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Introducing multi-stage qualification for micro-level decision-making (MSQMLDM) method in the energy sector – a case study of photovoltaic and wind power in tehran

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ABSTRACT

Buildings are consuming approximately 60% of the total electricity supply and 40% of the primary energy consumption around the world. Further, they are responsible for approximately one third of the greenhouse gas (GHG) emissions. Various approaches have been adopted to reduce energy consumption and GHG emissions in buildings such as green buildings and low-carbon buildings. In spite of the existing differences among these methods, some similarities are available, especially in using renewable energy. Therefore, the present study aims to create a method to choose the best renewable building-integrated power production units. This method is based on multiple criteria, and it also tries to be useful for non-experts such as architects and building owners. Multi-Stage Qualification for Micro-Level Decision-Making (MSQMLDM) method is implemented to compare the electric power production units from renewable and non-renewable sources in term of technical and financial (initial costs and payback period) clusters. The application of the new method seems easier than the conventional Multi-Criteria Decision Making (MCDM) models, which is mostly performed by experts. This method is a step-by-step procedure which contains three main stages. First step discusses about technical issues. Second step is focusing on a system design and the last one is about financial investigations. Then, the best choices were classified by Preference logic, based on Optimality Theory (OT). Finally, the best choices were ranked based on cost priority and payback period priority. Results indicates that photovoltaic and wind turbine should be adopted as two types of renewable energy technologies in Tehran. These technologies were investigated by MSQMLDM method based on different technical and energy policy conditions. Based on the results, photovoltaic system without battery, with selling-contract and subsidy is regarded as the best alternative. The method tries to simplify the use of MCDM models by focusing on technical and financial issues. It is predicted that this method could be useful for larger scale projects by adding other important technical or financial priorities to the sequence.

Keywords:

Renewable energy;
MCDM;
Preference logic;
Optimality theory.

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1. Introduction

Energy is essential for human beings. The industrialization of the world and technological developments have increased the need for energy around the world, which led to major environmental concerns, serious political conflicts, inevitable economic dependency and important social consequences [1].

Worldwide electricity consumption is expected to be approximately doubled over the next two decades according to the International Energy Outlook for 2004 (IEO2004) reference case forecast. Further, the total demand for electricity is predicted to experience a 2.3% average annual increase from 13.29 PWh in 2001 to 23.07 PWh in 2025 [2].

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Nowadays, economic and environmental parameters should be prioritized to select the primary energy resources needed to supply this consumption since 85% global greenhouse gas emissions are sourced by the energy sector [1]. In addition, the current energy resources are predicted to be limited in future. Furthermore, the main challenge is related to electricity-producing technologies which rely on non-renewable fuels such as coal, oil, natural gas and uranium, which will be consumed most during 100 years [3].

Therefore, considering the available conditions and the future estimations for energy requirements, people should be encouraged to find alternative energy resources. More countries pay more attention to renewable energy resources when global oil and natural gas reserves are declined, and environmental problems caused by fossil fuels are intensified [4]. In this respect, renewable energy is emerged as a solution for a sustainable, environmentally friendly and long term, cost-effective source of energy for the future [5].

Regarding the consumer's prices in the Middle East and North Africa (MENA) region, the energy from nonrenewable sources seems cheaper than that of renewable ones [6], which makes the use of renewable energy controversial. For instance, Iran has not been involved in any comprehensive plan for the energy yet although some short run and medium run policies have been adopted for energy production and consumption in different periods [7]. Four main policies play a significant role in demanding for energy during 1980–2010 including the heavy subsidization of energy use, especially in households and transportation sectors, keeping up with oil production according to the OPEC recommendations, development and utilization of natural gas, and the electrification of the rural areas [7].

In addition, no federal energy policy is currently available in the United Arab Emirates. Under the constitution, individual emirates are autonomous in managing and regulating energy and its resources [8]. To date, only a few energy regulations have been federalized such as the phase-out of incandescent light bulbs and inefficient air-conditioning units through the Emirates Authority for Standardization and Metrology. In addition, gasoline pricing is federally mandated and regulated [8].

On the other hand, in developed countries, decision makers have established some policies which encourage the transition to renewable fuels such as solar, wind, hydropower, geo-thermal and biomass. For example, UK government commissioned the Energy Saving Trust to undertake an analysis of microgeneration potentialities in the UK [9]. Based on the report, published in December 2005, microgeneration could reduce household emissions by approximately 15% by 2050 [9]. In USA, the Renewable Portfolio Standard (RPS) was first implemented in 1990s as a similar means to accelerate the adoption of renewable technologies [10].

Middle East include a lot of potentials to use renewable energy sources [6,11,12]. Based on the suggested policies in the present study, the main question raised here is whether it is logical to use renewable energy technologies in small projects with limited investment by considering the current situations in the region and which criteria should be adopted to select an appropriate technology. For this purpose, Multi-Stage Qualification for micro-level Decision-Making (MSQMLDM) method was implemented to answer the questions.

The present study includes following sections. First of all, a brief overview of MCDM methods are presented. The section three is related to important factors in micro-level and macro-level decision-making in energy sector. Also, MSQMLDM method is introduced in this section. Then, PV and wind turbine system are investigated via MSQMLDM method. Finally, the results of the case study are discussed and future strategies are proposed for energy planning.

2. Multi-criteria decision making (MCDM)

MCDM is regarded as a general class of operation research models and a well-known field of decision-making. These methods can handle both quantitative as well as qualitative criteria and analyze the existing conflicts in criteria and decision makers [5,13].

2.1. MCDM methods in energy sector

MCDM methods are applied to different types of energy problems over the last three decades. The advantage of these models is related to the evaluation of multiple, sometimes conflicting, criteria. Criteria may include factors related to financial performance as well as technical, social, or even esthetic aspects. Evaluations may be based on historical data or preference rankings by domain experts.

Multi-criteria decision making methods and tools include Data Envelopment Analysis (DEA) [14], the Analytic Hierarchy Process (AHP) [15], Multi-Attribute Utility Theory (MAUT) [16], PROMETHEE [17], ELECTRE [18] and the like. Each of these methods has its own strengths, weaknesses and areas of application [19]. Some of these methods such as Multi-Attribute Utility Theory (MAUT), Goal Programming (GP), PROMETHEE and ELECTRE address energy management and energy programming. Finally, MCDM has been implemented to evaluate, rank and prioritize energy production technologies (e.g., [19-25]).

The evaluation measures used in the previous studies are classified into financial factors, technological factors, environmental factors, and social/economic/ political factors. Financial factors include capital investment, along with the fixed and variable operating costs of the production facility. Technical factors focus on the production efficiency of the generation source. Environmental factors involve air quality, emissions, noise and their impacts on human health as well as the natural environment. Social/Economic/Political criteria emphasize the creation of employment opportunities, national security and other related factors [3].

2.2. Strengths and weaknesses of MCDM methods

MCDMs allow for considering conflicting criteria, providing a structure and organization to guide a transparent analysis process and handling both qualitative and quantitative criteria [26].

These studies have also experienced some limitations. In many decision-making situations, it is relatively difficult to obtain exact numerical values for the criteria or attributes. Thus, many parameters cannot be appropriately evaluated and the data related to different subjective criteria and their weights are usually expressed in linguistic terms by the decision maker unless the fuzzy set theory is integrated to MCDMs [5]. The variables are taken from the literature in some MCDM methods and the criteria under these variables are mostly selected by few management experts [1].

In general, in spite of a large number of available MCDM methods, no best method is available for all kinds of decision-making situations. Different methods often produce different results even when they are applied to the same problem based on the same data. There is no better or worse method while the technique which fits better in a certain situation should be emphasized [5].

2.3. Objective of the study and research questions

MCDM studies are based on collecting various data and different formula and complicated comparisons should be employed for evaluation although they are not accurate in some circumstances.

It is believed that MCDM methods and its results are useful for policy experts, investors and utility company executives responsible for making policy and investment decisions [3]. However, some variables were not considered here as the present study aimed is to provide an appropriate method for non-experts like architects and building owners for micro-level energy planning such as in residential and commercial buildings.

Considering the above-mentioned problems and developing a new method, the following research questions were raised:

- What criteria should be used to evaluate energy alternatives for residential and commercial buildings, which is easy to evaluate by non-experts at the same time?
- Which renewable energy technology is the best and preferred alternative for energy demands of buildings?

For this purpose, a model was implemented to investigate both renewable and non-renewable energy sources of electricity-producing power units.

Solar and wind energy were considered in the present study as renewable energy sources for electricity power demand. However, biomass and geothermal were excluded due to lack of basic infrastructures to be employed as a small power plants in Tehran. Photovoltaic and wind turbine systems were regarded as renewable energy power plant technologies profiled in the present study.

3. Review of related literature

3.1. Micro-level and macro-level decision-making in energy sector

Selecting an appropriate source of energy for investment is regarded as a task involving different factors although they are different based on micro-level and macro-level decision making.

In previous studies, Korfiati et al. [12] sought to estimate the potential of solar energy. In their work, they applied publically available data to try to calculate solar energy potential on a global scale. This study was based on four definitions for renewable energy potentials: Theoretical, Geographical, Technical and Economic potentials [12]. Connolly & Mathiesen [27] discussed about national energy pathways toward sustainability. They investigated one potential pathway towards a 100% renewable energy system with regards to technical and economic performance. Also, for the first time, Mahbub et al. [28] coupling the EnergyPLAN simulation model – a descriptive analytical model for medium/large-scale energy systems – which is able to describe all the relevant energy sectors (electric, thermal and transport) to a multi-objective evolutionary algorithm. They have shown that it is possible to automatically identify a set of energy scenarios which optimize conflicting objectives.

In general, renewable energy decision-making is considered as a multiple criteria decision-making problem through correlating criteria and alternatives [5,29]. The task should take several conflicting aspects into consideration due to an increasing complexity of the social, technological, environmental, and economic factors [5].

In macro-level decision-making, especially for policy-makers in energy sector, financial, technological, environmental and social/economic/political factors are emphasized. On the other hand, some factors are not essential in micro-level decision-making for energy demands, especially in private sector projects such as residential and commercial buildings. In this case, social/economic/political criteria are less emphasized. Since the characteristics related to renewable sources involve almost unlimited amounts of "fuel'' and a low or zero carbon footprint (except biomass) [3], environmental factors are not regarded as a problematic issue. However, the most important problems for investors are mostly related to the performance of energy production, installation services, and project costs [30].

In the following chapters, a model is provided to choose electricity producing technology based on financial and technical considerations. The model is mainly designed for the feasibility study of renewable energy technologies for micro-level decision-making, especially in small-scale projects.

3.2. Multi-stage qualification for micro-level decision-making (MSQMLDM)

MSQMLDM is a step-by-step method for the feasibility study of employing energy production technologies in small projects and businesses, especially in private sector. The method includes some steps and the project could disqualify in each stage whenever no logic is available for employing the system.

In this method, each technology is evaluated based on Technical Criteria (TC) as a power source and its production capabilities and Financial Criteria (FC) as the financial value of the technology and the payback period. Further, system design should be added between the two criteria. Therefore, the method should at least include three main stages.

1. Technical investigations
    - Energy production capabilities: Factors pertaining to potential of production are basic requirements of the technology regard to climatic condition and efficiency of the technology.
    - Installation and after-installation services: Proper services for a system installation, maintenance and availability of a system accessories.
2. Renewable power plant system design
    - Designing a system according to amount of required power: Design a system according to amount of energy needs through renewable energy modeling tools, calculators and design guides such as: Sunny Design Web [31,32], RETScreen [33], HOMER [34,35].
3. Financial investigations
    - System's cost estimation: Two points should be considered. First, cost to build, operating and maintaining a selected technology. Second, investigate in policies to find out if there is a grant-in-aid for using renewable technologies in the region.

$$C_{\text{power production unit}} = \sum_{i=1}^{n} \left(C_{\text{appliance, i}} + C_{\text{building, operating and maintaining, i}} \right) \quad (1)$$

C: cost

- Payback period for investment: The payback period is one of the most important techniques in evaluating capital budgeting and there is a wide acceptance of this technique by managers and investors [36].

$$PP = \text{Years before full recovery} + (\text{Unrecovered cost at start of the full recovery year}/\text{Cash flow during the full recovery year}) \quad (2)$$

PP: payback period

Based on this method, the best choices should be adopted by logic of preference based on optimality theory (OT) if several choices are eligible to be employed [37]. The following example helps to clarify the theory.

Client A is going to run a renewable power production technology. In doing so, the initial cost and the payback period should be considered. The system costs and payback period could be varied even for the same systems because of energy policies, like subsidy programs. Therefore, the sequence of priorities is as follows:

$$C >> PP \text{ or } PP >> C$$

(C: cost, PP: payback period)

Consider two technologies T1 and T2. Client A includes the following priority sequence:

$$C >> PP$$

T1 and T2 include the following property:

$$C_{T1} < C_{T2}$$

In other words, T1 has lower cost than T2. According to OT, Client A prefers T1 over T2 regardless of the payback period for investment.

3.3. The procedure for implementing MSQMLDM

In this method, technologies are investigated in each stage and its subcategories, respectively. Technical investigation is regarded as prerequisite for other steps. If the system involves the fundamental requisites at this step, the investigation should continue for next levels. The choices should be classified with preferable sequence based on OT. Figure 1 illustrates the procedure.

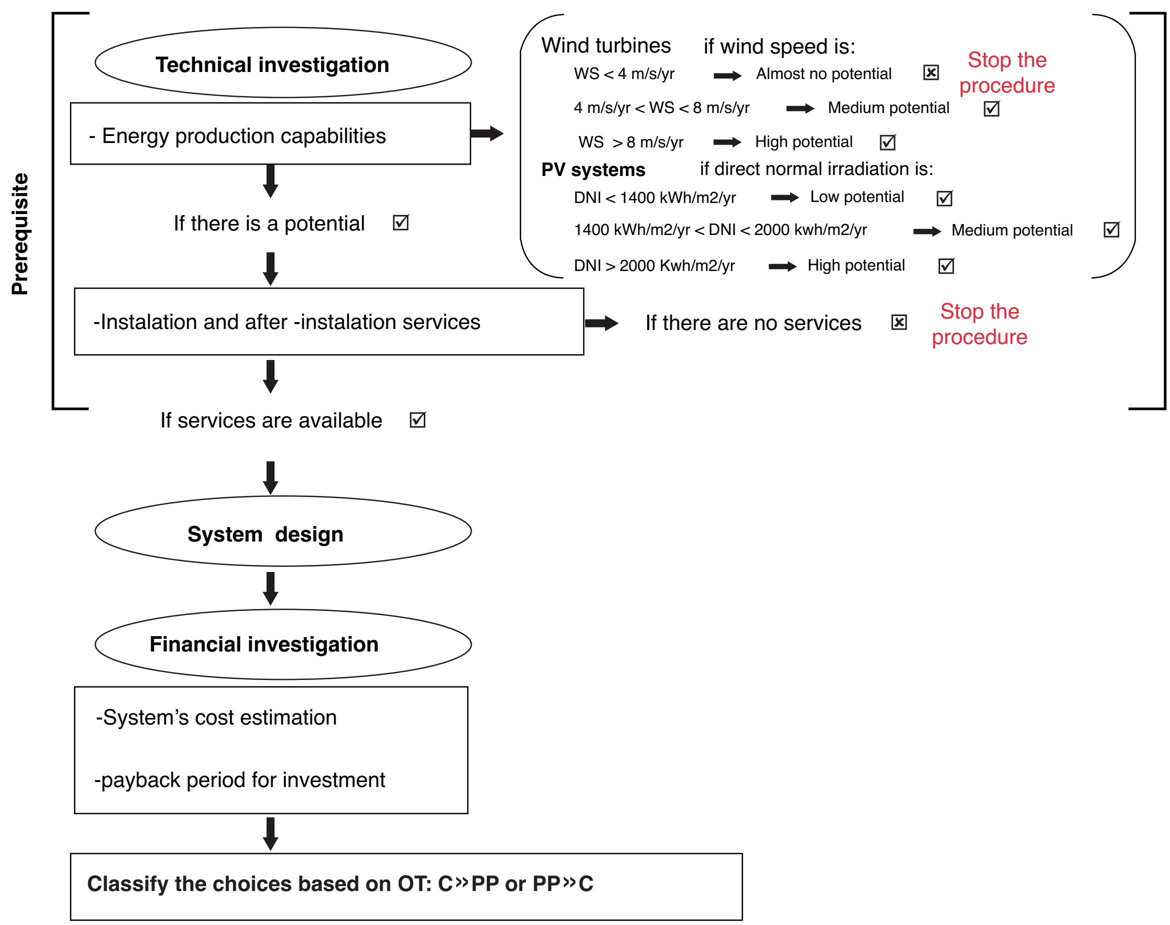


Figure 1: MSQMLDM method procedure

Note: in some projects, other factors may be considered such as energy production per square meter, initial costs per 1kWh of energy production, which should be added as a subcategory to the relevant main stages, as well as the priority sequence.

4. Case study

Per capita consumption of energy in commercial and residential sector is 1.9 times more than that of the world average [38]. In Tehran, CO2 emissions are very high, as the residential and commercial buildings made the largest share (41%) by 2008 [39]. Due to pollution and its several damage in some cities of Iran like Tehran, non-renewable sources of energy should be replaced with renewable sources.

The case study used in the present study included a home with three households consuming 3000 kWh annual electricity power. Photovoltaic (PV) and wind turbine systems were selected as there are enough basic infrastructures to be employed as a power production units. These systems were investigated based on MSQMLDM method. Both technologies were considered to include 20-year-service life and grid-connected.

4.1. Climatic condition of Tehran

Average solar radiation in Tehran ranged between 5.2–5.4 kWh/m^2 per day and wind speed average is 5.5m/s. Tehran features a semi-arid climate (Köppen-Gieger climate classification: BSk) [40]. Average annual rainfall and temperature are 230 mm and 17°C, respectively [41]. Figure 2 indicates the climatic conditions of Tehran.

4.2. Electricity power tariff in Iran

Iranian Students' News Agency (ISNA) reported that 10% increase occurred in domestic electricity power tariff in 2016 in each step while it raised 24% in 2015 [43] (Table 1).

Based on the report of The Iranian Ministry of Energy, the price of electricity power produced by renewable energy systems every year was 0.14 USD per kWh in 2015 and raised to 0.16 USD per kWh in 2016 [44,45]. People who are using renewable energy can sell electricity produced by these systems to the electricity power companies by contract.

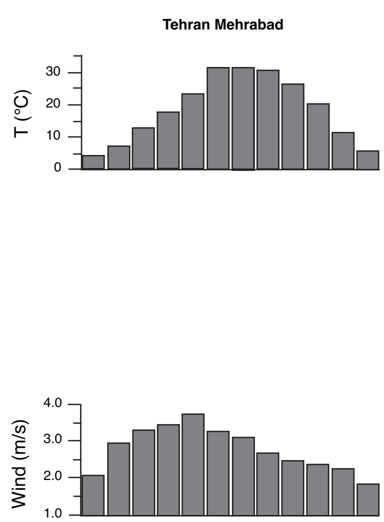
4.3. Renewable power plant system design software

Sunny Design software

1. Enter project data such as project name, country, city, voltage level.
2. Define load profile such as the type of project, annual energy consumption.
3. Configure PV system including information about manufacturer/PV module, number of PV

Table 1: Monthly electric power price during 2015–2016

Average energy consumption per month (kWh per month)	Price per kWh in 2015 (USD)	Price per kWh in 2016 (USD)
0–100	0.011	0.012
100–200	0.013	0.014
200–300	0.028	0.31
300–400	0.51	0.56
400–500	0.59	0.65
500–600	0.74	0.81
Over 600	0.82	0.9



	Unit	Climate data location	Project location
Latitude	°N	35.7	35.7
Longitude	°E	51.3	51.3
Elevation	m	1,191	1,191
Heating design temperature	°C	–1.3	
Cooling design temperature	°C	37.2	
Earth temperature amplitude	°C	23.9	

Month	Air temperature	Daily solar radiation - horizontal	Wind speed	Earth temperature
	°C	kwh/m^2/d	m/s	°C
January	3.0	2.44	3.5	1.0
February	5.3	3.33	5.0	2.5
March	10.3	4.08	6.4	7.3
April	16.4	5.42	7.1	15.7
May	22.1	6.42	7.2	21.9
June	27.5	7.64	6.7	26.9
July	30.4	7.50	5.5	29.1
August	29.2	6.92	4.9	28.1
September	25.3	5.75	4.7	23.1
October	18.5	4.25	4.7	16.0
November	11.6	2.92	3.9	8.7
December	5.6	2.25	3.5	2.9
Annual	17.2	4.92	5.3	15.3
Measured at m			10.0	0.0

Figure 2: Left: Monthly summary of surface meteorological data at three sites near Tehran [42]. Right: Climatic data of Tehran (RETScreen-Climate database)

modules, orientation/mounting type and the type of inverter.

4. Wire sizing: power loss of selected wire sizing can be calculated on this step.

After importing all data, the software illustrates a report about PV system performance under the two following conditions:

A) Without an increase in self-consumption;

B) With an increased in self-consumption (use battery for energy storage).

RETScreen 4 software

RETScreen 4 software is proposed three methods to design a wind turbine system. Method one is based on capacity factor of the system. Method two uses annual wind speed, atmosphere pressure and air temperature for analysis, while method three uses monthly wind speed. Among these methods, method two and three are more accurate due to their use of climatic data of the region for analyzing the system. In RETScreen 4, some data such as project name, location, type of project and some climatic data should be first imported and the user should select between the three methods for analysis.

4.4. Photovoltaic system

In this section, PV system is studied based on MSQMLDM method.

Technical investigation

- Energy production capabilities

Climatic condition: Regarding Tehran climate, there is a high potential to use PV systems, therefore these systems can be implemented.

System efficiency: The solar irradiation would be between 1640 to 1970 kWh/m^2 per year on 80% of the land in Iran's territory [46]. Figure 3 shows the solar radiation of the proposed site in the present study. There are two types of panel efficiency in Iran, low efficiency panel (16%) and high efficiency panel (20%) [47].

- After-installation services

The services for system installing, maintenance and system accessories are available in Tehran and can be implemented by many companies.

Renewable power plant system design

PV system: Use Sunny Design Web software [31,32] to estimate, with two conditions:

A) Without increased self-consumption

B) With increased self-consumption

In the present project, 10 panels were selected. Figure 4 illustrates the orientation and mounting type of PV arrays-facing. Maximum sunlight should be considered for PV orientation and mounting.

Canadian Solar is selected as a PV module manufacturer. Different types of suitable inverters are suggested based on imported data by the

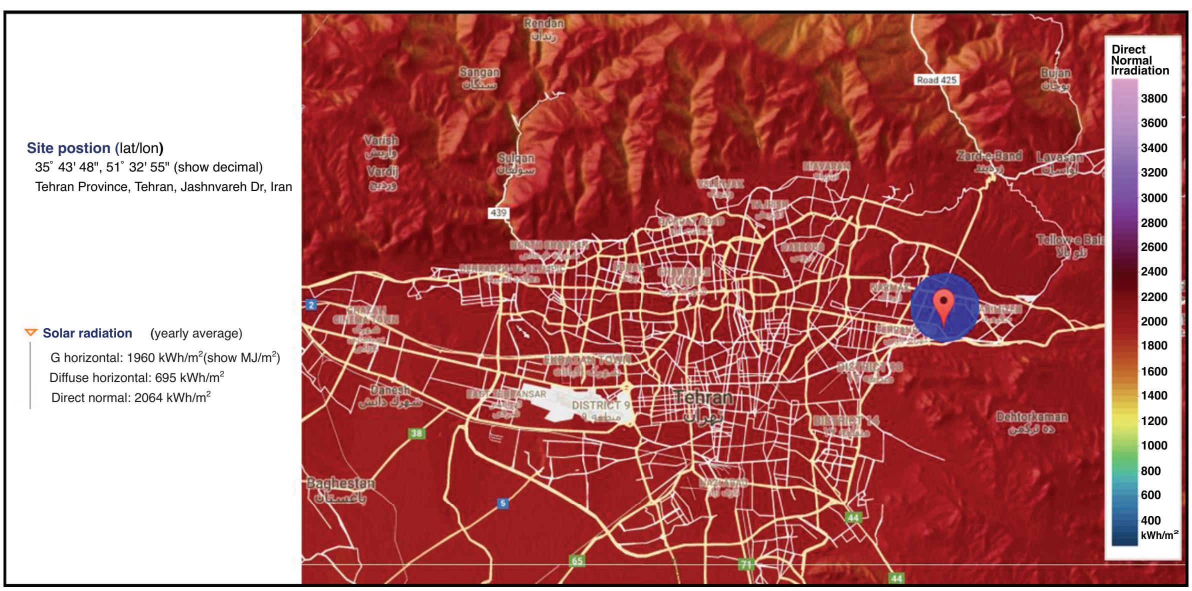


Figure 3: Solar radiation in the proposed site [48]

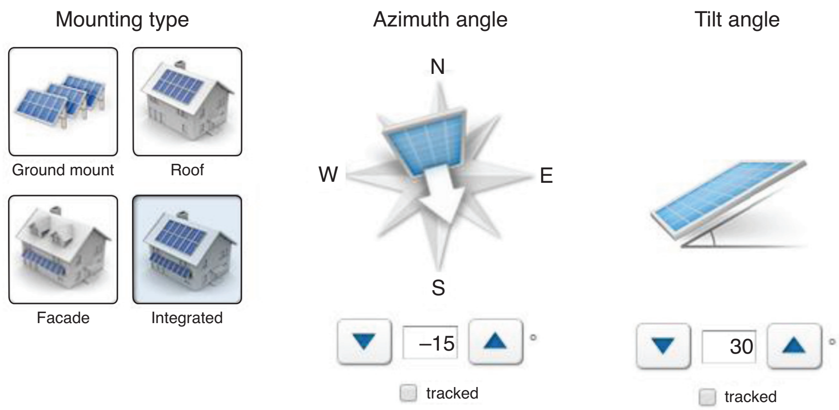


Figure 4: PV panels orientation and mounting

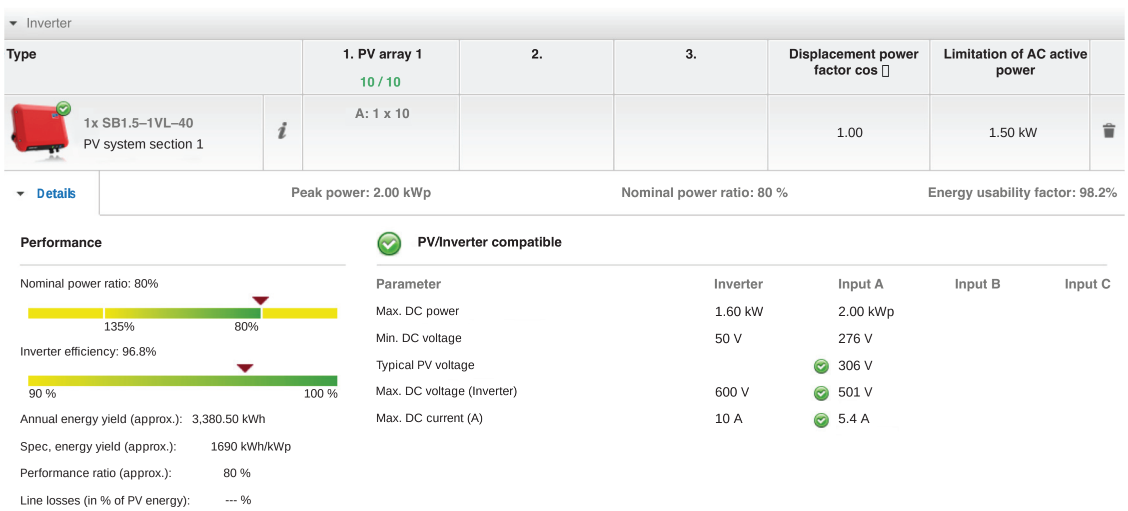


Figure 5: Inverter for PV system

software. Figure 5 indicates the inverter with the best performance.

Final report about PV system performance under the two conditions is shown in Figure 6.

As it is observed in Figure 6, the energy produced by these panels are estimated to be 3381kWh in a year.

Financial investigation

- Project cost estimation

Cost of building, operating and maintenance of the PV system: The prices related to PV system appliances are calculated with and without battery condition. The expenses related to PV system appliances without battery are shown in Table 2.

Note 1: costs of appliances in this study are collected by interviewing producers and companies in Iran.

Note 2: Annual growth rate is considered 10% in electricity power price from urban power grid.

Moreover, as the costs of cables ranged between 61.35 and 92$, the average cost is 76.67$ and the system cost could be about 3336.67$ in this condition. The expenses related to a PV system appliances with battery are shown in Table 3.

The average cost of cables is 76.67$, battery life is almost 20 years and solar panel life is estimated 25 year based on the manufacturer's opinion. The linear performance of PV panels is guaranteed in this period and its performance is going to diminish after this period. Therefore, one series of batteries are needed for using a PV system for 20 years. In this case, the cost of a PV system could be about 6761.67$.

Figure 7 illustrates the electricity bill payment in PV system with battery, PV system without battery and without solar system.

Subsidy program for PV systems: The deputy of Ministry of Energy declared that the government

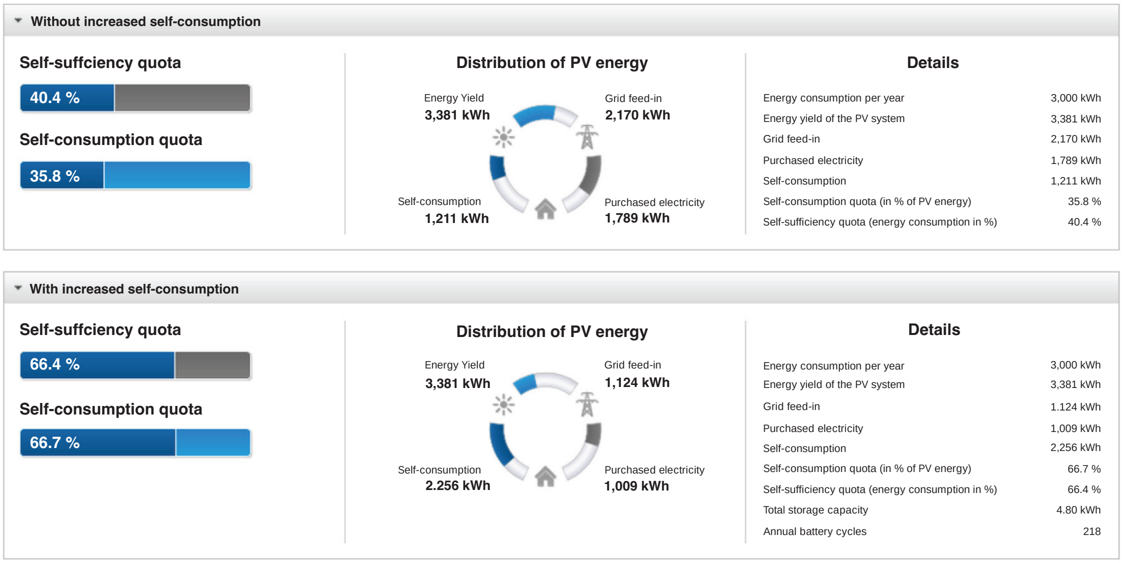


Figure 6: The PV system results (with and without increasing self-consumption)

Table 2: Costs of a PV system without battery

Type of appliance	Manufacturer	Model	Number	Unit price (USD)	Total Price (USD)
PV panel	Canadian solar	CS5A-200M	10	1.07 (per W)	2147
Inverter	SMA	SB 1.5-1VL-40	1	828	828
Structure*	–	–	1	285	285
					Total: 3260

* Cost of structure includes panel structure, building, and operating the system.

Table 3: PV system cost with battery

Type of appliance	Manufacturer	Model	Number	Unit price (USD)	Total Price (USD)
PV panel	Canadian solar	CS5A-200M	10	1.07 (per W)	2147
Inverter	SMA	SB 1.5-1VL-40	1	828	828
Structure*	–	–	1	285	285
Battery	SMA	Sunny Island 3.0M	1	2693	2693
Manager	SMA	Sunny Home Manager	1	364	364
Energy meter	SMA	–	1	368	368
					Total: 6685

* Cost of structure includes panel structure, building, and operating the system.

pays 50% of the PV system expenses as it costs up to 3067$ [49]. However, only a limited amount of this plan is allocated to each province and people should register in a specific period for using the plan.

- Payback period for investment

Based on the government's grant-in-aid program for PV systems and electricity trade with electricity companies, the return on investment under different conditions is shown in Figure 8 and 9.

4.5. Wind Turbine system

Technical investigation

- Energy production capabilities

Climatic condition: Wind speed average is about 5.3m/s in Tehran which is a medium potential and appropriate to operate a wind turbine system.

System efficiency: Wind turbines convert around 45% of the wind passing through the blades into electricity and nearly with a peak efficiency of 50% [50].

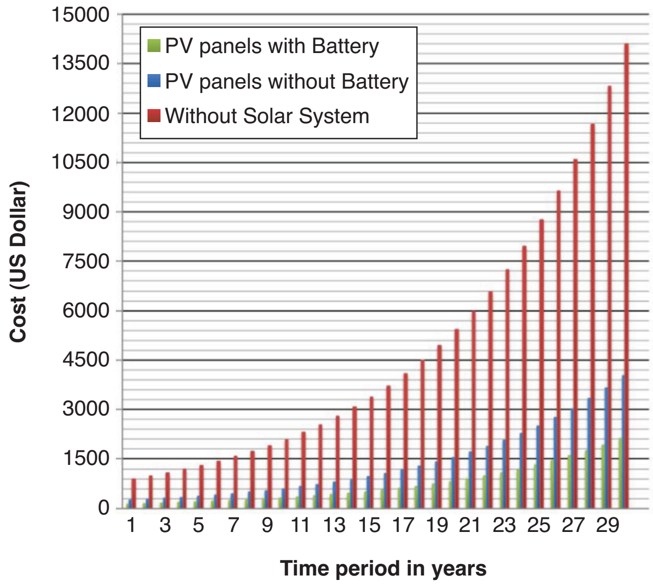


Figure 7: Annual electricity bill payment in three different cases

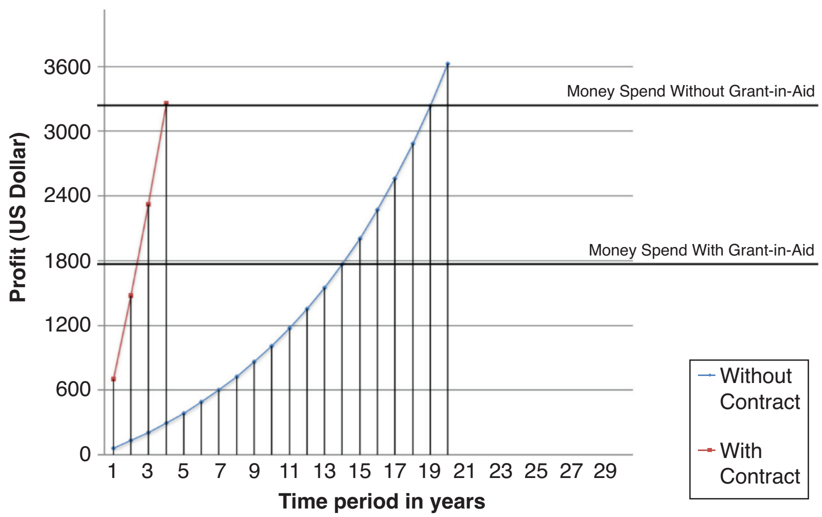


Figure 8: The payback period in a PV system without battery under different conditions

- After-installation services

The services operated by several companies in Tehran are available for system installing, maintenance and system accessories.

Renewable power plant system design

The estimation of electricity production and designing the system is accomplished by RETScreen 4 software. The system is designed by method 2. Based on an average wind speed over a year in method 2, the wind turbine specifications and climatic data should be imported as illustrated in Figure 10.

It is worth noting that the software is estimated 4MWh (4000kWh) energy production from the wind turbine system as illustrated in Figure 11.

Financial investigation

- Project cost estimation

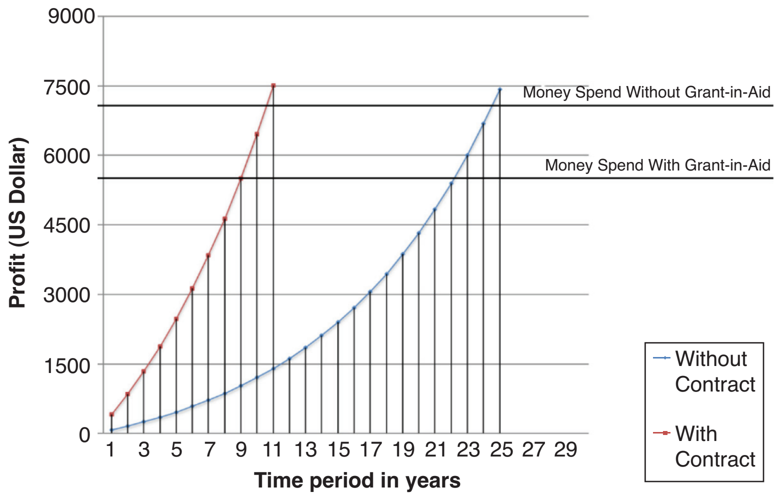


Figure 9: The payback period in a PV system with battery under different conditions

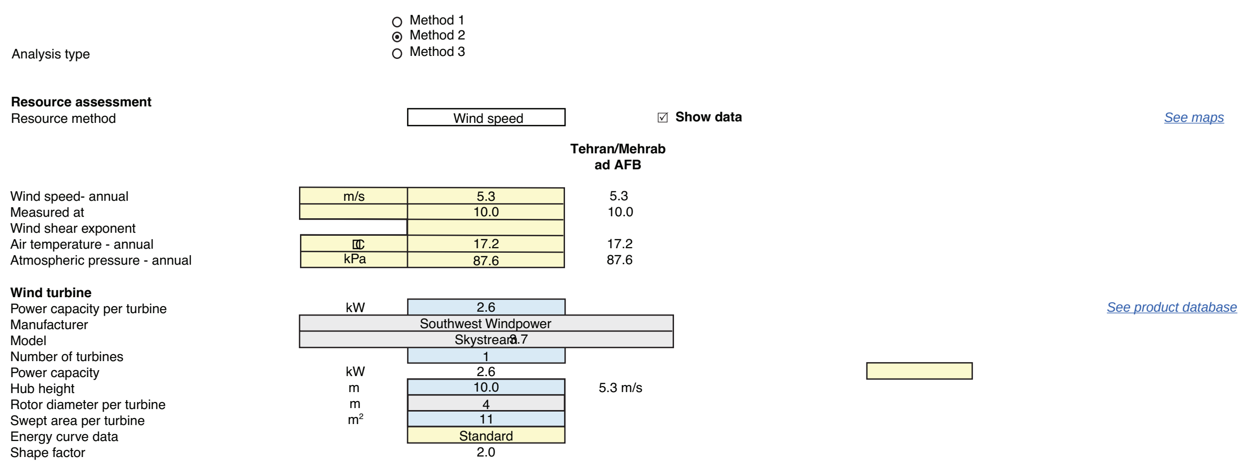


Figure 10: The wind turbine system design by method 2

Table 4 indicates the costs related to building, operating, and maintenance of the wind turbine system.

Figure 12 illustrates the amount of electricity bill payment in two conditions.

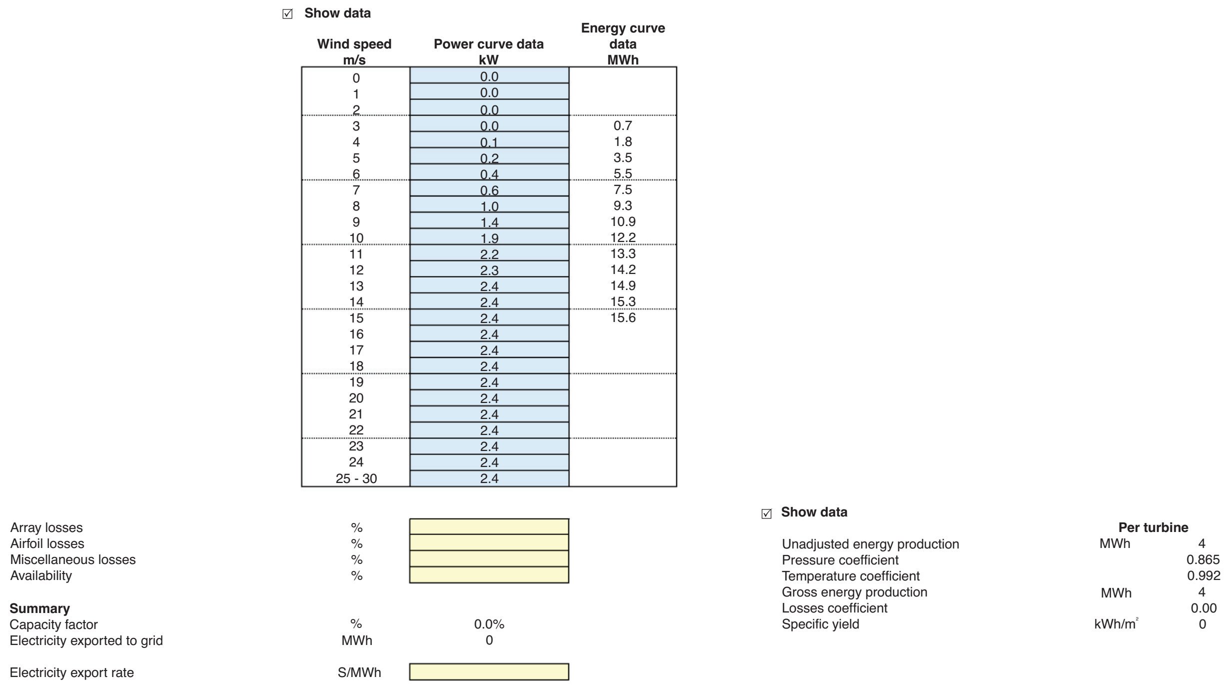
Subsidy program for wind turbine systems: Wind turbine systems involve different conditions, compared to PV systems in a private sector's projects in Iran. No grant-in-aid programs are available in wind turbine systems and these subsidies are only allocated to photovoltaic systems.

- Payback period for investment

Figure 13 illustrates the payback period in a wind turbine system.

5. Results of MSQMLDM method for the PV and the wind turbine systems

Tables 5, 6 and 7 indicate the results of the PV and the wind turbine systems analyzed by MSQMLDM method, which was investigated based on three stages and technical and financial criteria. These criteria include subcategories, and each factors should be



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Wind speed m/s	Power curve data kW	Energy curve data MWh
0	0.0	
1	0.0	
2	0.0	
3	0.0	0.7
4	0.1	1.8
5	0.2	3.5
6	0.4	5.5
7	0.6	7.5
8	1.0	9.3
9	1.4	10.9
10	1.9	12.2
11	2.2	13.3
12	2.3	14.2
13	2.4	14.9
14	2.4	15.3
15	2.4	15.6
16	2.4	
17	2.4	
18	2.4	
19	2.4	
20	2.4	
21	2.4	
22	2.4	
23	2.4	
24	2.4	
25 - 30	2.4	

Array losses	%	
Airfoil losses	%	
Miscellaneous losses	%	
Availability	%	
Summary		
Capacity factor	%	0.0%
Electricity exported to grid	MWh	0
Electricity export rate	S/MWh	

☑ Show data

		Per turbine
Unadjusted energy production	MWh	4
Pressure coefficient		0.865
Temperature coefficient		0.992
Gross energy production	MWh	4
Losses coefficient		0.00
Specific yield	kWh/m²	0

Figure 11: Data related to the wind turbine system analysis based on method 2

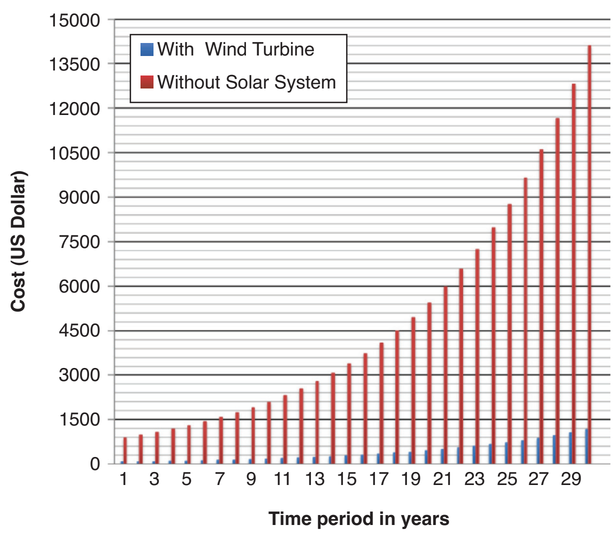

Figure 12: Annual electricity bill payment under different conditions

investigated to show whether factors are eligible or not. The PV system is investigated in two types, with and without battery, and each type with four conditions including with and without grant-in-aid, along with, with and without contract in selling surplus solar electric power to the grid. The system service life is considered to be twenty years.

Further, no financial subsidy policies are available although there is a chance for solar electric power trade in wind turbine system. Therefore, the wind

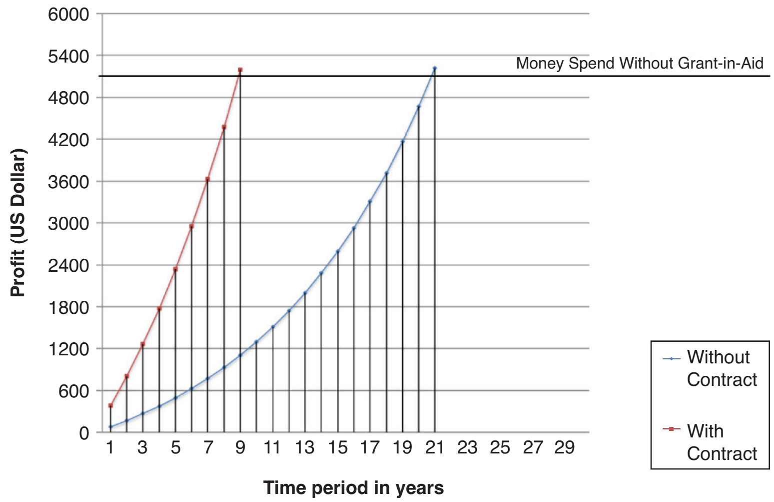

Figure 13: Payback period in a wind turbine system under different conditions

Table 4: Costs related to the wind turbine system

Type of appliance	Manufacturer	Model	Number	Unit price (USD)	Total Price (USD)
Wind turbine	Southwest Windpower	Skystream 3.7 (2.6 KW)	1	2140	2140
Inverter	SMA	Windy boy 3000-US 3000 W	1	1860	1860
Structure*	–	–	1	1217	1217
					Total: 5217

* Cost of structure includes wind turbine structure, building, and operating the system.

Table 5: The results of MSQMLDM method for the photovoltaic system based on increasing self-consumption

PV system					
Technical investigation		**System design**	**Financial investigation**		
Energy Production potential	After-installation services	On-grid With battery	Available facilities based on policies	Initial cost	Payback period
Avg solar radiation per day = 5.2–5.4 kWh/m^2	Full service is available in the region ☑		With contract, with subsidy	\$5152	≈9 yrs ☑
Sunshine hours per year ≈ 2905 hrs ☑			With contract, without subsidy	\$6685	≈10.5yrs ☑
			Without contract, without subsidy	\$6685	≈24.5yrs ☑
			Without contract, with subsidy	\$5152	≈22 yrs ☑

turbine system is evaluated in two conditions including with and without electric power selling-contract. The system service life is also considered to be twenty years.

Based on optimality theory (OT) and considering the initial cost and the payback period, the best system choices for the project were classified as Table 8 and 9, respectively.

Table 6: The results of MSQMLDM method for the photovoltaic system without increasing self-consumption

PV system					
Technical investigation		**System design**	**Financial investigation**		
Energy Production potential	After-installation services	On-grid Without battery	Possible facilities based on policies	Initial cost	Payback period
Avg solar radiation per day = 5.2–5.4 kWh/m^2	Full service is available in the region ☑		With contract, with subsidy	$1727	≈2.5 yrs ☑
Sunshine hours per year ≈2905 hrs ☑			With contract, without subsidy	$3260	≈4 yrs ☑
			Without contract without subsidy	$3260	≈19 yrs ☑
			Without contract, with subsidy	$1727	≈14 yrs ☑

Table 7: The results of MSQMLDM method for the wind turbine without increasing self-consumption

Wind turbine					
Technical investigation		**System design**	**Financial investigation**		
Energy Production potential	After-installation services	On-grid Without battery	Possible facilities based on policies	Initial cost	Payback period
Wind speed Avg ≈5.5 m/s ☑	Full service is available in the region ☑		With contract	$5217	≈9 yrs ☑
			Without contract	$5217	≈21 yrs ☒

Table 8: The best choices of PV and wind turbine systems for the project if P(x) » C(x)

	Type of the system	Initial cost	Payback period
1	PV system, Without battery, With contract and subsidy	$1727	≈2.5 yrs
2	PV system, Without battery, With contract and without subsidy	$3260	≈4 yrs
3	PV system, With battery, With contract and subsidy	$5152	≈9 yrs
4	Wind turbine system, Without battery, With contract	$5217	≈9 yrs
5	PV system, With battery, With contract, without subsidy	$6685	≈10.5yrs
6	PV system, Without battery, Without contract, with subsidy	$1727	≈14 yrs
7	PV system, Without battery, Without contract and subsidy	$3260	≈19 yrs

Table 9: The best choices of PV and wind turbine systems for the project if C(x) ≫ P(x)

	Type of the system	Initial cost	Payback period
1	PV system, Without battery, With contract and subsidy	$1727	≈2.5 yrs
2	PV system, Without battery, Without contract, with subsidy	$1727	≈14 yrs
3	PV system, Without battery, With contract and without subsidy	$3260	≈4 yrs
4	PV system, Without battery, Without contract and subsidy	$3260	≈19 yrs
5	PV system, With battery, With contract and subsidy	$5152	≈9 yrs
6	Wind turbine system, Without battery, With contract	$5217	≈9 yrs
7	PV system, With battery, With contract and without subsidy	$6685	≈10.5 yrs

6. Conclusions

Adopting and choosing alternative energy sources for small-scale projects is a multidimensional decision-making process, which mainly involves economic and technical characteristics at different levels. Based on this approach, MSQMLDM can be regarded as an appropriate method to analyze all perspectives in relation to micro-level decision-making process by establishing a step-by-step process in all alternatives and factors which play a significant role in making the decision.

The results indicate that PV system without battery, with selling-contract and grant-in-aid can be the best alternatives for the defined project due to the shortest payback period and the lowest initial cost. Further, initial expenses can be significantly reduced by registering for grant-in-aid program in any PV system. However, these subsidies are limited and a specific amount of this plan should be allocated to each province in Iran. This plan is only limited for photovoltaic systems. The reduction of payback period by selling surplus electricity to the grid by solar electricity power selling-contract is regarded as another appropriate opportunity.

Based on the results of the present study, the photovoltaic system without battery involves better condition in payback period due to the elimination of a battery cost although the demands for power grid could increase in this condition. Further, it is worth noting that selling-contract is financially more effective than registering for the grant-in-aid. For instance, the PV system without battery with selling-contract and without subsidy can involve a four-year payback period while it is a fourteen-year payback period for the similar system without selling-contract and with subsidy. Since the systems service life is considered to be 20 years, the photovoltaic system with battery, without selling-contract and the wind turbine system without selling-contract are not eligible. Furthermore, the payback period for the photovoltaic system without battery and without selling-contract is almost as long as the system service life. For the same system, significant differences are observed in payback period between the system without contract and with contract. In addition, solar electric power selling-contract is highly recommended since it is available for any kind of renewable energy sources technologies and it provides a good opportunity to diminish the payback period.

Considering the results, the policies designed to incentivize the production of solar should be retained and expanded and motivational policies should be established in wind, hydro and geothermal. In contrast, subsidies for non-renewable technologies should be curtailed. Finally, these results provide good insight into using an optimal mix of renewable and non-renewable energy sources for electricity power demands. Therefore, further study is recommended for applying the model in light of very specific constraints such as CO_2 production, available land mass, capital investment, and the like which represent the specific goals of the decision makers. Future studies are also suggested to broaden the scope of this model for the larger scale planning to involve both demand and supply side methods which can contribute to an effective energy strategy in Iran and other countries.

References

[1] O. Demirtas, "Evaluating the Best Renewable Energy Technology for Sustainable Energy Planning," *International Journal of Energy Economics and Policy*, vol. 3, pp. 23–33, 2013. http://www.econjournals.com/index.php/ijeep/article/view/571.

[2] Energy Information Administration, "International Energy Outlook 2004," Washington, 2004.

[3] E. W. Stein, "A comprehensive multi-criteria model to rank electric energy production technologies," *Renewable and Sustainable Energy Reviews*, vol. 22, pp. 640–654, 2013. https://doi.org/10.1016/j.rser.2013.02.001.

[4] D. D. Chiras, Environmental science, 7th ed., Sudbury: Jones and Bartlett, 2006.

[5] R. Abu Taha and T. Daim, "Multi-Criteria Applications in Renewable Energy Analysis, a Literature Review," *Research and Technology Management in Electricity Industry*, pp. 17-30, 2013. http://dx.doi.org/10.1007/978-1-4471-5097-8_2.

[6] D. R. Jalilvand, Renewable Energy for the Middle East and North Africa, Berlin: Friedrich-Ebert-Stiftung, 2012. http://library.fes.de/pdf-files/iez/08959.pdf.

[7] S. Moshiri and S. Lechtenbohmer, Sustainable Energy Strategy for Iran, Wuppertal: Wuppertal Institute for Climate, Environmental and Energy, 2015. https://epub.wupperinst.org/frontdoor/deliver/index/docId/6175/file/WS51.pdf.

[8] Masdar Institute/IRENA, "Renewable Energy Prospects: United Arab Emirates", Remap 2030 analysis. IRENA, Abu Dhabi, 2015. www.irena.org/remap.

[9] Climate Change: The UK Programme 2006, Norwich: TSO, 2006.

[10] R. Wiser, C. Namovicz, M. Gielecki and R. Smith, "Renewable portfolio standards: A factual introduction to experience from the United State," 2007. https://emp.lbl.gov/sites/all/files/lbnl-62569.pdf.

[11] E. Wheeler and M. Desai, "Middle East Institute," 26 January 2016. [Online]. http://www.mei.edu/content/article/iran%E2%80%99s-renewable-energy-potential.

[12] A. Korfiati, C. Gkonos, F. Veronesi, A. Gaki, S. Grassi, R. Schenkel, S. Volkwein, M. Raubal and L. Hurni, "Estimation of the Global Solar Energy Potential and Photovoltaic Cost with the use of Open Data," *International Journal of Sustainable Energy Planning and Management*, vol. 9, pp. 17–30, 2016. https://doi.org/10.5278/ijsepm. 2016.9.3.

[13] S. Pohekar and M. Ramachandran, "Application of multi-criteria decision making to sustainable energy planning- A review," *Renewable and Sustainable Energy Reviews*, vol. 8, pp. 365-381, 2004. https://doi.org/10.1016/j.rser.2003.12.007.

[14] E. Hermans, T. Brijs, G. Wets and K. Vanhoof, "Benchmarking Road Safety: Lessons to learn from a data envelopment analysis," *Accident Analysis and Prevention*, vol. 41, no. 1, pp. 174-182, 2009. https://doi.org/10.1016/j.aap.2008.10.010.

[15] T. L. Saaty, The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation, New York: McGraw-Hill, 1980.

[16] R. L. Keeney, "The Art of Assessing Multiattribute Utility Functions," *Organizational Behavior and Human Performance*, vol. 19, no. 2, pp. 267–310, 1977.

[17] M. Behzadian, R. Kazemzadeh, A. Albadvi and M. Aghdasi, "PROMETHEE: A Comprehensive Literature Review on Merhodologies and Applications," *European Journal of Operational Research*, vol. 200, no. 1, pp. 198–215, 2010. https://doi.org/10.1016/j.ejor.2009.01.021.

[18] A. Papadopoulos and A. Karagiannidis, "Applicarion of the Multi-Criteria Analysis Method Electre lll for the Optimisation of Decentralised Energy Systems," *Omega*, vol. 36, no. 5, pp. 766–776, 2008. https://doi.org/10.1016/j.omega.2006. 01.004.

[19] M. Velasquez and P. T. Hester, "An Analysis of Multi-Criteria Decision Making Methods," *International Journal of Operations Research*, vol. 10, no. 2, pp. 56–66, 2013. http://www.orstw.org.tw/ijor/6_volume10_no2.html.

[20] A. I. Chatzimouratidis and P. A. Pilavachi, "Sensitivity analysis of technological, economic and sustainability evaluation of power plants using the analytic hierarchy process," *Energy Policy*, vol. 37, no. 3, pp. 788–798, 2009. https://doi.org/ 10.1016/j.enpol.2008.11.021.

[21] E. Georgopoulou, D. Lalas and L. Papagiannakis, "A multicriteria decision aid approach for energy planning problems: The case of renewable energy option," *European Journal of Operational Research*, vol. 103, no. 1, pp. 38-54, 1997. https://doi.org/10.1016/S0377-2217(96)00263-9.

[22] E. Heo, J. Kim and K.-j. Boo, "Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 8, pp. 2214–2220, 2010. https://doi.org/ 10.1016/j.rser.2010.01.020.

[23] S. C. Kim and K. J. Min, "Determining Multi-Criteria Priorities in the Planning of Electric Power Generation: The Development of an Analytic Hierarchy Process for Using the Opinions of Experts," *International Journal of Management*, vol. 21, no. 2, pp. 186-193, 2004. https://lib.dr.iastate.edu/ imse_pubs/109/.

[24] K. Nigim, N. Munier and j. Green, "Pre-feasibility MCDM tools to aid communities in prioritizing local viable renewable energy sources," *Renewable Energy*, vol. 29, pp. 1775–1791, 2004. https://doi.org/10.1016/j.renene.2004.02.012.

[25] T. Tsoutsos, M. Drandaki, N. Frantzeskaki, E. Iosifidis and I. Kiosses, "Sustainable energy planning by using multi-criteria analysis application in the island of crete," *Energy Policy*, vol. 37, pp. 1587-1600, 2009. https://doi.org/10.1016/ j.enpol. 2008.12.011.

[26] V. Belton and T. J. Stewart, Multiple Criteria Decision Analysis: An Integrated Approach, Boston: Kluwer Academic, 2002.

[27] D. Connolly and B. Vad Mathiesen, "A technical and economic analysis of one potential pathway to a 100% renewable energy system," *International journal of Sustainable Energy Planning and Management*, vol. 1, pp. 7-28, 2014. https://doi.org/ 10.5278/ijsepm.2014.1.2.

[28] M. S. Mahbub, M. Cozzini, P. A. Østergaard and F. Alberti, "Combining multi-objective evolutionary algorithms and descriptive," *Applied Energy*, vol. 164, pp. 140–151, 2016. https://doi.org/10.1016/j.apenergy.2015.11.042.

[29] N. H. Afgan and M. G. Carvalho, "Multi-criteria assessment of new and renewable energy power plants," *Energy*, vol. 27, pp. 739-755, 2002. https://doi.org/10.1016/S0360-5442(02) 00019-1.

[30] S. S. Deshmukh and M. K. Deshmukh, "Micro-level integrated renewable energy system planning," *International energy journal*, vol. 9, pp. 9-20, 2008. http://www.rericjournal. ait.ac.th/index.php/reric/article/view/368.

[31] SMA Solar Technolody AG, "SUNNY DESIGN 3 and SUNNY DESIGN WEB," [Online]. Available: http://files.sma. de/dl/19409/SD3-SDW-BA-en-20.pdf. [Accessed 2015].

[32] A. Rawea and S. Urooj, "Remedy of Chronic Darkness & Environmental effects in Yemen Electrification System using Sunny Design Web," *International Journal of Renewable Energy Research*, vol. 7, no. 1, pp. 285-291, 2017. http://www. ijrer.org/ijrer/index.php/ijrer/article/view/5461.

[33] N.R.C Government of Canada, "RETScreen international home," [Online]. Available: http://www.nrcan.gc.ca/energy/ software-tools/7465. [Accessed 2015].

[34] HOMER, "HOMER energy," [Online]. Available: http://www. homerenergy.com/index.html. [Accessed 2015].

[35] T. Lambert, P. Gilman and P. Lilienthal, "Micropower system modeling with homer," in Integration of *Alternative Sources of Energy*, John Wiley & Sons, 2006, p. 504. https://www.wiley.com/en-us/Integration+of+Alternative +Sources+of +Energy-p-9780471712329.

[36] M. K. Al-Ani, "A strategic framework to use payback period in evaluating the capital budgeting in energy and oil and gas sectors in Oman," International journal of economics and

financial issues, vol. 5, no. 2, pp. 469–475, 2015. http://www.econjournals.com/index.php/ijefi/article/view/1127.

[37] F. Liu, "Von Wright's "The Logic of Preference" Revisited," *Synthese*, vol. 175, no. 1, pp. 69–88, 2010. https://link.springer.com/article/10.1007%2Fs11229-009-9530-z.

[38] Office of energy and power affairs, Energy Balances of Iran, 2012, Tehran: Ministry of Energy, 2013.

[39] W.-H. Arndt, J. Huber, R. Kämpfer and F. Nasrollahi, CO2 Balance for Buildings and Transportation in Hashtgerd New Town and Tehran Region, Berlin: Universitätsverlag der TU Berlin, 2013.

[40] P. Pourvahidi and M. B. Ozdeniz, "Bioclimatic analysis of Iranian climate for energy conservation in architecture," Scientific Research and Essays, vol. 8, no. 1, pp. 6–16, 2013. http://www.academicjournals.org/journal/SRE/article-abstract/81D638530685.

[41] Municipality of Tehran, Organization of waste Recycling and Composting (OWRC), "Baseline review of Solid Waste Management Chain, Tehran Integrated Waste Management Strategy and Implementation Plan," World Bank - IBRD, 2004.

[42] E. Crosbie, A. Sorooshian, N. Abolhassani Monfared and O. Esmaili, "A Multi-Year Aerosol Characterization for the Greater Tehran Area Using Satellite, Surface, and Modeling Data," *Atmospher*e, vol. 5, no. 2, pp. 178–197, 2014. http://www.mdpi.com/2073-4433/5/2/178.

[43] ISNA, "Iranian Students' news Agency," 11 March 2015. [Online]. Available: http://www.isna.ir/news/93122012121. [Accessed 2015].

[44] IRIB News Agency, "IRIB NEWS AGENCY," 15 June 2015. [Online]. Available: http://www.iribnews.ir/fa/news/85086. [Accessed 2016].

[45] Renewable Energy Organization of Iran, "SUNA," 8 May 2016. [Online]. Available: http://www.satba.gov.ir/en/home. [Accessed 2016].

[46] L. A. Aguilar, J. Mayer, M. H. Ghafouri, N. Khosroshahi, C. Grunder, E. Vasaf, S. Haid, S. Mahdavi, A. Mahmoudi and F. Jafarkazemi, "Enabling PV Iran, The Emerging PV Market in Iran," German Solar Association-BSW-Solar, Berlin, 2016. https://www.solarwirtschaft.de/fileadmin/media/pdf/AA_Report_BSW_Iran.pdf.

[47] M. Spath, B. Newman and J. Bultman, "Technical assistance report on Photovoltaic Splar Cell Design and Manufacturing in Iran," ECN and Climate Technology Center and Network, Petten and Copenhagen, 2017. https://www.ctc-n.org/system/files/dossier/3b/201500004._photovoltaic_solar_cell_design_and_manufacturing_in_iran._final_report.pdf.

[48] "SOLARGIS," Solargis s.r.o., [Online]. Available: https://solargis.info/. [Accessed July 2017].

[49] "Bargh News," 6 September 2015. [Online]. Available: http://barghnews.com/fa/news/10860. [Accessed 2016].

[50] NSW Department of Environment, Climate Change and Water, The wind energy fact sheet, Sydney: Department of Environment, Climate Change and Water NSW, 2010.

[51] D. Štreimikienė, T. Baležentis, I. Kriščiukaitienė and A. Baležentis, "Prioritizing sustainable electricity production technologies: MCDM approach," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 5, pp. 3302-3311, 2012. https://doi.org/10.1016/j.rser.2012.02.067.

[52] R. Masoudi Nejad, "A Survey on Performance of Photovoltaic Systems in Iran," *Iranica Journal of Energy and Environment*, vol. 6, no. 2, pp. 77–85, 2015. http://www.ijee.net/Journal/ijee/vol6/no2/1.pdf.