimization of energy consumption as one of the ways to ensure energy security is significantly considered by energy policymakers [1]. For example, although the EU's energy consumption declined between 2002 and 2016, the EU's GDP grew by more than 40% over the same period [2], and by improving energy efficiency the trend of decoupling energy consumption and economic growth could be also seen in other regions [3]. However, developing countries, especially oil-producing ones, do not often manage to plan properly to improve their energy efficiency [4]. The Islamic Republic of Iran is one of the richest countries in terms of hydrocarbon reserves [5]. Iran with 9% of the world's proven oil reserves is the fourth-largest holder of crude oil and the second-largest holder of natural gas with 16.1% of the world's proven natural gas reserves [6]. However, due to inefficient energy consumption, Iran is about to face the risk of failing to meet its rising energy demand. One of the most important indicators used to measure the efficiency and optimal use of energy is the energy intensity index [7], which is the energy consumed per unit of GDP. According to the International Energy Agency, Iran has the highest energy intensity index among the countries in the Middle East, and the trend is yet to reverse as opposed to the global trend [8]. Given the increasing rate of urbanization in developing countries, which leads to more demand for energy, the continuation of this trend could bring serious challenges in terms of energy supply security [9,10].

In addition to energy security risks, inefficient energy consumption causes numerous environmental challenges, most importantly increasing greenhouse gas emissions [11]. Iran's per capita carbon dioxide emissions from fuel consumption increased from 6.8 tons per capita in 2008 to 7.01 tons per capita in 2018 [12]. Increasing fossil fuel

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consumption could worsen this trend and bring environmental degradation [13]. Energy Efficiency is considered to be a proper tool to meet growing energy demand with fewer emissions [14].

To improve energy efficiency in Iran, several policies and laws have been approved, including general energy policies, consumption pattern reform policies, and the law of the Sixth Development Plan [15]. However, none of these laws has been able to prevent the uncontrolled increase in energy consumption in the country [16,17]. As such, energy efficiency in Iran has become a necessity [18]. Therefore, the purpose of this article is to study the amount of energy loss and evaluate the energy-saving capacities in different sectors and present proper strategies considering the socio-political-economic conditions of Iran. Most of the data in this article are from Iran Hydrocarbon Balance 2018, the last published report by relevant organizations on Iran's energy data. Because developments in the field of energy efficiency are time-consuming and require high investment, the 2018 data are still valid and can be used as a basis for analysis of the current situation and planning for the future. In the following sections, previous studies on energy efficiency in Iran will be reviewed, then the methodology of this research will be described. In the next stage, energy loss and energy-saving capacities in 4 sectors of energy production, conversion, distribution, and consumption will be examined, and finally, proper strategies to realize the identified capacities will be proposed.

2. Literature review

The hot topic of energy efficiency and energy savings has received remarkable attention in the literature due to its important role in securing nations' energy supply security. As energy efficiency plays an important role in achieving the EU's targets for energy consumption and emission reduction and there is a relatively broad range of policy instruments to improve energy efficiency and savings, Wiese et al. have reviewed different policy instruments for energy efficiency and savings such as market-based instruments, financial incentives, and regulatory and non-regulatory measures and assessed the strengths and weaknesses of different measures. The results indicated that a combination of multiple instruments is needed to meet energy efficiency targets and energy efficiency targets cannot be met by a single policy instrument [19].

The industrial sector is one of the most significant sectors to implement energy efficiency policies aiming to reduce energy consumption in energy-intensive industries. Safarzadeh et al. reviewed and classified different policy instruments to improve energy savings in the industrial sector, known as industrial energy-efficiency programs (IEEPs), and suggested some recommendations to elevate the performance of IEEPs [20]. Chowdhury et al. evaluate energy efficiency potential in two UK energy-consuming industries, Iron and steel, and food and drink. They also investigated possible business models for energy service companies to adopt suitable energy efficiency technologies. According to the findings. There is a potential to reduce energy consumption in UK industrial sector by more than 15% [21].

Using a meta-frontier data envelopment analysis, Feng and Wang evaluated energy savings potential in the industrial sector of China at the provincial level between 2000 and 2014. According to their findings, the level of energy efficiency in China's industrial sector is low and there is significant potential to improve energy efficiency by improving management efficiency, bridging the regional technology gap, and optimizing the industrial scale [22]. Yáñez et al. evaluated the energy efficiency potential in the Colombian oil industry. According to Their findings, there is a potential to save 15.8 PJ of energy (the equivalent of 25% of total energy consumption) and reduce 0.75 Mt of CO2 (the equivalent of 19% of total greenhouse gas[1] emission) in this sector. Using a bottom-up approach, they also identified 20 measures and technologies that could be applied to optimize energy consumption in the sector. According to their results, 96% of the potential to reduce energy consumption in the Colombian oil industry could be realized by measures and technologies that are cost-effective [23].

The residential sector has also a great share of global energy consumption and different measures have been taken to optimize household energy consumption around the world [24]. Mahar et al. investigated the energy efficiency and saving policy in Pakistan. The results showed that although there was the Building Energy Code in Pakistan since 1990, energy efficiency policies had not been properly implemented at the national and provisional level due to a lack of institutional setups regarding energy efficiency and saving [25], something that is true in the case of Iran, too.

Krati assessed the energy efficiency potential for the building sector in the Arab Region and reviewed current policies and regulations for energy efficiency in the sector. According to the results, energy consumption in the building sectors varied significantly among Arab countries from Saudi Arabia with one of the largest energy use per capita in the World with over 9000 kWh/person of electricity used annually in buildings to Sudan and Yemen with the lowest energy use per capita in the World with barely 100 kWh/person/year of electrical consumption. According to their calculations, there is a potential to reduce energy consumption in Arab Countries by 12.70 TWh/year only with the implementation of strict energy efficiency codes for buildings [26].

Alekseev et al. described current energy efficiency policies in the Russian construction and housing sector from different aspects including the government management system, financial incentives, etc. The paper provided three recommendations for the government of Russia to improve energy efficiency in the sector as follows: 1. To evaluate the potential of energy efficiency. 2. To formulate an extensive regulatory framework and implementation procedure to increase energy efficiency. 3. To continuously monitor the implementation of energy efficiency policies and quantitively measure the deviation between policies and actual performances [27]. Moreover, Zhou et al., evaluate energy efficiency and CO2 emission reduction in the Chinese building sector in four scenarios to 2050. According to their findings, different technologies, procedures, and systems could have a significant contribution to decreasing Building energy consumption; however, stringent policies are needed to fully realize the energy efficiency potential in the Chinese building sector [28].

Barkhordar et al. investigated the impact of Iran's 2010 energy subsidy reform on improving energy efficiency in six energy-intensive industries of Iran. According to their findings, more than 80 PJ of energy-saving potential has not been realized yet. They categorized the challenges of low investment in energy efficiency by investors as informational, financial and administrative, and regulatory challenges. They believed that before fully removing energy subsidies, the challenges that discourage investors to invest in energy efficiency projects should be addressed [29]. In another study, Mohammadi et al. assessed the potential of energy savings and emission reduction in the petrochemical sector of Iran. They analyzed two petrochemical processes, namely polymeric and non-polymeric productions. According to the findings, there is a potential to reduce natural gas consumption in Iran's petrochemical sector by 1100 million-cubic meters per year and to reduce GHG emissions by 2.53 million tons of CO2-eq/year [30].

Numerous studies evaluated energy efficiency potential and investigated different policies to improve energy efficiency in different sectors from railroad transportation to provincial electricity consumption to different companies [29,31–35]. However, to the author's knowledge, no research evaluates energy efficiency potential in the whole energy chain value of Iran (the same is true for other countries). This research is aimed to bridge this gap in the literature by determining the potential of energy saving in different sectors from energy production down to the final energy consumption sectors like buildings, industries, etc., and provide some appropriate policy recommendations to realize these potentials. Moreover, determining policies and strategies is not enough to design a roadmap to a better future. To address this deficiency

[1] GHG.

this paper proposes a methodology to map relationships and posterior relations between policies.

3. Research design

This research is aimed to develop insights into the potential of Iran's energy efficiency improvement (saving) capacities. So, a deep analysis has been implemented on real data that had been gathered over the energy value chain from production (extraction) to consumption. It is important to note that in this research energy value chain only represents the energy side and does not follow economic perspectives/chain.

This paper is a kind of data analysis work. Environmental scanning is selected as the core methodology to examine and assess the energy efficiency state in Iran. Generally, environmental scanning (ES) can be defined as "a systematic way to understand the surrounding environment" [36]. ES has been implemented by numerous researchers (such as [37–42]), and different methods have been utilized based on the problem context. Literature review, statistical retrieval, surveys, interviews, SWOT analysis [43], market research [44,45], STEEP analysis [41,46], etc. are some of the well-known methods to design an ES methodology. Here, the energy value chain is mapped into phases considering: production (extraction), distribution, and consumption. Then for each phase, relevant data and statistics are collected and analyzed, referring to national and international reports. Next, the current situation is compared to the average efficiency level presented by international agencies such as International Energy Agency (IEA) and standard levels that are presented by relevant Iranian institutions such as Iran National Standard Organization. The gap initialized Iran's energy efficiency improvement capacity (=nominal), however, some adjustments are needed to calculate the actual capacity. This research proposes calculations to estimate the actual saving capacity and analyses the results for the case of Iran's energy system. Then, an initial policy basket is formed and purified through 47 expert panel sessions. On average, 7 experts participated in each session, referring to 9 thematic areas in the field of energy-saving and efficiency including [1] management and planning [2], financing [3], governance [4], price and non-price strategies [5], rules and procedures [6], energy efficiency markets [7], energy technology and industries [8], socio-cultural aspects, and [9] education. Appendix I provides information about selected experts participated in the program. Then proposed policies are listed and presented to a focus group consisting of experts from multi-dimensional disciplines (policy-making, foresight, oil and gas, power management, technology management, and economics) to develop the final policy set to improve energy efficiency (in Iran) and fill the emerging supply/demand gap.

Finalized policies are reported in three categories. First, energy management and reducing energy intensity; Second, reduction of wastage in energy production, conversion, and transmission; and third, consumption management and reduction of energy loss in the final consumer. Then to map how policies are interlinked, an interpretive structural model (ISM) [47] is performed. Generally, the ISM is used to visualize and present unclear and poorly articulated mental models [47,48].

Although ISM has already been used in different fields and the theory has been sufficiently improved by many researchers, it is poorly utilized for mapping decisions/policies. Chen used the ISM combined with Decision Making Trial and Evaluation Laboratory (DEMATEL) to identify causal relationships and hierarchical structure among factors in complex systems with a relatively small computational burden [49]. Similarly, Liang et al. used DEMATEL-ISM to analyze factors affecting the economic operation of electric vehicle charging stations [50]. Zhang and Han evaluated medical supply chain risk control factors using ISM [51]. Authors established relationships among elements forming the cold chain system of medicines. Then they implemented MATLAB software to calculate reachability and construct a multi-level ladder interpretation structure model. Sindhwani et al. also employed ISM to analyze factors influencing agility in the case of organizations [52].

This paper primarily is aimed to detect energy-saving and efficiency potentials. To perform a real-world application Iran has been selected as the case study. Although an extensive analysis has been done and the optimal policy set has been extracted, there is a challenging question. In the changing and competitive world with a lack of resources, should policies be prioritized? In other words, are policies interrelated? To answer these questions this research proposes to perform an interpretive structural model (ISM), which maps policy relationships.

A major concern is often ignored. Policies are interconnected and behave in a dynamic environment. Here, the proposed methodology utilizes ISM to sketch a map of how policies are linked, their causality, and priority and posteriority relations. ISM provides ideas about what and when policies and strategies should be applied.

ISM represents the system of relationships between policies using graph theory for the complex relationship among a set of elements (here elements are determined policies) [47]. The interpretive structure model contains two components, nodes, and links. Here, nodes represent policies determined through expert panels, and links are denoted and refined based on the ISM methodology using transitivity analysis.

In this research, ISM is used to show the dynamics of policies and how they are linked through causal cycles. ISM has been performed by researchers for different cases to clarify how decisions interact since, we believe that policies, strategies, and actions are not independent, rather they are somehow correlated.

The proposed ISM process is developed based on the following steps:

Step I. Detect and define policies: this step is equipped by ES and expert panels to define the policy set. As noted, three categories are formed to comprehensively cover supply, demand (end-user), and management aspects.

Step II. Interpretive Logic of relationships: policies are compared via a paired-wise comparison at this step. So, directions of relationships are identified in an expert-based process. In other words, experts evaluate if the investigated policies in a paired-wise comparison matrix (for instance policies *A* and *B*) are correlated/interconnected. And if a correlation exists, its behavior is evaluated (*A* affects *B*, and vice versa or they have a two-way correlation).

Step III. Designing the reachability matrix: experts' judgments are summarized based on the median operator (as consensus conditions). Results are usually presented via the matrix, table, or digraph adjacency. The paired-wise comparison data is used here to develop the interpretive logic. It is translated to the reachability matrix where 1 is allocated to a cell when corresponding policies are intercorrelated. For more details about how to develop a reachability matrix see: [49,53].

Step IV. Check for Transitivity: Transitivity denotes if elements of a similar nature will stand together. It is a property of relationships. In other words, transitivity, says if element *A* is related to *B* and element *B* is related to *C*, then *A* is related to *C*. The reachability matrix has to be checked for the transitivity rule and updated till full transitivity is established. Checking the transitivity guarantees considering neglected relations. Here MATLAB software is used to check transitivity in the network.

Step V. Level Partition on Reachability Matrix: it is carried out to determine reachability and antecedent sets for all elements [47,54]. Then, elements (here policies) are arranged graphically where directions are determined based on the reachability matrix. Note that transitive relations are presented in the form of dashed lines. Researchers are allowed to eliminate unnecessary transitive relations.

Step VI. Developing the Interpretive Structural Model (ISM): to develop the total ISM, the final digraph (obtained in step V) is translated into a binary form depicting all the interactions by each entry. Then the structural model is generated with nodes (i.e., policies) and links in a leveled manner. Inputs for the ISM digraph are provided by Ref. [1] the reachability matrix that showed via black lines in the diagram (see Figs. 9 and 11), and [2] transitivity calculations that uncover hidden relationships between policies (i.e., nodes). Links that are proposed by transitivity analysis are shown via red dashed lines.

3.1. Data description

To estimate energy loss in different sectors of energy production, conversion, distribution, and consumption in Iran, the Iran Hydrocarbon Balance reports published by the Institute for International Energy Studies, affiliated with the Ministry of Petroleum of the Islamic Republic of Iran have been used. Iran's Ministry of Energy also publishes Energy Balance, the last version of which reported the data from 2018 [55]. As the Hydrocarbon Balance is published by Iran's Ministry of Petroleum, which is responsible for almost all the primary energy supply of Iran, the hydrocarbon Balance is the main source of data in this paper. The latest edition of this report was published in 2020, in which the data for the year 2018 are reported [12]. This report contains data on the production, distribution, and consumption of various types of energy carriers, including crude oil, natural gas, and electricity. In general, in this report, to study the processes of energy production down to the final consumption of different energy carriers and to estimate the amount of production and consumption of each in different sections, energy flow analysis based on an energy reference system including primary energy, secondary energy and final energy levels has been used. In this paper, to calculate the energy-saving potential in the sectors of energy production, conversion and distribution in Iran, the data of all energy carriers are reviewed separately and then aggregated. In the field of final energy consumption, data available in various sectors including industrial, residential, commercial, and transportation are examined. The data is gathered based on formal national reports mostly reported by Iran's Ministry of Petroleum and Ministry of Energy (corresponding to power and water sectors), which are responsible for nations' power sectors. It should be noted that the sources related to other data used in this article, like Iran National Standard Organization, will be referred to as provided.

4. Results

Here, the current situation of energy consumption and the potential for energy saving in different sectors across Iran's energy value chain is evaluated.

4.1. Energy production and consumption in Iran

The production and final supply of energy in Iran in 2018 are shown in Table 1.

Due to its vast resources of crude oil and natural gas, more than 99% of Iran's primary energy supply consists of these two fossil fuels (34.87% crude oil and 64.29% natural gas) and the share of other sources of energy in the primary energy basket is less than 1%. According to Table 1, the loss of energy in Iran from the production process to the final energy supply is about 573 million barrels of oil equivalent (17.00% of energy production). Table 2 shows the final energy consumption in different sectors.

The largest share in final energy consumption is related to the residential sector, which also reflects Iran's policy of providing comfort and well-being to the nation. However, energy consumption per capita in Iran's residential sector is three times the global average, which indicates that there are many opportunities in the sector to implement different energy efficiency strategies. The next highest consumer of energy in Iran is the industrial sector, whose energy demand, like the residential sector, is mostly met by natural gas. Following these two sectors, transportation has the third-highest share in the country's energy consumption basket, which is mainly supplied by petroleum products. Iran's energy intensity in transportation is ranked 85th out of 94 countries. And finally, the Petrochemical and agriculture sectors have the lowest share of Iran's final energy consumption.

Table 1
Energy production and supply in Iran in 2018 (12).

Sector	Million barrels of oil equivalent
Production	3405.03
Import	29.54
Export and Storage	1020
Gas and gas-liquid Injection	163.70
Internal and operational and other consumption	214.33
Energy Loss during energy production and distribution	573.2
Final energy supply	1463.34

Table 2
Final energy consumption in Iran in 2018 by different sectors (12).

Sector	Million barrels of oil equivalent
Residential, commercial, service, public	488.72
Industry	375.32
Transportation	357.99
Petrochemical Feed	164.79
Agriculture	57.89
Others	4.67
Unspecified consumption	13.96
Total	1463.34

4.2. Energy loss in energy production, conversion, transmission, and distribution

As explained in the previous section, energy loss during the production process to the final energy supply in Iran is more than 570 million barrels of oil equivalent. Energy losses in this process include the sectors of energy production, conversion, transmission and distribution. In this part, energy losses and the potential for energy saving related to the aforementioned sector are estimated.

4.2.1. Energy loss in the energy production phase

The production phase in the present article refers to the extraction, refining and conversion of various energy carriers. Therefore, the energy consumption of oil and gas production, oil and gas refining, petrochemicals and power plants are evaluated in this part.

About 2.5% of the oil and gas produced in Iran is always consumed during the extraction phase and the rest is delivered to the refining sector. This amount in 2017 was equal to 84 million barrels of crude oil equivalent. In the United States, however, the percentage is always less than 2%. Assuming 2% as a standard of consuming energy in oil and gas extraction, there is a potential to save about 20 million barrels of crude oil equivalent in the sector.

According to Iran National Standard Organization, energy consumption in all 10 crude oil refineries and 12 natural gas refineries in Iran has met respective standards. Therefore, according to the indicators considered by this organization, energy loss in Iran's crude oil and natural gas refineries is optimal and there is not any considerable potential to save energy in this sector.

Energy consumption in the petrochemical sector (as fuel) has increased from 51 million barrels of oil equivalent in 2011 to 70 million barrels of oil equivalent in 2018. Iran National Standard Organization has reviewed 40 units out of 55 petrochemical units in Iran in 2018, of which 30 units have complied with existing standards and 10 units have not. Therefore, the loss of energy in this sector is estimated at 5.16 million barrels of oil equivalent.

490.50 million barrels of oil equivalent of energy supply enter the power plant sector. Of this amount, 181.9 units are converted into electricity and 310.70 units are wasted. The amount of energy loss in the power plant sector depends on the efficiency of the country's power plants. Iran's power plant efficiency is about 38% and has not changed significantly in recent years. Meanwhile, more than 80% of the nominal capacity of the country's power plants are gas-fired, combined cycle and heating power plants. Most of these power plants also use gas turbines. Since the average efficiency of gas turbines can be increased by up to

50%, there is a very high potential in this sector to save energy both through converting gas-fired power plants to combined cycle one and increasing the efficiency of gas turbines. This will prevent the loss of about 120 million barrels of oil equivalent.

Another area that is very significant in estimating energy loss in the energy production phase is the burning of oil-associated natural gases. In 2018, more than 128 million barrels of oil equivalent to associated natural gas were burned in Iran. Although it is predicted that due to the decline in Iranian oil production in recent years, the volume of flare-associated gas in Iran has decreased, without taking appropriate measures, the volume of flare-associated gases in Iran will also increase. All the burned gases, which are equivalent to 128.30 million barrels of oil equivalent, could be collected using appropriate technologies.

Due to small losses in the oil and gas refineries and petrochemical sector, in this part, only losses related to oil production, gas production (including associated gases and energy burned for extraction), and electricity generation are considered. According to calculations, about 522 million barrels of crude oil equivalent energy is wasted in this sector, of which about 250 million barrels of oil equivalent through various ways, including increasing the efficiency of gas power plants and collecting associated gas, can be recovered. To implement most of the above methods, state-of-the-art technologies, as well as the formulation of a suitable mechanism to facilitate the financing process of using these technologies, including the liberalization of fuel prices (especially for natural gas) is needed.

4.2.2. *Energy loss in the transmission and distribution sector*

Transmission and distribution loss is the loss of energy related to transferring different energy carriers like power, crude oil and petroleum products, and to the final consumers. In this section, the losses of transmission and distribution of crude oil, petroleum products, natural gas and electricity are evaluated, as presented in Fig. 1. According to Fig. 1, the amount of energy loss in transferring oil through pipelines is very limited and can be ignored. In 2016, only 3500 barrels of oil were lost in the sector. Although energy loss in the transferring petroleum products has decreased compared to 2011 since 2012 it began to increase and in 2018, 1.70 million barrels of oil equivalent were wasted in the process of transmission and distribution of petroleum products. Gas-transmission-related losses have increased since 2014. In 2018, about 1.47 million barrels of oil equivalent have been wasted in the natural gas transmission process.

In the process of natural gas transmission, one of the significant problems that, if addressed, could have a great contribution to reducing the energy intensity of the country is the concept of “unspecified natural gas consumption”. Unspecified consumption is practically an energy loss. Three contributing factors have led to this type of energy loss in Iran: 1. Damaged and worn-out equipment in the rural and urban gas transmission network, 2. leakage from gas meters, and 3. Illegal gas consumption. According to Fig. 1, the unspecified consumption of natural gas in Iran has been increasing since 2011 and in 2018 reached about 61 million barrels of oil equivalent, or about 10 billion cubic meters, which is approximately 5% of total natural gas consumption.

As shown in Fig. 1, electricity transmission and distribution losses have been declining over the last decade. However, the share of electricity transmission and distribution losses is much higher than other energy carriers. In 2018, about 19.30 million barrels of oil equivalent of electricity produced in the country had been wasted in the process of transmission and distribution which makes it the second-largest sector that wastes energy in the process of energy transmission and distribution after natural gas networks.

As shown in Fig. 1, the main sources of energy loss in the transmission and distribution sector are related to the transmission and distribution of electricity due to lack of upgraded equipment and unspecified natural gas consumption which is related to the transmission and distribution of natural gas. It is possible, by strict control of the natural gas distribution process, to prevent the loss of more than 60 million barrels of oil equivalent energy. On the other hand, by upgrading and modernizing electricity transmission and distribution equipment, it is possible to recover about 15 million barrels of oil equivalent in this sector based on international standards. In total, the potential for energy savings in the transmission and distribution sector is estimated at 76 million barrels of oil equivalent.

To realize the evaluated potential, in addition to upgrading the transmission and distribution infrastructure of all sources of energy, especially power systems, it is required to formulate proper standards and monitor the implementation of those standards in transmission and distribution processes. Without strict monitoring of transmission and distribution processes, it will not be possible to recover energy losses in this sector. It is worth mentioning that another factor that can help recover energy losses in this sector is to create a market for the exchange of recovered energy at the market price, and not a subsidized one, to provide an incentive to engage energy service companies (ESCOs) in this sector.

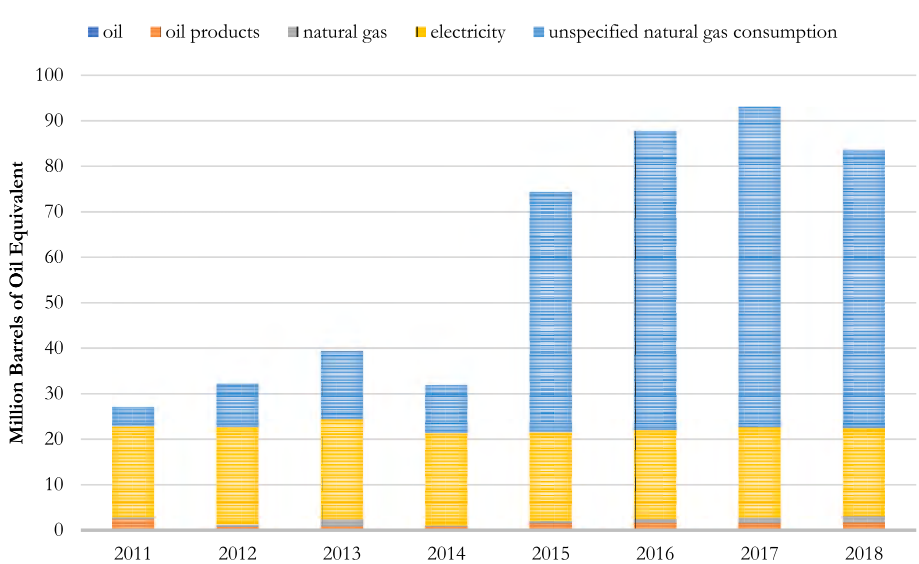

Fig. 1. Total energy losses in transmission and distribution (12).

4.4. Energy loss in the final consumption sector

The energy produced in the extraction, processing, and conversion phases is supplied to the final consumers, including the residential, commercial, transportation, industry, agriculture, industry, and so on. The final energy consumption in Iran by different sectors is shown in Fig. 2. It should be noted that since losses related to energy consumption in petrochemicals (as fuel) have been assessed in production section 1.3, it is not included here (final consumption). Due to the small share in the country's energy consumption basket, the study of energy loss in the agricultural sector has also been ignored. According to Fig. 2, total final energy consumption in Iran has been continuously rising. Residential, public, and commercial sectors are responsible for the largest share of total final consumption, followed by the industry and transportation sectors respectively. In the next subsections, the potential for energy saving especially in the aforementioned sectors is estimated.

4.4.1. Residential sector

About 408 million barrels of oil equivalent were consumed in the residential sector in 2018, which shows that it is the largest energy consumer in Iran. Of all energy carriers, natural gas has the largest share in the energy consumption of the residential sector. According to Fig. 3, it is clear that the share of natural gas in residential energy consumption has grown significantly at expense of the share of petroleum products over the past two decades as a result of adopting the policy of maximum replacement of petroleum products with natural gas by Iranian decision-makers [56], and natural gas is now responsible for nearly 90% of the total energy consumption of the sector. It is worthwhile to note that according to Fig. 3, the total share of the residential sector in the total final energy consumption of Iran is decreasing.

Iran is divided into 8 climatic regions. To compare the current state of energy consumption in residential buildings with the most efficient state, 6 cities that had the most similarity to the characteristics of each climatic region (Appendix II) were selected according to two standards of energy labeling for buildings i.e. 14254 and 14253: Tehran represents climatic region 5, Tabriz represents climatic regions 1 and 2, Bandar Abbas represents climatic region 8, Kashan represents climatic region 6, and Rasht represents climatic region 3 and 4. The standard classification of energy consumption in the residential sector in different climates of Iran and its comparison with the current situation is shown in Fig. 4.

Referring to Fig. 4, it is clear that the average energy consumption of homes in Iran is higher than the worst energy consumption class. This indicates serious problems in the insulation and architecture of the Iranian buildings that have pushed the current energy consumption beyond the standard limits. Energy consumption in the residential sector in Europe is about 190 kWh per square meter per year [58] and in the United States about 150 kWh per square meter per year (in other words total energy consumption of residential buildings in Europe and the U.S. A. is 112 and 106 million barrels of oil equivalent respectively), which are significantly lower than the energy consumption of buildings in Iran. The amount of saving capacity in the residential sector can be considered as the difference between Iran's consumption (323 million barrels of oil equivalent) and Europe's (112 million barrels of oil equivalent), which is equal to 211 million barrels of oil equivalent per year. On the other hand, if the current situation of energy consumption (323 million barrels of oil equivalent) is compared to the optimal energy consumption class, meaning class A (59 million barrels of oil equivalent), the potential for energy saving in the residential building of Iran is estimated at 264 million barrels of oil equivalent. In this paper, for the sake of being rational and not idealistic, the difference between Iran's consumption of residential building and Europe's is considered as a potential for energy saving in this sector.

In addition to buildings, home appliances are also of significant importance in residential energy loss. Each of these devices is classified according to specific standards by the Iran National Standard Organization. A comparison of the current energy consumption of home appliances in Iran with the state in which their energy consumption is the most optimal is shown in Table 3.

According to Table 3, the energy consumption of household appliances is equal to 321 million barrels of oil equivalent per year. By upgrading all of them to class A, the amount of energy that could be saved will be equal to 54 million barrels of oil equivalent per year. As a result, the entire household sector has a capacity of 265 million barrels of oil equivalent to saving energy. The main reason for non-optimal energy consumption in the residential sector of Iran is non-standard construction and the use of energy-intensive home appliances. To realize the potential for energy savings in this sector, it is necessary to carefully implement the existing regulations in the field of construction (such as Article-19 law [60]) and to develop measurable performance indicators to monitor the implementation of these regulations, like building energy labels. Currently, there are 8 energy efficiency plans in the residential sectors in Iran, that are yet to be implemented. The total value of these plans is estimated at about 6.3 billion dollars with the potential of saving 90 million barrels of oil equivalent per year. For more details, see appendix III.

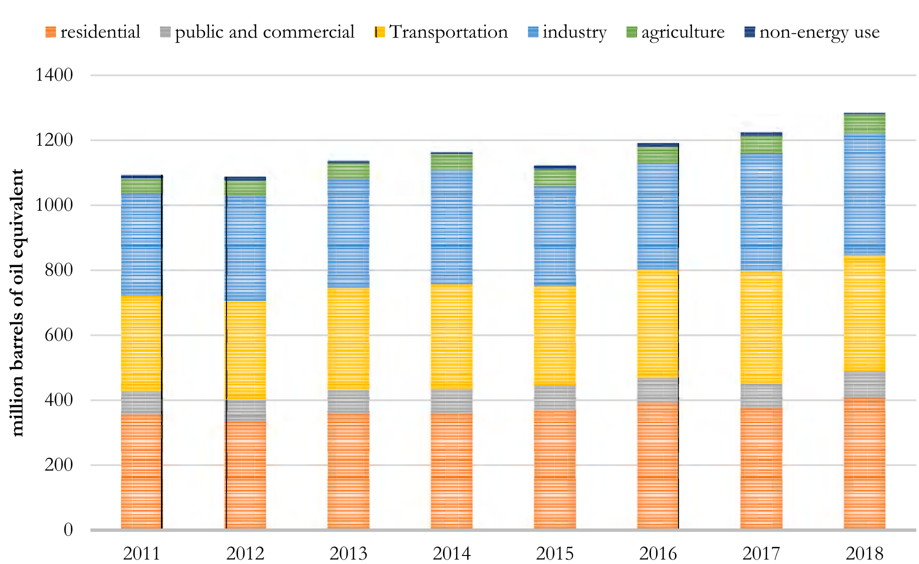

Fig. 2. Total amount of different sectors in final energy consumption (sectors' share trends can be interpreted visually) (12).

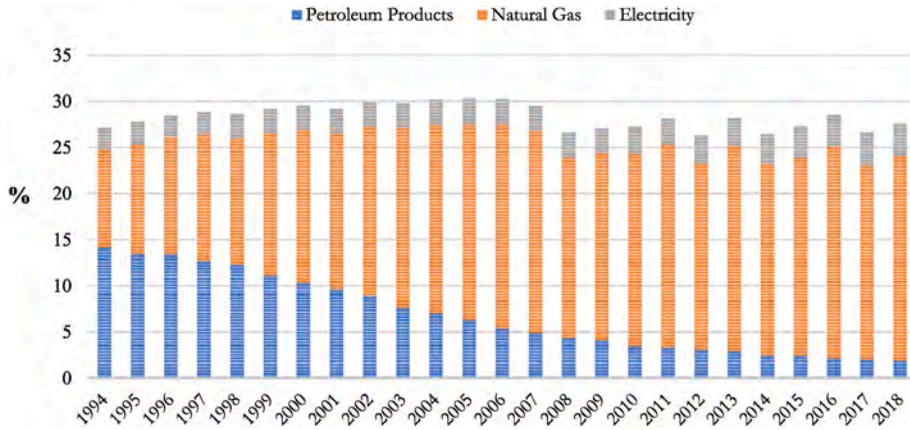

Fig. 3. **Share of the residential sector in the total energy consumption of the country by different energy sources** (12).

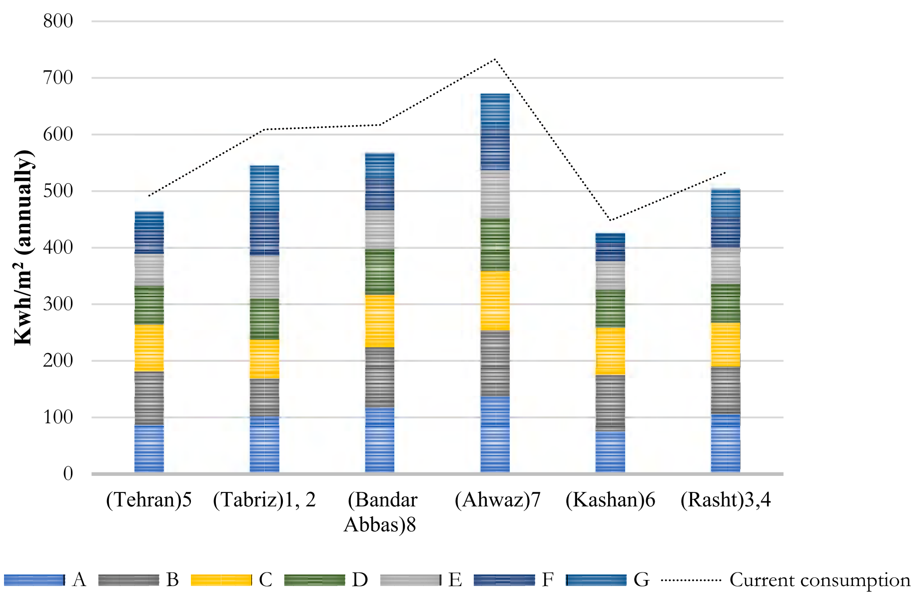

Fig. 4. **Residential building energy consumption (buildings less than 100 square meters) and comparison with consumption criteria** [57].

Table 3
Comparison of current energy consumption of home appliances with the situation that they are all in category A [59].

Home appliance	Current energy consumption (mmboe/y)	Optimal energy consumption (mmboe/y)
Chimney-vented gas heater	149	110
Refrigerators	20	17
Water coolers for homes	6	5
Gas central heating boilers and furnaces	143	132
Washing machine	3	2.8
Total	321	267

4.4.2. Industrial sector

Consuming 357.99 million barrels of crude oil equivalent, the industrial sector in Iran is the second-largest consumer of energy after the residential sector. Chemical industries, non-metallic mineral products, and base metals are Iran's most energy-consuming industries, which in total account for about 80% of Iran's energy consumption in the industrial sector [61]. Therefore, the energy productivity index in the industrial sector of Iran is lower than other countries in the world.

According to Fig. 5, it can be seen that Iran's energy productivity is lower than the best (US) and worst (Belgium) OECD countries [63]. The potential for energy saving in Iran's industry sector is estimated at about 100 million barrels of oil equivalent [64], 67% of which is the share of the iron and steel sector and 17% is the share of the cement sector [65]. Due to the low energy productivity index in the industrial sector of Iran and as a result, high energy intensity in this sector, the realization of this potential depends more than anything on the development of a national productivity plan and setting annual realistic goals, measurable performance indicators, the establishment of a statistical and performance evaluation system in such a way that the energy intensity is continuously reduced. In addition, creating an appropriate mechanism to encourage companies and industries to optimize energy consumption, including the mandate to meet their demand at market prices, not subsidized ones, and supporting industries to use technologies with optimal energy consumption can also help significantly reduce the energy consumption of the industrial sector in Iran.

4.4.3. Commercial and public sector

The commercial and public sectors, consumed about 81 million barrels of oil equivalent in 2018. To estimate the optimal amount of energy consumption in commercial and public buildings, standards of the Iran National Standards Organization, which are shown in Fig. 6, could be used as a criterion.

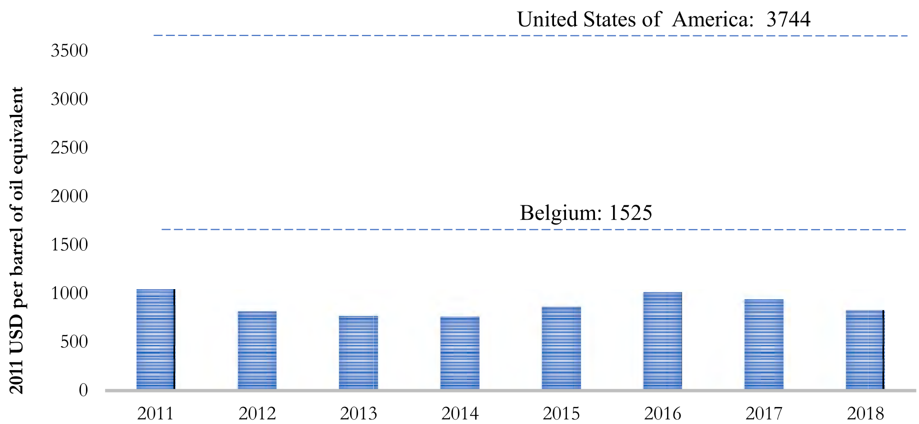

Fig. 5. Iran energy productivity in the industrial sector [62].

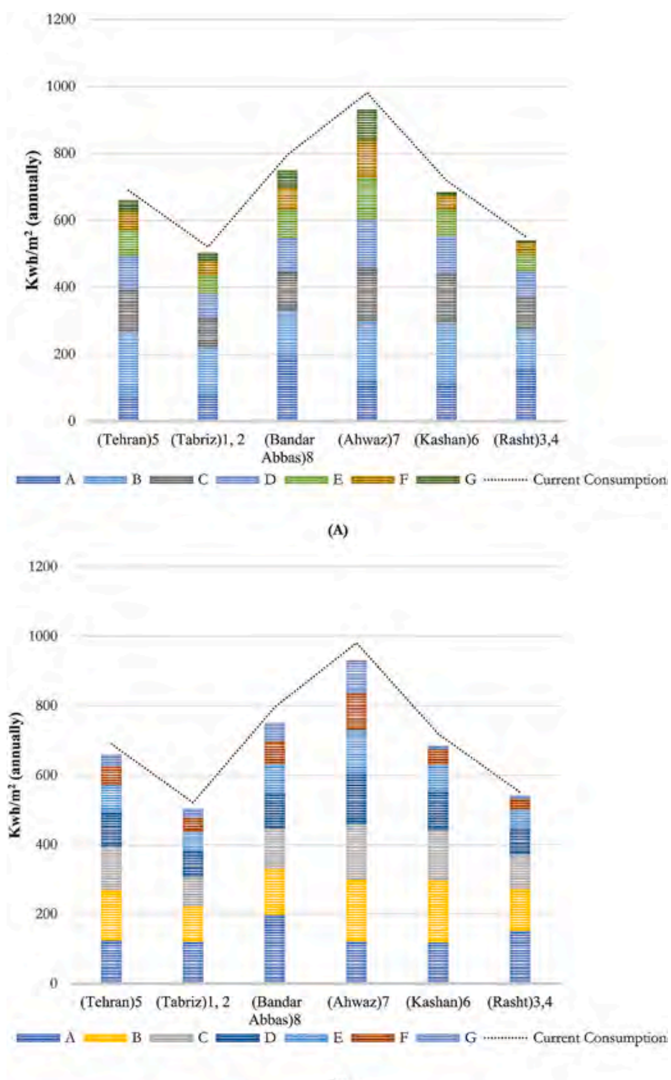

Fig. 6. Energy consumption of office buildings, (A): public sector, (B): private sector [57].

According to Fig. 6, it is clear that energy consumption in the private and public office buildings of Iran is more than the worst standard class. Meanwhile, the average energy consumption in the European commercial sector is approximately equal to 300-kW hours per square meter per year which falls in class C of Iran standards for consuming energy in commercial and public buildings. The difference between energy consumption in Iranian and European commercial buildings, which is equivalent to 20 million barrels of oil equivalent per year, can be considered as the potential for energy saving in this sector.

4.4.4. *Transportation sector*

In 2018, more than 358 million barrels of oil equivalent were consumed in Iran's transportation sector. Road transportation which transfers more than 60% of passengers and 70% of goods [66] has the largest share compared to other modes of transportation (maritime, railroad, and airline). One of the most important ways to save energy in the transportation sector is to reduce the share of road transport and increase the share of rail transport (as the most energy-efficient transport mode) in transferring passengers and goods. Based on the difference between the per capita fuel consumption of railway and road vehicles and the current capacity of Iran's railway network. If the share of rail transport in passenger transfer increases by 50 or 100% (the capacity of railway networks increases by 50% or 100%), there could be 11 to 28 million barrels of oil equivalent potential to save energy, as shown in Table 4.

Similarly, based on the difference between per capita fuel consumption of railway and road vehicles and the current capacity of Iran's railway network, If the share of rail transport in good shipping increases by 50 or 100% (the capacity of railway networks increases by 50% or 100%), there could be 20 to 37 million barrels of oil equivalent potential to save energy, as shown in Table 5.

The average amount of fuel consumption of vehicles also plays an important role in saving fuel consumption in this sector. The average fuel consumption of Iran's light cars is far more than the world's average. If the average fuel consumption of light vehicles in Iran decreases from the current 7.93 L/100 km to the world average of 5.50 L/100 km, gasoline consumption will be reduced by 30 million liters per day or 52 million barrels of oil equivalent per year [67]. The average fuel consumption of all types of heavy vehicles in Iran is also beyond the world's average, which has a great effect on gasoline consumption in the country. If the average fuel consumption of Iran's heavy vehicles decreases from the current 48 L/100 km to the world average of 36 L/100

Table 4
Potential of saving energy by increasing the share of railroad transportation in passenger transport-Authors' calculation.

Subject	Volume
The current share of railroad transportation	12.50%
Potential of saving energy in the case of increasing the share of railroad transportation by 50%	11 mmboe
Potential of saving energy in the case of increasing the share of railroad transportation by 100%	28 mmboe

Table 5
Potential of saving energy by increasing the share of railroad transportation in freight transport- Authors' calculation.

Subject	Volume
The current share of railroad transportation	7.30%
Potential of saving energy in the case of increasing the share of railroad transportation by 50%	20 mmboe
Potential of saving energy in the case of increasing the share of railroad transportation by 100%	37 mmboe

km, gasoline consumption will be reduced by 20 million liters per day or 54 million barrels of oil equivalent per year [67]. In total, the energy-saving capacity of the transportation sector can be estimated between 137 and 180 million barrels of oil equivalent, as shown in Table 6. This potential can be realized by increasing the efficiency of the vehicle's fleet and shifting the mode of transportation from road to railroad.

4.4.5. *Recap of energy saving capacity in different sectors*

The potential of saving energy in different sectors, which was calculated in the previous sections, is shown in Table 7.

As shown in Table 8, about 850 million barrels of oil equivalent of energy consumed in the energy production, conversion, transmission, distribution phases and various sectors of final energy consumers are recoverable, which is equivalent to 25% of total energy production in Iran. Of this amount, about 350 million barrels of oil equivalent are related to the production, distribution, and transmission phases (equivalent to 10% of total energy production) and 500 million barrels of oil equivalent (equal to 34% of total final energy consumption) can be saved in the final consumption sector.

5. Policy recommendation and discussion

5.1. *Policy initialization*

As noted before, 47 expert panels for 9 different thematic subjects were held which resulted in initializing policies to three main categories [1], energy management and energy intensity reduction [2], reduce energy waste in energy production, conversion and transmission, and [3] reducing end users' energy consumption and waste. These categories cover three main sides of a national energy ecosystem containing, management/policymaking/regulation, the supply side, and the demand side. Tables 8–10 summarize major policies under each category.

Now policies are determined as tools to facilitate migration to a better future where the country improves energy efficiency and utilize energy-saving capacities in term of gaps in energy management systems, losses in the supply cycle, and waste at the end-user (demand side). Now it's time to map policies and determine the relationships between them. It helps policymakers to prioritize policies and design scheduled strategy sets.

Table 6
Potential of saving energy in the transportation sector.

Subject	Volume
Current energy consumption in the transportation sector	320 mmboe
Potential of saving energy in the case of increasing the share of railroad transportation by 50%	31 mmboe
Potential of saving energy in the case of increasing the share of railroad transportation by 100%	65 mmboe
Potential of saving energy by increasing the fuel efficiency of light vehicles	52 mmboe
Potential of saving energy by increasing the fuel efficiency of heavy vehicles	54 mmboe
Total	137 to 180 mmboe

Table 7
Potential of energy saving in different sectors.

Sector	Potential of Energy Saving (mmboe/y)
Production	270
Transmission and Distribution	76
Residential	265
Industry	100
Transportation	137
Commercial and Public	20
Total	858

Table 8
Policies introduced via expert panels to manage energy systems and reduce energy intensity.

Code	Proposed policies
Mng.1	Reforming consumption and efficiency governance structure and establishing a regulatory body
Mng.2	Facilitating inter-agency coordination and participation of stakeholders
Mng.3	Establishing an independent financial structure
Mng.4	Development of financing mechanisms and supporting both domestic and foreign investments
Mng.5	Reviewing laws related to energy and fossil resources to guarantee continual improvement
Mng.6	Developing the national productivity plan, evaluation indicators, and data gathering systems
Mng.7	Periodical evaluation and re-setup of price policy instrument
Mng.8	Developing, applying and monitoring national standards for the case of production, imports, and exports
Mng.9	Inforcing public demand via empowering the civil society using cultural capacities
Mng.10	Supporting knowledge-based and start-up business
Mng.11	Developing energy-saving market

Table 9
Policies introduced via expert panels to reduce energy waste from the supply side.

Code	Proposed policies
Sup.1	Minimizing flaring gases
Sup.2	Increasing the efficiency of thermal power plants (via thermal recycling)
Sup.3	Online monitoring of distribution networks
Sup.4	Maximizing electricity transmission and distribution efficiency
Sup.5	Upgrading the consumption standard in equipment and processes (in the terms of energy production, conversion, and transmission)

Table 10
Policies introduced via expert panels to reduce energy waste and control consumption on the demand side.

Code	Proposed policies
Dmn.1	Developing a standard system for building energy consumption and waste
Dmn.2	Targeting energy subsidies
Dmn.3	Supporting the production of efficient goods/equipment (with the priority of home equipment)
Dmn.4	Establishment of energy consumption management standards in all industrial sectors
Dmn.5	Facilitating the transition from energy-intensive industries with medium technology to low-energy industries with high technology
Dmn.6	Improving and empowering public transportation structure/organization based on smartening the transportation network and developing railway systems
Dmn.7	Improving the efficiency of internal combustion engines (especially in the case of public transport systems)

5.2. *The interpretive structural model (ISM)*

The process of an ISM has been discussed in section 3. As noted, MATLAB software has been used to calculate transitivity closure and map the interpretive structure. Before presenting standard ISM outputs, let's review experts' raw judgments which are received via paired comparisons. Figs. 7, 8 and 10 schematically represent policies based on the degree experts noted how they can drive other policies or how they are dependent on others. Note that the maximum value is determined by the number of policies under each category.

Fig. 7 shows there is a cluster of four policies that drives others significantly, containing: (Mng.6); developing the national productivity plan, evaluation indicators, and data gathering systems, (Mng.1); reforming consumption and efficiency governance structure and establishing a regulatory body, (Mng.5); reviewing laws related to energy and fossil resources to guarantee continual improvement, and (Mng.2); facilitating inter-agency coordination and participation of stakeholders. While policies such as (Mng.10); supporting knowledge-based and start-up businesses and (Mng.11); developing an energy-saving market dependent on others dramatically. Applying the ISM uncovered hidden relationships that experts may ignore unintentionally. So, if *A* is related to *B*, and *B* is related to *C*, then A is related to *C*, even if the expert did not mention it. Transitivity is an important property in the study of preference structures [68]. Checking transitivity closure of the first category (i.e. energy management and energy intensity reduction) represented that all policies, except "supporting *knowledge-based and start-up business*" are interrelated directly or at least with a second-level relationship (i.e. they are mutually correlated). This means the modification of energy (consumption/demand) management and optimization needs massive resources and attempts to approach an upgrade energy management structure. For the case of supporting knowledge-based and start-up businesses, results showed that it cannot be applied and managed successfully if other policies have not been taken seriously. As Fig. 7 shows, it is significantly dependent on other policies. This is a radical finding and recommendation for policymakers which reveals that knowledge-based and start-up businesses cannot effectively influence energy efficiency unless supported by other (mostly governmental) policies.

Referring to Fig. 8, mentioned policies behave moderately, most with average driver index and dependency. However, before applying the ISM and checking for transitivity closure "*online monitoring of distribution networks*" reflected a lower dependency level while it seems to be a major driver. In addition, although "*upgrading the consumption standard in equipment and processes (for terms of energy production, conversion, and transmission)*" is dependent on other policies, it is a critical driver which can trigger the success and failure of reducing energy waste in energy production, conversion, and transmission.

Implementing ISM reveals some hidden policy relations which are represented via red dashed lines in Fig. 9 as the total interpretive structural model (TISM). In addition, Fig. 9 levelized the structure and policy relationships graphically. Compared to the previous category, this one is simpler and the results showed that (Sup.4); maximizing electricity transmission and distribution efficiency, (Sup.5); upgrading the consumption standard in equipment and processes (in terms of energy production, conversion and transmission), and (Sup.3); online monitoring of distribution networks are most basic and prioritized policies to support improving efficiency at power plants and reducing flare gases. As it has been shown, experts' raw judgments did not reflect the interconnection between Sup.3 and Sup.4 as drivers, and Sup.2 and Sup.1 from upper levels in the TISM graph. As a result, the importance of Sup.3 and Sup.4 has increased. In addition, they have been introduced as potential bottlenecks which can increase failure risks.

Fig. 10 shows experts' opinions, extracted and mapped based on a paired comparison study. Similar to the previous category (i.e. reducing energy waste in energy production, conversion, and transmission) most policies are mapped in the middle of the chart. But, Dmn.2 entitled "*targeting energy subsidies*" behaves differently with high driver property. So it can be concluded that to ensure demand-side optimum management, a subsidizing mechanism must be revised and modified.

Moreover, applying ISM proved the noted conclusion and uncovered some interesting outcomes (see Fig. 11). As an example, at the fifth level, modifying and optimizing energy consumption in the transportation system (i.e. Dmn.6) is crucial to support demand-side efficiency management. Then, Dmn.5, Dmn.7, Dmn.4, and Dmn.1 are prioritized which focused on standardization, facilitating the transition to non-energy intensive plants, and improving internal combustion engine technology and efficiency. These policies will lead to a decreased share of energy in Iran's economic development and GDP, which is equal to the damping energy intensity level. Results showed that Dmn.3 (i.e. Supporting the production of efficient goods/equipment) is the last policy that must be initialized and supported by others (as can be seen in Fig. 11).

6. Conclusions

In this paper, the energy balance of Iran was presented and the potential of energy saving in different elements of the energy value chain and different sectors of final energy consumption was analyzed. Accordingly, the potential energy saving in the energy production phase is around 250 million barrels of oil equivalent which are mostly related to flaring oil-associated natural gas and the relatively low efficiency of

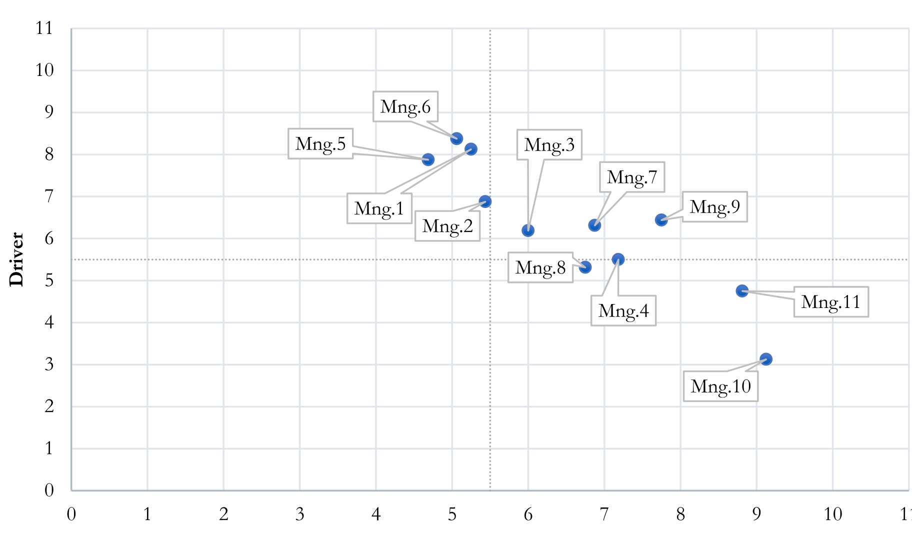

Fig. 7. Driver-Dependence map for policies under energy management and energy intensity reduction category (crossed lines show the average values).

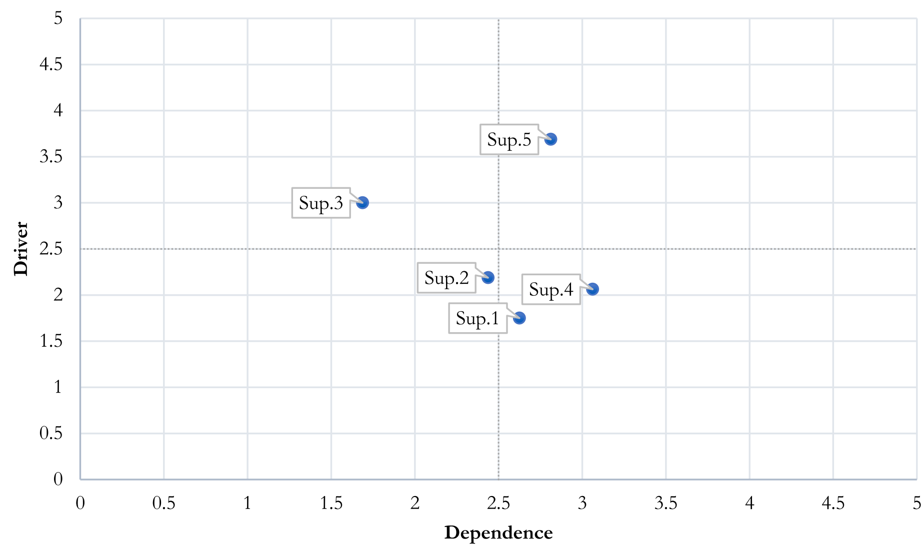

Fig. 8. Driver-Dependence map for policies under reducing energy waste in energy production, conversion, and transmission category (crossed lines show the average values).

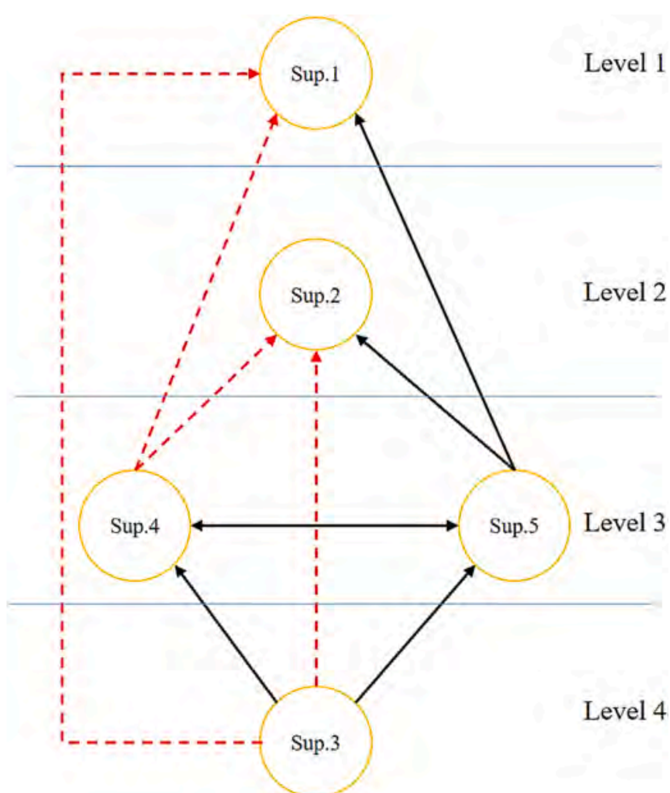

Fig. 9. Total interpretive structural model (TISM) with significant transitive links for the case of reducing energy waste in energy production, conversion, and transmission.

Iran's power plants. In the transmission and distribution phase, the main contributing factors to energy loss are the transmission and distribution of natural gas and electricity. The potential energy saving for this phase was estimated at 76 million barrels of oil equivalent. To calculate the potential of energy saving in final energy consumption, the energy consumption of four main sectors, residential, industrial, public and commercial, and transportation were evaluated.

In the residential sector, the potential for energy saving was estimated at 265 million barrels of oil equivalent which can be realized through retrofitting buildings, using building energy labels/codes, and upgrading home appliances.

In the industry sector, the potential for energy saving is estimated at about 100 million barrels of oil equivalent which are mostly related to iron and cement subsectors. For the public and commercial sector, the potential for energy saving is estimated at 20 million barrels of oil equivalent, most of which is related to the characteristics of public and commercial buildings.

In the transportation sectors, the potential for energy saving is about 137–180 million barrels of oil equivalent, which can be realized through increasing the share of railroad transportation in both passenger and freight transportation and decreasing the average fuel consumption in both light and heavy vehicles to the world average. Totally, the minimum potential energy consumption in Iran's energy sector is 858 million barrels of oil equivalent.

Then, it is concluded that improving energy efficiency and consumption/waste management in Iran is a complex problem that consists of many sectors, as stakeholders, which cannot be addressed directly. This research proposed an analytical research design that has been equipped with 47 expert panel sessions under 9 major themes. Results showed that the focal problem must be divided into three categories consisting of [1] energy management and energy intensity reduction [2], reducing energy waste in energy production, conversion, and transmission, and [3] reducing end users' energy consumption and waste. Sets of policies obtained via expert panels. Table 8–10 present practical policies introduced by experts through 47 expert panels/sessions. 23 policies were initialized but still, there are some critical questions. Are these policies intercorrelated? How? From the perspective of theory, this research is aimed to propose a procedure to discover and map policies' relations.

These initial policies are structured and analyzed using an interpretive structural model which helped researchers to assess experts' paired judgments (on policy sets regarding each category) and uncover neglected relationships. Findings have been shown using TISM graphs which levelized and prioritized policies to manage resource allocation and optimum efficiency improvement management at the national level. In other words, macro-level policy roadmaps have been developed corresponding to each category. Figs. 7, 9 and 11 represent the structural model for every three main areas (noted above).

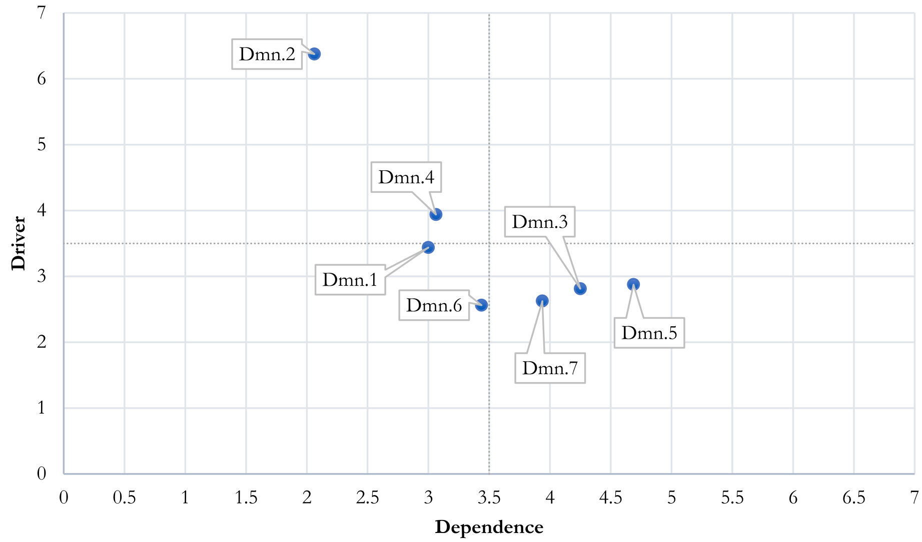

Fig. 10. Driver-Dependence map for policies under reducing end users' energy consumption and waste category (crossed lines show the average values).

Author contribution statements

Ahmad Mortezaee and Reza Hafezi conceived of the presented idea. Amirhossein Souhankar developed the theory and performed the computations. A. Mortezaee and R. Hafezi verified the analytical methods. R. Hafezi and A.H. Souhankar drafted the manuscript with input from all authors. R. Hafezi supervised and edited the final version. All authors discussed the results and contributed to the final.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors are unable or have chosen not to specify which data has been used.

Appendixes

Expert ID	Expertise	Occupation	Related expert panel
001	Natural gas-based fuel	Former manager of Iran Fuel Conservation Company	Main member of all expert panels
002	Energy Governance	Petroleum Engineering Department, Amirkabir University of Technology	Main member of all expert panels
003	Energy foresight	National Research Institute for Science Policy (NRISP)	Main member of all expert panels
004	Technology & Innovation Policy	National Research Institute for Science Policy (NRISP)	Main member of all expert panels
005	Energy Policy	National Research Institute for Science Policy (NRISP)	Main members of all expert panels
006	Energy efficiency	Energy specialist	Main members of all expert panels
007	Energy efficiency in power systems	Research Analyst	Management and planning
008	Electricity	Manager at Iran Thermal Power Plant Holding Co.	Management and planning
009	Energy systems	Energy Specialist	Financing
010	Fuel conservation	Analyst at Iran Fuel Conservation Company	Financing
011	Energy economics	Energy specialist	Energy efficiency markets
012	Fuel conservation	Analyst at Iran Fuel Conservation Company	Energy efficiency markets
013	Oil and natural gas	Energy specialist	Governance
014	Energy efficiency	Senior energy analyst	Governance
015	Energy consumption in buildings	Analyst at Iran Road, Housing & Urban Development Research Center	Price and non-price strategies
016	Fuel conservation	Analyst at Iran Fuel Conservation Company	Price and non-price strategies
017	Power systems	Manager at Tavanir Holding	Energy technology and industries
018	Power systems	Manager at MAPNA Holding	Energy technology and industries
019	Energy and Environment	Researcher at Climate and Energy Policy Laboratory, Georgia Tech	Socio-cultural aspects
020	Energy Audition	Manager at Asia Watt Engineering Co.	Rules and procedures
021	Energy Standards	Energy Manager at Iran National Standard Organization	Rules and procedures
022	Energy systems	Energy Specialist	Education

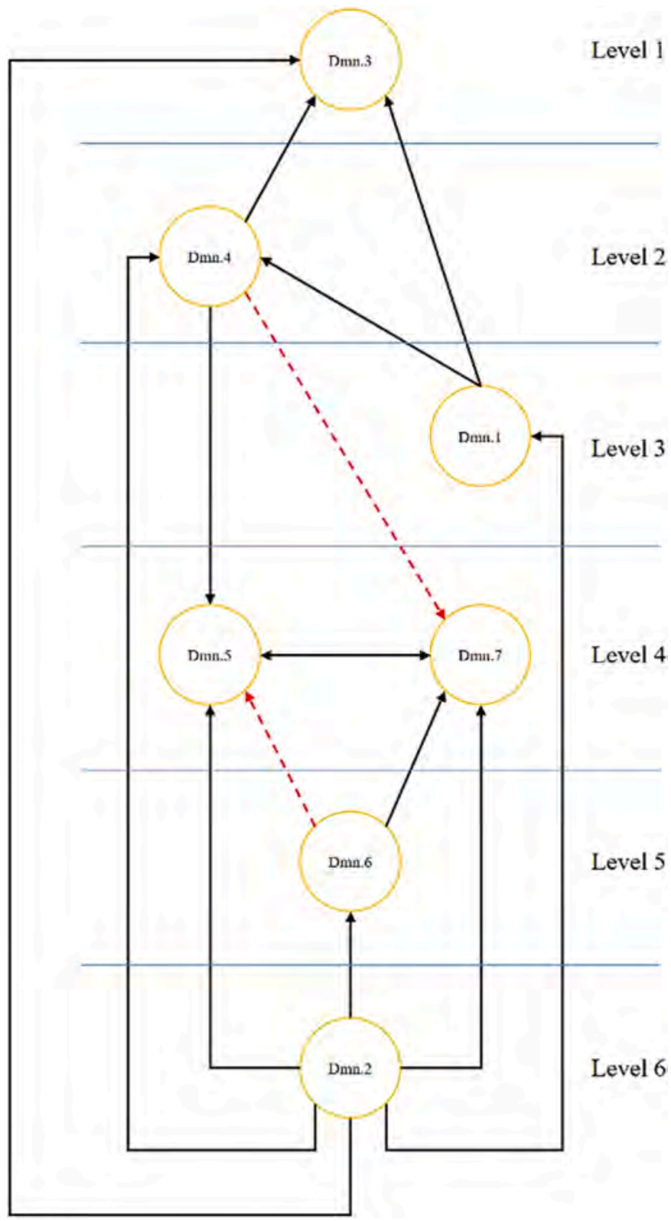

Fig. 11. Total interpretive structural model (TISM) with significant transitive links for the case of reducing end users' energy consumption and waste.

Appendix I. Information about selected experts who have participated in panels

Appendix II. Eight climatic regions of Iran

Climatic region	Average maximum temperature in summer (°C)	Average of relative humidity in summer (%)	The average minimum temperature in winter (°C)	Average of relative humidity in winter (%)	Representative city
1	25–30	45–55	−10 to −5	65–75	Tabriz
2	35–40	25–40	−10 to −5	65–75	
3	25–30	More than 60	0–5	More than 60	Rasht
4	30–35	More than 50	0–5	More than 60	
5	35–40	20–45	0–5	40–60	Tehran
6	35–45	15–20	0–5	35–50	Kashan
7	45–50	20–30	5–10	60–70	Ahwaz
8	35–40	More than 60	10–20	More than 60	Bandar Abbas

Appendix III- most important plans to improve energy efficiency in Iran's residential sector [69]

#	Title	Value (million $)	Potential of saving energy (mmboe/year)
1	Smartening of heating systems	50	1.9
2	Improving the efficiency of buildings' engine rooms	50	1.9
3	Replacement of joint of gas riser pipe for 13 million subscribers	200	6.4
4	Replacement of 9 million damaged and old heaters	1600	33.14
5	Replacement of engine rooms with a wall-mounted gas combi boiler	100	3.18
6	Replacement of 1 million oil/gas-fired heaters with hermetic gas-fired heating units	204	8.4
7	Improving the energy efficiency of new-built buildings according to article 19 of Iran's national building code	600	4.5
8	Replacement of single-glazed windows with double-glazed ones	3510	35.7
Total		6340	95.12

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