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Improving renewable energy policy planning and decision-making through a hybrid MCDM method

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Abstract

Shifting from fossil to clean energy sources is a major global challenge, but in particular for those countries with substantial fossil-fuel reserves and economies depending on fossil-fuel exports. Here we introduce an improved framework for renewable energy planning and decision-making to help such countries to more effectively harness their abundant renewable energy resources. We use Iran as a case for the analysis. The framework includes identifying and removing barriers that prevent the use of renewables. It is based on combining two models: Benefit, Opportunity, Cost, Risk (BOCR) and Analytic Network Process (ANP) models. In the analyses, the mutual weight of strategic criteria is employed such as technology, economy, energy vulnerability, security, global effects, and human wellbeing. Using the integrated model, we find that solar energy would be the preferential renewable energy source for Iran. Also, the role of infrastructures, policies, and administrative structures in renewable energy to facilitate their development was analyzed. The renewable energy policy-making framework presented is applicable to other countries as well.

Key Words: Renewable Energy, Multi-Criteria Decision Making, Analytic Network Process, BOCR, Policy Analysis

Nomenclature

ANP	Analytic Network Process
AHP	Analytic Hierarchy Process
BOCR	Benefits, Opportunities, Costs, Risks Analysis
CCHP	Combined Cooling, Heating and Power
CHP	Combined Heat and Power
DEMATEL	Decision-Making Trial and Evaluation Laboratory
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
MCDM	Multi-Criteria Decision Making
Mtoe	Million tons of oil equivalent
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
RE	Renewable Energy
REIC	Renewable Energy Initiative Council
RIPI	Research Institute of Petroleum Industry
STEEP	Social, Technological, Economic, Environmental, Political
SUNA	Renewable Energy Organization of Iran
SWARA	Step-wise Weight Assessment Ratio Analysis
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution

UNFCCC	United Nations Framework Convention on Climate Change
VIKOR	VlseKriterijumska Optimizacija I Kompromisno Resenje
WASPAS	Weighted Aggregated Sum Product Assessment

1. Introduction

The world economy rests on intensive use of fossil fuels, which are well-known for their negative impact not only on the environment and climate but also on health (Dincer, 2000; Tietenberg and Lewis, 2016). The share of fossil fuels in the world's primary energy consumption is presently about 81% (BP, 2017). Though adequacy is not a concern for present fossil-fuel use, their reserves are, however, limited on a long-term basis (Abbaszadeh et al., 2013; EIA, 2017). Therefore, clean and efficient energy pathways are of high importance for future energy policies (Alizadeh et al., 2016b; Karbassi et al., 2007; Zamani-Sabzi et al., 2016). Such developments would benefit from appropriate local and global energy policy planning frameworks.

Energy and climate policy planning frameworks are of particular importance to countries that produce fossil fuel because their economies and economic development are strongly linked and locked-in to fossil-fuels. For example, Iran would represent a highly relevant case in this context, as Iran has the 4th largest oil reserves and 2nd largest natural gas reserves in the world (CIA, 2017), and has less focused on the development of alternative energy in the past (Dehghan, 2011). Through increasing domestic energy consumption (6.2% yr⁻¹ over the last ten years), a growing share of the fossil fuel export is being diverted to domestic consumption (Alizadeh et al., 2016b). Consequently, Iran is the 3rd largest natural gas consumer, and it could become the largest one in the near future (BP, 2017). Moreover, Iran's energy intensity is very high, or 3-times that of

the world average and per-capita energy demand is over 10-times that of Japan or the EU (Alizadeh et al., 2016a; IEA, 2017b). Iran could become an energy importer in the future, if not being able to diversify its energy production (Alizadeh et al., 2016b). Another alerting fact is that Iran is among the top CO₂ emitters, representing close to 2% of the global greenhouse gas emissions (IEA, 2017a). A similar situation prevails in other large fossil-fuel producing countries such as Russia and the Persian Gulf region (BP, 2017). Harnessing more effectively local sustainable energy solutions could positively address both the climate and economic issues in the fossil-fuel producing countries. But this would also necessitate changes in the national energy policy to better consider the clean options in the energy planning (Alizadeh et al., 2015a; Azadi et al., 2017; Moshiri et al., 2015).

Based on this background, we aim here to provide a systematic decision support framework for policymakers based on multi-criteria decision making (MCDM), using Iran as an example. We combine a Benefit, Opportunity, Cost, Risk (BOCR) model with the Analytic Network Process (ANP) in order to integrate strategic planning and decision-making. Combining BOCR and ANP creates a hybrid model that eventually could overcome the pitfalls of past decision-making processes (Kabak and Dağdeviren, 2014). The BOCR-model is a frequently used strategic management framework for decision analysis, in which alternatives, decisions, options, and potential actions are assessed through four indicators (Lee et al., 2009; Saaty and Ozdemir, 2003; Yi et al., 2011). ANP is a practical MCDM-method (Saaty, 2004) used to calculate priorities while considering interdependencies. Our proposed hybrid model goes beyond the present status of each of the ANP and BOCR models by addressing two main challenges associated with these methods. Firstly, we improve the ability of the ANP in determining criteria in fields where no

similar applications exist. Our proposed integrated framework addresses this improvement through six contributions: (i) avoiding arbitrary scales and determining the criteria priorities based on pair-comparison rates from decision-makers' assessments; (ii) considering both tangible and intangible decision variables; (iii) converting qualitative values into numerical values for comparative analysis; (Popp et al.) designing a simple and initiative overall process, which decision-makers can easily understand and apply without specialized knowledge; (v) allowing participation of all stakeholders and decision-makers in the decision-making process; and finally, (vi) allowing feedback and interdependence among the criteria (Liang and Li, 2008). Secondly, the handicap of MCDM methods to determine criteria in areas without prior knowledge could be overcome with survey-type of approaches, e.g. a SWOT-analysis (strengths, weaknesses, opportunities, threats), which may, however, encounter problems with disagreement among the participants on the driving forces for the future scenarios (Alizadeh et al., 2016c). Contrary to the SWOT, the BOCR- method used here allows selecting the factors to be examined. We believe that this new conceptual framework could lead to new knowledge in both decision-making and strategic planning domains in energy.

The number of studies on renewable energy ranking for different countries is ample. For example, Bohanec et al. (2017) used an MCDM method to assess electricity generation resources for Slovenia. (Büyüközkan and Gülleryüz, 2016) used a combined Decision Making Trial and Evaluation Laboratory (DEMATEL) – Analytic Hierarchical Process (ANP) method to choose the best renewable energy option for Turkey. (Amer and Daim, 2011) developed a method to select renewable energy technologies for Pakistan. (Brahim, 2014) developed a method to prioritize renewable energies to enhance energy security in the Philippines. (Wang et al., 2010; Wu et al.,

2018) used a fuzzy MCDM method based on cumulative prospect theory to evaluate renewable energy sources for China. (Lee and Chang, 2018) conducted a comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan. (Kim et al., 2017) evaluated electrical energy storage technologies for renewable energy in the United States. (Choudhary and Shankar, 2012) used a Social, Technological, Economic, Environmental, Political (STEEP) - fuzzy AHP - Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) framework to assess and choose of thermal power plant location for India. Choosing Iran as the case here also involves new information as no prior research exists on prioritizing renewable energy in Iran.

The remainder of this article is structured as follows: the potential and current status of RE in Iran is described in Section 2. In Section 3, brief information about ANP and BOCR is given. The steps of the proposed integrated BOCR–ANP model are explained in Section 4. In Section 5, the new model is applied to prioritize the Iranian RE resource use. Finally, conclusions and future research directions are discussed in Section 6.

2. Status of renewable energy and the energy policy framework in Iran

In this chapter, we will briefly review Iran’s renewable energy potential and its policy framework for RE.

2.1 Renewable energy potential

The potential of major renewable energy sources in Iran is summarized in Table 1. Renewable energy stands for less than 1% of electricity production. Previous studies have shown that the RE potential is significant, but it is still underused, requiring significant investments to capture even

a fraction of the overall potential (Fadai et al., 2011; Ghorashi and Rahimi, 2011; Hosseini et al., 2013). Only 135 MW of wind power is in use, or 0.4% of the total electricity generation (Heidari et al., 2018; Najafi et al., 2015). But a recent study found that about 500 MW of wind power could be added on a commercial basis representing 1.7 % of the national electricity production (Aghahosseini et al., 2018). The overall potential could be in the range 800 MW which could cover 2.5% of the electricity consumption (Morteza et al., 2018; Mostafaeipour et al., 2014).

Hydropower has a total capacity of 45 MW representing 0.14% of all electricity production (Mohammadnejad et al., 2011; Payman et al., 2012). Based on a relatively low price of hydropower (\$0.04/kWh) (EIA, 2017), the Iranian government has planned to increase its role in the future (IME, 2013). The solar radiation resource in Iran is huge, with yearly insolation values of 2200 kWh m⁻², which is twice that of e.g., Central Europe (Alamdari et al., 2013; Khuzani et al., 2018). However, the total installed capacity of photovoltaics is only 100 MW (Alamdari et al., 2013; Khuzani et al., 2018). Geothermal and biomass also present a major potential for Iran's energy mix (Hosseini and Wahid, 2013). Significant sources for biomass include wood, crops, fast-growing trees and grasses, residues from the agriculture or forestry, and municipal and industrial waste (Tabatabaei et al., 2017).

Currently, commercial bioenergy use in Iran is negligible. However, the amount of residues from agriculture and waste streams are considerable, e.g., estimated biomass waste from agriculture is 8.78 Mton, animal waste 7.7Mton, and municipal solid waste (MSW) 3 Mton a year (BP, 2017). Although around 30% of the overall land could potentially be used for cultivation, the need for irrigation would be considerably restricting the use of "active" biomass crops for biofuels and

bioenergy (Afshar et al., 2012). These feedstocks could be used for biogas production (Hosseini et al., 2013). Also, organic waste materials would be adequate to produce 3 billion liters of bioethanol, which corresponds to 12% of the Iranian gasoline use (Najafi et al., 2009; Najafi et al., 2011). Future biomass sources could include algae and cellulosic materials to produce biodiesel (Najafi et al., 2011). Iran has a considerable geothermal resource as the country is located on the geothermal belt (Noorollahi et al., 2009). There is only one geothermal plant in use (55 MW), with plans to quadruple the capacity in the coming years (Porkhial, 2015; Yousefi et al., 2010). Also, 9% of Iran's surface area could be used to generate geothermal energy (Najafi et al., 2011). Table 1 summarizes the RE potential in electricity generation based on investment projections.

Table 1

Renewable energy potential for electricity generation in Iran. (BP, 2016; IEA, 2015, 2017b; IHA, 2016; IRENA, 2017; SATBA, 2018).

RE Type	Capacity and Production	Present use	Under construction	Total projected by 2025
Wind	Capacity (MW)	118-135	489-547	830-870
	Gross prod (GWh/yr)	1122-1206	-	-
	Share of total electricity generation (%)	0.40-0.43	-	-
Solar	Capacity (MW)	105-115	67-72	670-720
	Gross prod (GWh/yr)	982-1094	-	-
	Share of total electricity generation (%)	0.35-0.39	-	-
Hydropower	Capacity (MW)	40-45	55-65	120-230
	Gross prod (GWh/yr)	337-421	-	-
	Share of total electricity generation (%)	0.12-0.15	-	-

RE Type	Capacity and Production	Present use	Under construction	Total projected by 2025
Biomass	Capacity (MW)	11-13	19.48-21.5	100-180
	Gross prod (GWh/yr)	28 -56	-	-
	Share of total electricity generation (%)	0.01-0.02	-	-
Geothermal	Capacity (MW)	10-15	-	80-100
	Gross prod (GWh/yr)	28-53	-	-
	Share of total electricity generation (%)	0.01-0.02	-	-
Percentage of total electricity generation		0.99	-	15

2.2 Policy-making framework for renewable energy

Iran has set goals in its 4th national development plan for increasing renewable energy deployment, which represents close to 1% of the country's electricity production, as shown in Table 1. The focus of this plan is on wind and geothermal power. The long-term vision is to produce 10% of the electricity from renewable energy by 2025. However, the RE policies have not been effective, as less than 40% of the RE goals set have been reached (PSSD, 2010). To speed-up the RE uptake, the Iranian government issued a Feed-in-Tariff, which increased the private sector investments, in particular in wind power (Du et al., 2018; Nejat et al., 2013). This policy increased the share of wind power up to about 0.4% of the total electricity generation.

Moreover, in the sixth 5-year development plan, the Iranian government imposed new legislation to raise the non-governmental investments in renewable and clean power plants to at least five percent of the country's power capacity until the year 2021. The administrative and policy-making structure in renewable energy is illustrated in Fig. 1. The Renewable Energy Initiative

Council (REIC) and Renewable Energy Organization of Iran (SUNA) are the two leading administrative and policy-making organizations engaged in RE. Along with the Ministry of Energy, SUNA was created as an upholder in 1995. In addition to contributing to the national renewable energy policies, SUNA identifies research priorities, initiates enabling projects such as developing the RE map for Iran, and accomplishes decision-making on projects such as rural off-grid PV networks. To increase the involvement of the private sector in RE and to improve technology adoption capabilities of RE in Iran (SUNA, 2010), SUNA also tracks technology advances, among others.

In mid-2008, another institution, the Iran Renewable Energy Initiative Council (REIC) was established under the Research Institute of Petroleum Industry (RIPI), in the Presidential Department of Science and Technology as a national-level hub with the mission of organizing and accelerating the efforts in RE. Key institutions, ministries (Ministry of Science, Ministry of Energy, Ministry of Industries, Ministry of Petroleum), and administrative bodies also take part in the REIC.

Fig. 1. Institutions and ministries engaged in the REIC structure (Fadai et al., 2011).

REIC aims to combine and support the dispersed efforts in RE by the engaged entities. Stimulating financial and human resources, avoiding parallel activities, clarifying the activities in the RE-related institutions, and commercializing research in this area are important goals for this council.

3. Review of decision-making methods and criteria in energy planning

Before presenting the methodology used in this study, we present a short review of decision-making methods and criteria to better understand their strengths and weaknesses in the RE planning and policy context.

3.1. Decision-making methods for energy policy

Multi-Criteria Decision Making (MCDM) techniques are popular in energy policy-making and sustainable energy management, including renewable energy planning and energy resource allocation (Kumar et al., 2017). MCDM can provide solutions to problems, including conflicting criteria and multiple objectives in energy planning decisions. MCDM employs different techniques such as weighted averages (Ghosh et al., 2016), weighted sums (Bohanec et al., 2017), priority setting (Greening and Bernow, 2004), outranking (Azzopardi et al., 2013; Roulet et al., 2002), fuzzy principles (Onar et al., 2015), and their combinations. MCDM methods such as the Analytic Hierarchical Process (AHP) (Genest and Rivest, 1994; Saaty, 1980; Tzeng et al., 1992), the Analytic Network Process (ANP) (Aragonés-Beltrán et al., 2010; Cannemi et al., 2014; Köne and Büke, 2007; Soltanisehat and Alla, 2018; Yeh and Huang, 2014), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Ervural et al., 2018; Hwang and Yoon, 1981; Şengül et al., 2015; Yoon, 1980), VišeKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Büyüközkan and Karabulut, 2017; Opricovic, 1998; San Cristóbal, 2011), the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) (Behzadian et al., 2010; Brans et al., 1986; Mardani et al., 2015; Vasić, 2018), the Step-wise Weight Assessment Ratio Analysis Method (SWARA) (Keršulienė et al., 2010; Vafaeipour et al., 2014; Zolfani and Saparauskas, 2013), Simple Additive Weighting (SAW) (MacCrimmon, 1968), Simple Multi-Attribute Rating Technique (SMART) (Edwards, 1971), SMARTS and SMARTER (Edwards and Barron, 1994), Weighted Sum Model (WSM) (Fishburn, 1967), Weighted Aggregated Sum Product Assessment (WASPAS) (Keršulienė and Turskis, 2014; Zavadskas et al., 2015; Zavadskas et al., 2012), Additive Ratio Assessment (ARAS) method (Zavadskas and Turskis, 2010), Decision Making Trial and Evaluation Laboratory (DEMATEL) (Fontela and Gabus, 1976), Data Envelopment Analysis (DEA) (Charnes et

al., 1978; Kaleibari et al., 2016), hybrids of methods (Kabak and Dağdeviren, 2014; Kahraman et al., 2009), and their different extensions and modifications (Turskis et al., 2019a; Turskis et al., 2019b) have been used within the energy sector analyses. Also, the applicability of different MCDM techniques has widely been investigated for prioritizing renewable energy sources (Kumar et al., 2017; Pohekar and Ramachandran, 2004; Sabzi and King, 2015a; Wang et al., 2009; Zamani-Sabzi et al., 2016; Zamani Sabzi et al., 2018).

Modern stakeholders implement projects in a highly dynamic environment (Lehtinen et al., 2019). Stricter sustainability concerns require new energy development projects (Medineckiene et al., 2015), better technologies (Ruzgys et al., 2014; Štreimikienė et al., 2016) and materials (Ali et al., 2017), high-skilled personnel (Keršulienė and Turskis, 2014) and contractors (Hashemi et al., 2018), and infrastructure to implement these plans globally (Turskis et al., 2015). These problems are multi-faceted and they involve risks both in local and international markets. Each of the criteria has a different impact on the solutions. Therefore, multi-criteria optimization methods could be useful to find optimal solutions (Beynaghi et al., 2019; Sabzi and King, 2015b; Sabzi and King, 2015c; Zavadskas et al., 2016a; Zavadskas et al., 2016b).

MCDM comprises four stages: criteria selection, weighting, decision evaluation, and aggregation. Each stage can deploy different methods based on the aim and the definition of the problem. In the decision-making process of sustainable energy supply, there are four categories of decision-making criteria: Technical, economic, environmental, and social criteria. Several of these criteria may be conflicting, which makes the decision-making processes in energy planning increasingly complex. Considering uncertainties adds further to the complexity, which could be addressed

with fuzzy multi-criteria decision-making approaches. These have also been used with renewable energy systems (Suganthi et al., 2015), including e.g. the Fuzzy AHP (Heo et al., 2010), the Fuzzy Axiomatic Design (Fadai et al., 2011; Kahraman et al., 2009), the Fuzzy TOPSIS (Kaya and Kahraman, 2011), hybrid fuzzy multi-criteria decision-making framework with picture fuzzy information (Wang et al., 2009), linguistic intuitionistic fuzzy numbers (Peng and Wang, 2017) and the Fuzzy MCDM (Torfi et al., 2010; Zamani Sabzi et al., 2016).

It should be noted that the way the criteria in MCDM are weighted may also affect the outcome. For example, while a study using the Fuzzy TOPSIS method resulted in prioritizing hydro as the best renewable energy technology in Turkey (Şengül et al., 2015), other studies employing hybrid AHP (Demirtas, 2013) and ANP-Decision Making Trial and Evaluation Laboratory (DEMATEL) (Büyüközkan and Gülleryüz, 2016) resulted in wind power as the best choice. Amer and Daim proposed an MCDM approach to select renewable energy technologies for sustainable development in Pakistan (Amer and Daim, 2011). Ulutas determined the appropriate energy policy for Turkey (Ulutaş, 2005). Table 2 shows a summary of the MCDM methods used based on the literature review. ANP seems to be the most popular method in sustainable energy decision processes in case of multiple conflicting criteria. Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) (Behzadian et al., 2010; Brans and Mareschal, 2005; Brans and Vincke, 1985; Brans et al., 1984; Brans et al., 1986; Soltanisehat et al., 2019; Vasić, 2018), Weighted Product Model (WPM) (Bridgman, 1922; Miller and Starr, 1969), and Elimination and Choice Expressing Reality (ELECTRE) methods (Hashemi et al., 2016; Kumar et al., 2017; Peng et al., 2019; Roy, 1968) are the next popular methods.

Table 2

Literature review on MCDM methods for prioritization of renewable energy.

Reference	AHP	ANP	DEMATEL	VIKOR	TOPSIS	SWARA	Fuzzy	PROMETHEE	ELECTRE	Hybrid
Amer and Daim, 2011	x									
Büyüközkan and Güleriyüz, 2016		x	x							
Cheng, 1997	x						x			
Demirtas, 2013	x									
Heo et al., 2010	x						x			
Kabak and Dağdeviren, 2014		x								x
Kahraman et al., 2009		x								x
Kumar et al., 2017									x	
Vasić, 2018								x		
Kaya and Kahraman, 2011					x		x			
Köne and Büke, 2007		x								
Brans and Vincke, 1985								x		
Behzadian et al., 2010								x		
San Cristóbal, 2011	x			x						
Hashemi et al., 2016									x	
Şengül et al., 2015					x		x			
Ulutaş, 2005		x								
Vafaeipour et al., 2014						x				
Zolfani and Saparauskas, 2013						x				
Brans, et al., 1986								x		
Brans and Mareschal, 2005								x		
Peng et al., 2019									x	
Wang et al., 2018							x			
Peng and Wang, 2017							x			

3.2 Decision-making criteria

The criteria used in the decision-making process creates an essential part of the decision-making framework and process. For example, the Iranian energy policy has been subjected to numerous studies, in which different criteria have been applied. In Table 3, results from reviewing several studies are summarized. Here we have listed the criteria under BOCR elements and strategically important factors.

A notable finding of this review is that the framework for decision-making in renewable energy policy in Iran seems to be incomplete. Strategic and policy analysis in decision making in renewable energy resources is not strong. Areas which have previously been studied include forecasting of electrical energy consumption (Azadeh et al., 2008), energy supply planning and uncertainties of investment costs (Sadeghi and Hosseini, 2006), sustainability of energy production and use (Karbassi et al., 2007), energy price policies for optimal use of CHP and CCHP systems (Tichi et al., 2010), energy consumption and economic growth (Mehrra, 2007; R Alizadeh, 2014), relationship between economic growth, CO₂ emissions, and fossil fuels consumption (Kotcioğlu, 2011; Lau et al., 2012; Lotfalipour et al., 2010; Omer, 2008; UNCED, 2013), production and consumption policy in oil and gas sector (Kiani and Pourfakhraei, 2010), energy price reform on households' consumption (Moshiri, 2015), feed-in tariff policy (Tabatabaei et al., 2017), climate-friendly technology transfer (Talaie et al., 2014), prioritization of alternatives for energy investments (Alipour et al., 2017), energy and sustainability (Arent et al., 2011; Keleş and Bilgen, 2012; Şekercioğlu and Yılmaz, 2012). Regional prioritizing of solar power plants (Vafaeipour et al., 2014), biomass-to-energy projects (Zolfani and Saparauskas,

2013), among others. Some authors used an energy mix optimization approach from an energy security perspective (Augutis et al., 2015; Brahim, 2014; Eaves and Eaves, 2007; EC, 2013; Escribano Francés et al., 2013; Gyamfi et al., 2015; Johansson, 2013; Martchamadol and Kumar, 2012; Mathews, 2014; Valentine, 2011). Each of these studies touched on a specific sector of energy and used different criteria, as shown in Table 3. However, none of these studies considered all criteria together, i.e., benefits, opportunities, costs, risks, technology, economy, security, global effects, human wellbeing, and energy vulnerability. In this paper, this gap will be addressed, and all these criteria are considered simultaneously.

Table 3

Literature review criteria in renewable energy policy making in Iran.

Source	BOCR Elements				Strategic Criteria					
	Benefit	Opportunity	Cost	Risk	Technology	Economy	Security	Global effect	Human wellbeing	Energy vulnerability
Azadeh et al., 2008			x			x	x			
Sadeghi & Hosseini, 2006			x		x	x			x	
A. R. Karbassi, Abdul, & Mahin Abdollahzadeh, 2007	x	x	x			x		x	x	
Tichi, Ardehali, & Nazari, 2010			x		x	x		x	x	
Mehrara, 2007			x	x		x	x			
Lotfalipour, Falahi, & Ashena, 2010			x	x	x	x		x	x	
Kiani & Pourfakhraei, 2010					x	x	x			x
Moshiri, 2015	x	x		x						
S. M. Tabatabaei, Hadian, Marzban, & Zibaei, 2017		x		x		x	x	x	x	

Source	BOCR Elements				Strategic Criteria					
	Benefit	Opportunity	Cost	Risk	Technology	Economy	Security	Global effect	Human wellbeing	Energy vulnerability
Talaei, Ahadi, & Maghsoudy, 2014					x	x	x	x	x	
Alipour, Alighaleh, Hafezi, & Omranievardi, 2017					x	x	x	x	x	
Vafaeipour et al., 2014				x	x	x		x	x	
Zolfani & Šaparauskas, 2013	x			x	x	x				
Hosseini et al., 2013			x		x	x			x	
Köne and Büke, 2007	x	x		x	x					
Mostafaeipour and Mostafaeipour, 2009					x	x	x		x	
Popp et al., 2011		x		x	x					
Mundaca and Luth Richter, 2015						x		x	x	
Ulutaş, 2005						x		x	x	
Augutis et al., 2015			x			x	x	x		
Brahim, 2014					x			x	x	
Eaves and Eaves, 2007						x	x	x		
EC, 2013						x	x	x	x	
Escribano Francés et al., 2013							x	x		x
Gyamfi et al., 2015			x				x			x
Johansson, 2013							x	x		
Martchamadol and Kumar, 2012			x		x	x				
Mathews, 2014	x					x		x		
Şekercioğlu and Yılmaz, 2012		x				x			x	
Valentine, 2011			x			x				x

Source	BOCR Elements				Strategic Criteria					
	Benefit	Opportunity	Cost	Risk	Technology	Economy	Security	Global effect	Human wellbeing	Energy vulnerability
Arent et al., 2011	x				x			x		
Keleş and Bilgen, 2012		x			x			x	x	x
Lau et al., 2012				x				x	x	
Wang et al., 2014	x				x			x		
Kotcioğlu, 2011				x		x		x	x	
Omer, 2008		x		x			x		x	
UNCED, 2013	x		x				x	x	x	
Gnansounou, 2008	x			x		x				x
Gupta, 2008		x	x					x		x
Schaeffer et al., 2012	x				x					x
WEC, 2007				x	x					x

4. Methodology

When including multiple decision-makers, multiple interrelated criteria, and uncertainties, the complexity of the decision process will further increase. Hence, in this paper, we choose the ANP method to evaluate the best policy for renewable energy planning. The most important benefit of ANP for our purpose is in its capability to successfully handle dependencies among decision-making criteria. The ANP model is here extended to a hybrid model based on BOCR and ANP. First, the BOCR analysis is used to determine Iran's energy status and the RE evaluation criteria.

Then the ANP analysis is applied to prioritize the renewable energy sources against the chosen criteria.

4.1. Analytic network process method

The ANP model is a multi-criteria decision-making technique introduced by Saaty (Saaty, 1996); Saaty (2004). It is a generalization of the AHP method (Saaty, 1980), which calculates the priority scales without making any assumption about the relationships between elements. Compared to the AHP technique, which considers a hierarchical structure of a problem's elements, ANP considers the interaction and interdependence of elements (clusters and nodes within a cluster) inside a network of criteria.

In the AHP, paired comparisons are made with judgments using numerical values taken from the AHP absolute fundamental scale of 1 to 9. A scale of relative values is derived from all these paired comparisons. It also belongs to an absolute scale that is invariant under the identity transformation, like the system of real numbers (Table 4). The AHP is a particular case or subset of the Analytic Network Process (ANP), which uses a network structure that allows dependence and feedback instead of a hierarchy. The software package Super Decisions enables users to implement the AHP/ANP quickly in decision-making. It can be downloaded from creativdecisions.net (Mu and Pereyra-Rojas, 2016). The ANP has compelling predictive content, demonstrated by several examples. The judgment shows the relative importance or relative influence of one of two elements over the other in a pairwise comparison concerning a third element/underlying control criterion. Since ANP considers all feedbacks and interaction among

the decision criteria, it has become more demanding for solving complex decision problems than the simple hierarchy methods (Saaty, 2004).

Table 4

Saaty's numerical scales (Saaty, 2004).

Intensity of importance	Definition	Definition
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one over another
5	Strong importance	Experience and judgment strongly favor one over another
7	Very strong importance	Activity is strongly favored, and its dominance is demonstrated in practice
9	Absolute importance	Importance of one over another affirmed on the highest possible order
2,4,6,8	Intermediate values	Used to represent a compromise between the priorities listed above
Reciprocal of above non-zero numbers		If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value compared with activity i

4.2. Benefits, Opportunities, Costs, Risks Analysis (BOCR) method

One of the challenges in using the ANP method is determining the criteria and sub-criteria for the case that has not completely been investigated, or for a case that decision-makers cannot come to an agreement for. To overcome these issues, different analytical methods such as BOCR and SWOT, which clarify the effectiveness of the alternatives in supporting or rejecting the decision maker's goals, can be used (Tchangani, 2015). Although ANP allows assessing the impact and interdependence, sometimes it is not fully comprehensible to decision-makers. Therefore, the

BOCR can help to get a better understanding of the effects by studying the elements in cause and effect relationships.

Combining the ANP and BOCR analysis has various applications in which a network model with one or more networks for each of the four BOCR factors is set up instead of a hierarchy. In the BOCR analysis method, the benefits-criterion refers to current revenues or profits gained from increasing renewable energy use. The opportunity-criterion is defined as the expectations about positive spin-offs, future profits, or revenues earned from future increases in renewable energy use. Finally, the risk-criterion refers to the expected consequences of increasing the use of renewable energy, while the cost-criterion represents the current losses and consequent negative development. Considering these four main elements, the BOCR will enable a potentially rich analysis of the alternatives (Wijnmalen, 2007).

In the BOCR analysis, alternatives are ranked based on the highest (best) to the lowest (worst) value under two criteria Benefits and Opportunity. while for the Cost and Risk criteria, the highest valued alternative is the worst one in the ranking. Therefore, the analysis needs to address the question, “How does this worst alternative for costs and risks impact the strategic criteria?”. According to (Wijnmalen, 2007), there are five methods to determine alternatives priorities under the BOCR factors. Table 5 shows the five methods of calculation formulas. B , O , C , and R are the synthesized weights of each alternative i under the merit BOCR factors; b , o , c and r are the normalized weights of each factor of BOCR. The additive formula is the best for long-term results, and the multiplicative formula is equivalent to the marginal cost/benefit and the best for short-term results (BO/CR).

Table 5

BOCR weight calculation formulas.

Analysis Method	Formula
Additive	$bB_i + oO_i + c(1/C_i)_{Normalized} + r(1/R_i)_{Normalized}$
Probabilistic additive	$bB_i + oO_i + c(1 - C_i) + r(1 - R_i)$
Subtractive	$bB_i + oO_i + cC_i - rR_i$
Multiplicative priority powers	$B_i^b O_i^o [1/C_{iNormalized}]^c [1/R_{iNormalized}]^r$
Multiplicative	$B_i O_i / C_i R_i$

4.3. Proposed integrated model

The proposed decision-making process consists of seven steps. Fig. 2 presents the general conceptual framework of the proposed approach. This approach is applied to prioritize renewable energy resources and to formulate policies on optimizing social and economic benefits.

Fig. 2. Conceptual framework of the proposed decision-making process.

5. Results and discussion

In this section, we go step-by-step through the proposed method in Fig. 2 and provide the results and related discussion accordingly.

5.1. Setting up the expert team of decision-makers (Step 1)

Academic fellows of top Iranian universities such as the Amirkabir University of Technology, Sharif University of Technology, and experts from the Ministry of Petroleum, electricity generation sector, and the Department of Environment participated in the expert panel. Altogether twelve experts contributed to the exercise, including diverse disciplines such as economics and management, energy systems, environmental engineering, science and technology policy, and technology foresight. The background of the experts is shown in Table 6. All experts contributed to all stages of our research in which expert judgment was needed.

Table 6

Background information on participators in the expert panel.

Category	Classification	Number
Working background	Environmental engineering	2
	Energy systems engineering	3
	Economics and management	3
	Technology foresight	2
	Science and technology policy	2
Educational level	Master-level	2
	Ph.D.	10
Sex	Male	7
	Female	5

5.2. Determining the hierarchical structure of the problem including goals, strategic criteria, alternatives (Step 2)

In the control hierarchy, the goal is on the first level, followed by the strategic criteria and BOCR (level 2), and its subnetwork (level 3) (see Fig. 3). The goal-level of the hierarchy structure of the decision problem in this research is in prioritizing renewable energy alternatives in Iran. Six criteria are considered for evaluating different alternatives with respect to the goal of the problem and every four criteria of BOCR. Based on the literature in Table 2, the expert team defined the main criteria as follows: Technology (Tech), Economy (Econ), Security (Sec), Global Effect (GE), and Human Wellbeing (HW). Each element of the BOCR analysis had a subnetwork, which represents the relationship of its clusters and elements.

The dependency between the criteria, BOCR sub-criteria, and the subnetwork is shown in Fig. 3. The symbols L_i demonstrates the levels of the hierarchy structure. The one-way arrows show a one-way dependency between two levels and the curved arrow over the BOCR subnetwork shows the feedback inside the network of sub-criteria clusters. Subnetwork benefits include the utilization of native resources, protection of the environment, development of allied industries, and pursuing international commitments such as the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol (Alizadeh et al., 2016c; Alizadeh et al., 2015b). Subnetwork opportunities comprise developing alternative environmentally friendly resources, job creation, and reduction in energy prices. Subnetwork costs include investment costs, operation costs, maintenance costs, land use, and ecological damage. Finally, the risks subnetwork includes a dependency on foreign technology, lack of a financial mechanism to

endeavor RE development, insufficient technological infrastructures, instability of energy resource, lack of public awareness about RE, business failure. Each subnetwork connects to the cluster of alternatives: Hydro, geothermal, solar, wind, biomass.

Fig. 3. The hierarchical structure of ANP.

The first strategic criterion, technology (Tech), includes the technical feasibility and reliability, as well as the continuity and predictability of the local agents' performance, and local technical know-how (a key factor for success in the current global marketplace) (Hosseini et al., 2013; Köne and Büke, 2007; Mostafaeipour and Mostafaeipour, 2009; Mundaca and Luth Richter, 2015; Popp

et al., 2011). The economy criterion (Econ) is defined as the economic value of sources, the implementation cost of the projects, and the availability of national funds (Kabak and Dağdeviren, 2014).

The effects of RE can be felt regionally and globally. RE, which is often displaced fossil-fuel-based energy, can contribute to improving air quality, reducing greenhouse gas emissions, and acid rain (Kabak and Dağdeviren, 2014). The rapidly increasing anthropogenic greenhouse gas emissions have caused observable changes in the climate, i.e., a global effect (GE). Without concerted action by the global community, the CO₂ levels could increase by 130% by the mid-century resulting in large-scale climate changes. Stabilization of the CO₂ levels will require replacing fossil fuels with emission-free sources in the immediate future (Mathews, 2014).

The human well-being (HW) criterion is one of the main elements of sustainable development (Anand and Sen, 2000). Human beings are at the center of sustainable development (UNCED, 2013). Deploying renewable energy resources will enhance economic development by e.g., creating new business opportunities and raising the living standard, but also by providing a healthier environment through better air quality and reduced climate impacts (Kabak and Dağdeviren, 2014). (Mu et al., 2018) used a computable general equilibrium (CGE) to quantify the full scope of job changes (direct, indirect and, induced) brought by renewable energy development in China. Their results show each TWh expansion of solar PV and wind power could create up to 45100 and 15800 direct and indirect jobs in China, respectively (Mu et al., 2018). Also, (Bulavskaya and Reynès, 2018) analyzed the economic impact of a transition towards renewable electricity mix in the Netherlands in terms of key economic variables (GDP,

employment, investment, value-added, prices, trade, tax revenue, etc.). They found that the transition to renewable energy may have a positive impact on the Dutch economy, creating almost 50000 new jobs by 2030 and adding almost 1% to the gross domestic product. (Haseeb et al., 2018) used annual data over the period of 1980–2016 to confirm that there is a positive short- and long-term connection between renewable energy and economic well-being in Malaysia. There are other studies which have found positive impacts of renewable energy development on job creation (Akuru et al., 2017; Bhattacharya et al., 2016; Connolly et al., 2016; Dvořák et al., 2017; Garrett-Peltier, 2017; Jacobson et al., 2017; Jacobson et al., 2015; Loomis et al., 2016; Sooriyaarachchi et al., 2015).

Energy security (Sec) describes energy system functionality against major interruptions in energy supply or price effects. Energy security comprises both the security of supply and security of demand (Johansson, 2013). The security of supply focuses on energy consumers and on balance between supply and demand. Whereas the security of demand focuses on resource availability, import dependency, supplier reliability, diversity in energy resources, secure transit routes, and infrastructure reliability. Renewable energy systems will improve some aspects of energy security because of good resource availability and spread. However, renewable energy systems enface other types of issues, such as dependence on advanced technologies.

The energy vulnerability (EV) factor can be defined as the degree to which the system is unable to cope with selected adverse events. As it is not always possible to identify all such events, some criteria need to be defined to select the relevant contingencies (e.g., likelihood, criticality, and

damages). The requirement of constant supply is one of the major causes of vulnerability (Gnansounou, 2008; Gupta, 2008; Schaeffer et al., 2012; Wang et al., 2014; WEC, 2007).

The criteria chosen here for the BOCR represent high-level decision-making criteria for energy and climate policy planning. These criteria could be refined by including sub-level criteria, e.g., under risk issues such as particulate emissions for fuels or recycling issues of energy technologies could be included. However, such sub-level criteria analysis was outside the scope of the present study.

5.3. Determining the weights of the strategic criteria with respect to the goals (Step 3)

After determining the hierarchy structure of the problem and required connections between the levels and between the subnetworks, experts will compare the strategic criteria with respect to the GOAL of prioritizing the best renewable energy alternatives. The weights of the strategic criteria are determined through a pairwise comparison matrix using the geometric average. For the pairwise comparison, we use Saaty's 1-9 scales according to the preference degree of one criterion against the other criteria. The super decision software (Saaty, 1996), which is the only free educational software to implement AHP and ANP developed by the team of the creator of the method, Thomas Saaty, is used to calculate the inconsistency rate (IR) for each comparison table. The inconsistency rate (IR) shows the errors and inconsistencies in the judgment and it will ensure the logic of the comparison. For instance, if A is preferable to B and B is preferable to C, then A should be preferable to C. Because of the complex political and economic situations often encountered in energy decisions and because of the wide range of judgments in energy policy,

we accept here a 15% inconsistency in the judgments during the pairwise comparison. If the inconsistency rate exceeds this level, the subjective judgments need to be revised.

5.4. Determining the weights of the BOCR with respect to the criteria (Step 4)

The next step involves determining the weights of the BOCR-factors. The expert team will evaluate the weights of the four elements of the BOCR. In order to compare the mutual importance of the BOCR elements, linguistic variables proposed by (Cheng, 1997) are used. The membership function of the linguistic variables is shown in Fig. 4 and the average number assigned to each variable is in Table 7.

Fig. 4. Membership function for linguistic variables.

Table 7

Average number for linguistic values.

Linguistic values	Average numbers
Very high (VH)	1
High (H)	0.75
Medium (M)	0.5
Low (L)	0.25
Very low (VL)	0

After assigning the numeric values to the linguistic judgments, the weights of each BOCR-factor are calculated using an arithmetic average. The results are shown in Table 8. To calculate the

weight of each factor, the values for each factor should be multiplied by the weight of the strategic criteria. By normalizing the result of this operation, the final weight of the BOCR-factors will be determined. The results shown in Table 8, indicate that the weights of the BOCR-factors fall between 0.2 and 0.3.

Table 8

The BOCR weights.

	Tech	Econ	Sec	GE	HW	EV	Weight
	0.4318	0.2556	0.0949	0.0401	0.0382	0.1393	
Benefit	0.85	0.70	0.40	1.00	0.75	0.60	0.30
Opportunity	0.80	0.50	0.65	0.80	0.75	0.65	0.20
Cost	0.60	0.40	0.30	0.40	0.55	0.60	0.29
Risk	0.45	0.75	0.45	0.35	0.40	0.45	0.20

5.5. *Determining the weights of the BOCR sub-network (Step 5)*

The weights of the BOCR sub-network are determined by a pairwise comparison matrix completed by the expert team. By taking a geometric average of the comparison results, the ‘supermatrix’ of the relative weights is formed. Finally, the weights of each item in the sub-network is determined by the super decision software (Saaty, 1996). The final weights of the BOCR sub-network are shown in Table 9, which indicates that the “Development of allied industries” among Benefits, “Job creation” among opportunities, “Land use” among costs and “Insufficient technological infrastructures” among risks are the most important subcriteria.

Table 9

BOCR sub-network weights.

BOCR		Sub-criteria	Final relative weights
Benefit	B1	Utilization of native resources	0.24
	B2	Protection of the environment	0.13
	B3	Development of allied industries	0.60
	B4	Pursuing international commitments such as UNFCCC and Kyoto Protocol	0.04
Opportunity	O1	Developing alternative environmentally - friendly resources	0.17
	O2	Job creation	0.58
	O3	Reduction in energy prices	0.25
Cost	C1	Investment costs	0.20
	C2	Operation costs	0.25
	C3	Maintenance costs	0.16
	C4	Land use	0.28
	C5	Ecological damage	0.11
Risk	R1	Dependency on foreign technology	0.08
	R2	Lack of a financial mechanism to endeavor RE development (e.g., governmental funds, foreign and domestic investments)	0.30
	R3	Insufficient technological infrastructures	0.25
	R4	Instability of energy resource	0.11
	R5	Lack of public awareness about RE	0.13
	R6	Business failure due to technological obsolescence, insufficient access to capital, the high price of generated	0.14

5.6. *Prioritization of the alternatives (Step 6)*

In the final step, the priorities of the renewable resources are determined. The pairwise comparison will determine the priority of the alternatives with respect to each factor in the BOCR

sub-network. There are 18 factors in BOCR sub-network, and therefore 18 comparison matrices will be built. For instance, Fig. 5 shows the result of comparing the alternatives with respect to B1 (Utilization of native resources). After calculating the geometric average from the comparison matrix, the weights of the alternatives will be determined. The result in Fig. 5 shows that solar energy has the highest benefits in utilizing native resources in Iran.

The quality of the comparison matrix and the output of the ANP depends largely on the consistency of the pairwise comparison. The Consistency Ratio (CR) (Goto et al.) is an index that measures the consistency of the subjective inputs in the pairwise comparison matrix. Much research has been done to define a standard CR measure in AHP and ANP methods (Mazurek and Perzina, 2017; Son, 2014). According to the literature, allowable CR should be less than or equal to a threshold, that depends on the size of the comparison matrix and on the pairwise comparison process (individual or group judgments). Following this concept, if CR is more than the allowable threshold then we can define the inconsistency concept as the adjustment needed to improve the consistency level in the comparison. This adjustment should not be too large ($< 10\%$), and it should not be too low (1%), which would not have any consequences (Saaty and Vargas, 2006). The inconsistency is an important index that provides new knowledge about the preferences' change (Saaty, 2008). The Superdecision software gives the inconsistency ratio for each comparison matrix (Mu and Pereyra-Rojas, 2016). In most of our comparison matrices, the inconsistency is less than 0.05, which is acceptable considering the scale of our problem.

Fig. 5. Example of comparison of alternatives. Here the comparison is done with respect to the utilization of native resources (B1).

By aggregating all 18 comparisons results in the final prioritization, the final ranking is calculated for different formulas of the BOCR analysis. The results showed in Table 6. Table 10 also, shows the prioritization results based on the standard formulas in the BOCR analysis. In all formula calculations, “Solar” receives the highest priority as the renewable energy source for substituting the current fossil fuels. The wind is the second-best alternative, nuclear and geothermal are the least preferred options.

Table 10

Prioritization of alternatives.

Energy Source	Additive		Probabilistic		Subtractive		Multiplicative		Multiplicative	
	additive						priority powers			
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Biomass	3.54	2	0.44	3	0.08	5	0.32	4	0.08	3
Geothermal	2.55	5	0.38	5	0.02	4	0.34	3	0.02	5
Hydro	2.90	4	0.41	4	0.08	6	0.25	5	0.03	4
Nuclear	2.29	6	0.38	6	0.11	3	0.22	6	0.02	6
Solar	3.58	1	0.53	1	0.17	1	0.50	1	0.33	1

Energy Source	Additive		Probabilistic additive		Subtractive		Multiplicative priority powers		Multiplicative	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Wind	2.65	3	0.48	2	0.14	2	0.41	2	0.12	2

As shown in Table 10, solar and wind have the highest priority among the six alternatives which were chosen for this study. According to the IEA/IRENA joint policies and measures database (IEA, 2018a), there are many important policies in Iran, which support our results. For example, in the 6th 5-year development plan, it supports strategic planning, economic instruments, and market-based instruments in the electricity sector with a focus on solar and wind power (IEA, 2018b). Another example is the law, which endorses supplying 20% of the electricity consumed from renewable sources. The law states that ministries, governmental entities, and non-governmental institutes need to provide 20 % of the electricity of their buildings from renewable sources by 2020. The Ministry of Energy will set appropriate tariffs to support the law, including feed-in tariffs for solar and wind power (IEA, 2018a). In another policy act, the government supports private and cooperative sectors by using managed funds and loan interest subsidies to pave the way for installing of 5000 MW wind and solar power (IEA, 2018b). Also, other policies supporting renewables have recently been established (See Supplementary information).

5.7. Sensitivity analysis and policy consequences (Step 7)

Several external effects or subjective opinions affect final decision making in energy (Ozdemir and Saaty, 2006). Sensitivity analysis helps to better understand different situations and their impact on the final decision. In the case of MCDM, the sensitivity analysis often examines how changes in the weights of the criteria and scoring may affect the overall ranking of the

alternatives (Chatzimouratidis and Pilavachi, 2008). Sensitivity analysis may also be linked to different “what-if”-a type of scenario (Syamsuddin, 2013). According to Wolters and Mareschal (1995) there are three types of sensitivity analysis for MCDM methods: 1) the sensitivity of the final ranking to specific changes in the evaluations of all alternatives on certain criteria, 2) the sensitivity of the final ranking to the particular changes in the scores of particular alternative on certain criteria, and 3) the minimum modification of the weights required to make a specific alternative ranked first. The first two methods are appropriate methods in dynamic circumstances, and the third one can be a tool to analyze the total weight space.

In the BOCR sensitivity analysis, we have considered the negative additive prioritization method (multiplicative formula). The weights of B, C, and R are the same for each alternative and will be ineffective in the sensitivity analysis. The ranking range is shown in Fig. 6 for each main criterion of BOCR. As solar and wind power has the highest-ranking against the four criteria, the combination of the four rankings will also put solar and wind as the best renewable energy options for Iran.

Name		Ideals	Normalized	Raw
Biomass		0.34	0.09	0.08
Geothermal		0.47	0.13	0.11
Hydro		0.33	0.09	0.08
Nuclear		1.00	0.27	0.24
Solar		0.75	0.20	0.18
Wind		0.78	0.21	0.19

6.a) Benefit Ranking

Name		Ideals	Normalized	Raw
Biomass		1.00	0.22	0.20
Geothermal		1.00	0.22	0.20
Hydro		0.60	0.13	0.12
Nuclear		0.31	0.07	0.06
Solar		0.99	0.22	0.2
Wind		0.63	0.14	0.13

6.b) Cost Ranking

Name		Ideals	Normalized	Raw
Biomass		0.53	0.14	0.12
Geothermal		0.43	0.11	0.10
Hydro		0.52	0.13	0.12
Nuclear		0.55	0.14	0.13
Solar		1.00	0.26	0.23
Wind		0.88	0.22	0.21

6.c) Opportunity Ranking

Name		Ideals	Normalized	Raw
Biomass		0.98	0.20	0.19
Geothermal		0.36	0.07	0.07
Hydro		1.00	0.20	0.19
Nuclear		0.96	0.19	0.18
Solar		0.90	0.18	0.17
Wind		0.77	0.16	0.15

6.d) Risk Ranking

Fig. 6. Alternatives prioritization in each BOCR criteria (SuperDecision Software Output)

In this paper, we focus on the first category of sensitivity analysis. Fig. 7 shows the sensitivity of the final ranking to specific changes in the evaluations of all alternatives on certain criteria. The y-axis shows the final weights of the alternatives, and the x-axis shows the weight range of the BOCR criteria. We found that the outcome for the solar ranking is almost stable. However, the overall ranks for other alternative changes when the priority of BOCR criteria changes.

Fig. 7a shows the changes in the rankings based on the change in the importance of Benefits as the independent parameter in the sensitivity analysis if other factors' values are fixed. For instance, when the priority of the Benefits is more than 0.12 nuclear surpasses the biomass and when the Benefit level is more than 0.4, nuclear surpass all other alternatives. This shows that nuclear energy is the most beneficial substitution to fossil energy in long-term planning.

Fig. 7b. demonstrates the change in the ranking of the alternatives due to a change in the Opportunity weight. Solar energy is the best in terms of boosting more opportunities. At an opportunity level of 0.08, wind energy will surpass nuclear energy, as the second-best option.

Fig. 7c shows the importance of cost in the prioritization of renewable energy sources. Solar energy is still the most cost-effective renewable source compared to the other sources. At the cost level of 0.23, biomass is the second-best (cost-effective) choice. Fig. 7d. shows the dominance of solar energy until the risk level reaches 0.65. Hydro energy is the best renewable energy option at risk levels above 0.7. At low-risk levels, 0.22, nuclear power surpasses wind.

Fig. 7. Sensitivity analysis graph for each criterion as independent variables (SuperDecision Software Output). a) Benefits as Independent variable, b) Opportunity as Independent variable, c) Cost as Independent variable, d) Risk as Independent variable.

The results of the sensitivity analysis show that the overall rankings are not stable and will change significantly based on the changes in the weight of benefit, opportunity, cost, and risk factors. To better understand the stability of the results, we implemented another version of the sensitivity analysis by defining different scenarios and changing the sub-criteria in benefit, opportunity, cost, and risk criteria. We developed two distinct scenarios to analyze the effect of the water crisis and Iran's nuclear deal on the ranking of renewable energy in Iran. The first scenario is the water crisis in Iran which may affect hydropower weights in our analysis. The main drivers of the Iranian water crisis are rapid population growth, inefficient agriculture, and industrial development, mismanagement of urbanization, global warming, and drought in the region (Madani, 2014; Motiee et al., 2001). Several solutions have been proposed for solving the water crisis in Iran (Madani, 2014; Motiee et al., 2001), ranging from the better spatial distribution of the population to increasing the water prices and creating efficient water markets. Bringing these solutions into the analysis will change the weight of sub-criteria in our model. Table 11 has summarized these changes. Changes in the weight of sub-criteria will also change the criteria's ranking, and as it is shown in Table 13, it will change the overall ranking results.

Table 11

Change in weight of sub-criteria and criteria in the model due to the water crisis.

Criteria	Reason for change
Environment protection (B2)	Protect the water sources
Energy prices reduction (O3)	Magnify the effect of overconsumption of the energy
Ecological damage (C5)	Capture the natural resource overuse compared with population growth
Lack of public awareness on RE (R5)	Capture the importance of training on energy resources and substitutions

Criteria	Reason for change
Technology	Magnify the modernity importance in agricultural and industrial systems
Human wellbeing	Capture the effect of spatial population management

The second important exogenous factor is the nuclear deal between Iran and the P5+1 (the permanent members of the United Nations Security Council plus Germany). The nuclear deal caused many European countries to invest in Iranian renewable energy projects, e.g., Saga Energy's (Norway) €2.5bn (\$2.9bn) contract to build the solar power plants, UK's Quercus plan to invest \$0.5 billion in solar power in addition to investments from Italy, Germany, and Greece. The foreign investments have many positive impacts on renewable energy in Iran and will consequently change the weight of some of sub-criteria and criteria are shown in Table 12.

Table 12

Change in weight of sub-criteria and criteria in the model due to Iran's nuclear deal.

Criteria	Reason for change
Pursuing international commitments like UNFCCC and Kyoto Protocol (B4)	Considering the effect of European standards in Iran
Job creation (O2)	Capture the impact of foreign investment on the job market
Investment costs (C1)	Magnify the currency exchange rate and the foreign investment costs
Dependency on foreign technology (R1)	Capture the dependency on foreign technology
Insufficient technological infrastructures (R3)	Magnify need to invest in infrastructures for new RE plants
Technology	Magnify the importance of importing modern technology
Security	Capturing the effect of creating sustainable energy resources
Economic	Capturing the effect of investment and the profits of foreign countries

In the second step of the sensitivity analysis process, the sensitivity of the final ranking to the specific changes in scores of some criteria related to hydro and nuclear energy scenarios is analyzed. The expert team was asked to assigned weights to the BOCR criteria after knowing and considering the two defined scenarios. Then the result is analyzed for their validity and consistency. Table 13 shows how, considering the two defined scenarios including the water crisis and the nuclear deal, would change the final ranking of renewable energies. Solar energy is still the first ranked energy source. However, nuclear energy surpasses hydro and geothermal energy. Also, nuclear energy and biomass have almost similar raw values, and hydropower and geothermal are almost at the same level. This will confirm the claim that deploying nuclear energy instead of fossil energy will align with the strategic development plan of the country. Also, decreasing the deployment of the water resources by decreasing the number of dams all around the country will help to diminish the impacts of the water crisis in the future.

Table 13

Pairwise comparison matrix for strategic criteria and weights result.

Name	Ranking	Rank	Ideals	Normals	Raw
Biomass		3	0.82	0.18	0.66
Geothermal		6	0.52	0.11	0.42
Hydro		5	0.53	0.12	0.43
Nuclear		4	0.81	0.18	0.66
Solar		1	1.00	0.22	0.81
Wind		2	0.90	0.20	0.73

6. Policy recommendations

In Section 2, the potential of RE development in Iran, along with the goals which have been set for 2025, has been explained. Also, the attainment of these goals has been discussed. In Sections 5.1 to 5.6, the BOCR-ANP method was used to prioritize the REs in Iran. We found that solar energy is the most appropriate renewable energy source for Iran, followed by wind energy. Then, in Section 5.7, after a sensitivity analysis, the effects of water drought and nuclear energy development consequences on RE development priorities were discussed. We found that solar remains the highest priority alternative. However, nuclear energy becomes higher prioritized than in the first round. In this section, several policy implications are discussed based on the outcomes in the previous sections.

6.1. Main obstacles of RE development in Iran

Based on the results of the Steps 5.3 (Determining the weights of the strategic criteria with respect to the goals (Step 3)), 5.4 (Determining the weights of the BOCR with respect to the criteria (Step 4)), and 4.5 (Determining the weights of the BOCR sub-network (Step 5)), *economic* and *technological* factors are the key obstacles for renewable energy development in Iran. In other words, the seismicity and tremendous initial cost, technological barriers, lack of sufficient financial resources for paying the difference in the cost of purchasing renewable electricity and non-renewable electricity, higher density of fossil fuels compared to renewable energy resources, and the existence of rich oil resources in Iran are the main limitations of renewable energy development in Iran. To deal with these two main limitations, the *guaranteed purchase of electricity* is an effective policy to encourage investment in renewable energies because the short-term perspective of this industry is the main concern of investors in renewable energies.

Tax exemption for companies involved in renewable energies projects is another governmental incentive. Renewable industries are now tax-exempt or pay lower taxes than polluting industries in most industrialized countries. Technical barriers for raising efficiency and reducing costs are the most important challenges facing Iran for the development of renewable energies. Most of these technologies come from European countries such as Germany, and they impose high costs on the renewable energy industry. Raising the *additional tax on polluting industries* is another way for paying more attention to renewable energies in some countries, but it has been very controversial.

Also, subsequently, the Clean Development Mechanism (CDM) was proposed in the Kyoto Protocol. This can mobilize private investment in the developing countries for more efficient use of fossil fuels and, therefore, cleaner development by bringing much-needed capital and new technology. In return, the investors would claim some emission reductions for their countries. Thus CDM offers developing countries finance and technology. Since the cost of reducing emissions in developing countries is much lower compared to Industrialized Countries (Australian Bureau Of Statistics), the latter would provide an incentive to appropriate technology and finance (UNDP, 1997). Technology Transfer (TT) promised in the FCCC at Rio could now be linked with CDM so as to ensure wider adaption of the technologies beyond the CDM project. That is, the “CDM project” should have a programmatic context of a long-term nature. Another way to obtain financial assistance and another opportunity for Iran is through the Global Environment Facility (GEF), which encourages fossil fuel substitution and promotion of renewable energy.

Another policy implication is to address the lack of dynamic strategic management team, which consists of experts from different organizations shown in Fig. 8. This is one of the main reasons for the non-development of RE in Iran. Planning and managing the specified budgets should be done towards maximizing goal achievement in a specified timeframe. Another vital fact here is the lack of effective cooperation models between RE industries, particularly the private sector, and custodian organizations. As shown in Fig. 8, two other bodies need to be added to the RE policy-making framework according to explanations and the results of our study in Section 2. First, the private sector and custodian organizations need to be added since small scale (small and medium-sized businesses and households) RE development has been successful in the last ten years, according to REIC (Fadai et al., 2011). Second, Drought, Flood and Water Crises Work Group, which is working in cooperation with the ministry of energy, department of the environment, and ministry of science, research, and technology. This new community has to work with RIPI and, ministry of industries and mines because a huge amount of water is wasted in these two sections. Also, the development of the environment and the Renewable Energy Organization of Iran (SUNA) should work together more closely. This is because all the environmental crises are studies in the department of environment, and a huge amount of funds come from petroleum purchases, which can be spent in RE development.

Fig. 8. Institutions and ministries engaged in REIC structure.

Even though we think that the added organizations can help the sustainable development of RE's in Iran, several reasons may cause postponement and lack of accuracy in performing the task in the RE institutions. These reasons include a vertical institutional structure with various layers, lack of transparency and separation of responsibilities, and the presence of similar responsibilities in numerous of the policymaking fragments.

6.2. Giving more priority to solar and wind energy development

Based on the result of Section 5.6, solar and wind have the highest priority to replace with fossil fuel providing less cost and risk and with high opportunity and benefit. According to the results of the sensitivity analysis in Section 5.7, even when some disruptions (e.g., water crisis and failure in the nuclear deal) happens, solar and wind are still have the highest priority to replace fossil fuel in Iran.

Many sites for solar and wind energies in Iran suitable for renewable energy projects are on government-owned land and the lease agreements for such sites follow a prescribed template and only limited amendments are permitted to that form. The provisions of the lease agreements

raise various concerns and give rise to uncertainty. For example, the extension of the initial term of three years is subject to the completion of a solar or wind power plant and the approval of the relevant authorities. In the case of the latter, the criteria and legal process in respect of obtaining said approval are not transparent. Similarly, the amount of rent is subject to adjustment by the government lessor without any reference to indexation. As a recommendation, it is an effective strategy to encourage foreign investment. Also, to address the above-mentioned issues, the template lease agreement needs to be revised, the duration of approval needs to be shortened, and the whole process needs more transparency.

6.3. The share potential of renewable sources in replacing fossil fuels

Next we applied the results from Table 13 to assess the mutual priority of renewable resources in terms of their appropriateness to replace fossil fuels. The share potential of each source with respect to their appropriateness priority is shown in Figure 9, including nuclear power. Solar energy and wind stand out as the two most suitable energy sources, which is in line with previous findings (IEA, 2018c) on the advantageous position of wind and solar power systems. Figure 9 confirms the fact that one energy production source only will not be able to replace the fossil fuel consumption, but a mix of sources will be needed. T

Fig. 9. The share potential of renewable and clean sources in replacing fossil fuels.

7. Conclusion and Policy Implications

Countries whose economies are heavily linked to fossil-fuel production will need to diversify their energy production e.g., by using more renewable energy. These countries are characterized by face increasing energy consumption, high-energy intensity, extensive emissions, economic and political challenges. Here, we have developed a hybrid MCDM method to help with energy planning and policy-making in such countries. We used Iran as a case example for applying the method.

The model developed here can be used as a tool in making strategic decisions on energy policy. The model is based on the analytic network process and benefit, opportunity, cost, and risk (ANP–BOCR) method. Utilizing the BOCR technique can help to identify potential benefits and opportunities, as well as probable costs and risks of the future choice of renewable energy alternatives. Another benefit of the proposed model is that it allows the participation of different experts, thus potentially increasing the effectiveness of decision-making. Multiple decision-

makers are often preferred to avoid bias and to minimize partiality in the decision-making process.

The ANP-part of the method enables the concurrent assessment of quantitative and qualitative criteria through the decision-making process. Also, the interdependencies of alternative renewable energy sources and BOCR criteria are analyzed. Additionally, we use the knowledge which comes from the analysis of these dependencies in identifying the weights for the criteria. Typically, previously used ranking approaches have not been able to consider the two last-mentioned aspects.

Applying the ANR-BOCR method to the Iranian case, showed that the local experts found “Technology” as the most important criterion for decision-making. Experts rated the technology factor about twice as high as the weight of economy; three times that of the energy vulnerability; four times that of security; and over ten times that of global effect and human wellbeing. This outcome means that the experts were more concerned about technological and economic factors in Iran. Also, we may interpret that the experts believe that Iran’s energy security will be increased in the best way if the technological and economic aspects of renewable energy are given the highest priority.

Iran’s strategic plans include six alternative renewable energy sources for the future. Our model prioritized solar, wind and biomass in future investments. Solar comes out as number one, which is well in line with Iran’s official plan and prevailing literature. Using a sensitivity analysis, we found that in the case of major disruptive events, solar and wind energy would still remain the

first two priorities. Based on the results obtained we discussed several policy implications mainly on empowering the RE development in Iran.

Though the model was calibrated for the Iranian case, the method can be applied elsewhere. This would necessitate providing country-specific BOCR criteria and weights.

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