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SWARA/WASPAS methods for a marine current energy plant location selection problem

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ABSTRACT

Increasing energy demand in the World has led countries to use renewable energy sources as a result of kinetic energy transformations of nature's building blocks such as wind, solar, hydrogen and water. This orientation has also increased technology, creativity, research and development and applicability. With the increasing renewable energy production researches, methods that minimize the harmful effects to the nature continue to be developed. This study is about a location selection problem for Turkish first marine current energy production plant that planned to be established. In order to solve the location problem a multi criteria decision model is proposed with 4 main criteria, 12 criteria and 3 alternatives. The criteria in proposed model are weighted with the SWARA method and the alternatives determined in the model according are ranked by WASPAS method. In Turkey, with made researches applicability of energy production from marine current has expressed many times, but an actual developments on the issue until today has not been made. Therefore, "location selection problem for marine current energy plant" is the first study to be introduced to the literature with its combined application method.
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1. Introduction

With the increasing population and supply-demand balance in the world, countries need for energy is gradually increasing [1,2]. The importance of the production and use of energy has increased and thus the energy has become an integral part of the industry.

Today, factors such as supply-demand imbalance, geopolitical problems and trade wars have led countries that do not have access to fossil energy resources to seek independence for energy production, and countries have explored innovative ways such as renewable energy production to meet their energy needs. The main feature of renewable energies is that it provides its source directly or with little process from nature and its harmful effects against nature is minimum [3]. Researches based on the conversion of kinetic energies of substances into electrical energy on one hand have led to the emergence of renewable energy types such as solar sourced energy, wind sourced energy, tidal energy, marine current energy, wave energy and geothermal energy, on the other hand have increased of these energy sources usage areas.

Turkey has a great potential for meeting its energy needs from sea, because it is surrounded by the sea on 3 sides. In this study, the location of the first marine current energy plant that can benefit from the bottom current in the Turkish seas has been selected. Within the scope of the study, a multi criteria decision making (MCDM) model consisting of 12 criteria has been proposed and 3 alternative locations determined with this model are evaluated. The solution phase of the proposed model has been realized with the combined SWARA and WASPAS methods, which have expanded usage areas rapidly in recent years.

The SWARA method, which gives decision makers the opportunity to choose their own priorities and includes objective opinions rather than a compulsory scale in the ranking of the criteria, has been used to determine the weight of 12 criteria. SWARA method, which is widely used in the literature in different weighting problems, is also used for some energy researches.

Such as, Ghenai et al. (2020) analyzed sustainability indicators for renewable energy systems with SWARA/ARAS hybrid method, Zavadskas et al. (2019) analyzed energy ecological parameters of internal combustion engine by neutrosophic MULTIMOORA/SWARA, Maghsoodi et al. (2018) selected renewable energy technology by using integrated H-SWARA-MULTIMOORA approach and Zolfani and Saparauskas (2013) prioritized sustainability assessment indicators of an energy system with SWARA method [4–7].

The WASPAS method, which is based on the combination of the

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Weighted Total Model and the Weighted Product Model, which aims to preserve information loss during the evaluation phase of the alternatives, has also been used to evaluate the 3 alternatives in the study. When the studies on energy in the literature are examined, it is seen that WASPAS method is included in some studies. For example, Ilbahar et al. (2020) assessed renewable energy alternatives with Pythagorean fuzzy WASPAS method, Schitea et al. (2019) selected site for hydrogen mobility roll-up by using intuitionistic fuzzy sets based WASPAS, COPRAS and EDAS, Balezentis and Streimikiene (2017) ranked energy policy scenarios with WASPAS, ARAS and TOPSIS methods and Nie et al. (2017) solved solar-wind power station location problem by using an extended WASPAS technique with interval neutrosophic sets [8–11].

In recent years, some researchers have proposed integrated or combined methods with SWARA and WASPAS methods and used them in different problems' solutions. For example, Ulutaş (2019) evaluated university website performance by using fuzzy SWARA and WASPAS-F, Jayant et al. (2018) selected 3 PL service providers with an integrated approach with MOORA, SWARA and WASPAS methods, Urosevic et al. (2017) used these methods in a personnel selection problem in the tourism industry, Karabasevic et al. (2016) proposed an approach to personnel selection, Nezhad et al. (2015) planned the priority of high tech industries in the nanotechnology in Iran [12–16]. Especially in energy sector, Vafaeipour et al. (2014) assessed regions priority for implementation of solar projects in Iran and Heidarzade et al. (2014) selected a place for wind farms with a hybrid method [17,18].

After literature review, it is clear that this paper is the first study about marine current energy plant's location selection with SWARA and WASPAS two-stage method.

When the literature related to obtaining energy from marine current is examined, it is seen that these studies are generally related to the technical feasibility. For example, Barakat et al. (2019) proposed a model for a hybrid marine current-hydrogen active power generation system, Karnyoto et al. (2018) designed a marine current micro-hydro power plants, Segura et al. (2018) made an economic-financial modeling for marine current harnessing projects, Quesada et al. (2014) analyzed marine currents energy potential in the Strait of Gibraltar and Zhou et al. (2013) reviewed of energy storage technologies for marine current energy systems [19–23]. On the other hand, in literature there are more technical researches about the subject such as: Liu and Tan (2018) examined mixed flow pump as turbine at pump mode about pressure fluctuation intensity and vortex characteristic and also Hao and Tan (2018) examined the same pump mode about cavitation performance and radial force [24,25]. Han and Tan (2020) researched dynamic mode decomposition and reconstruction of tip leakage vortex, Liu et al. (2019) suggested a theoretical model for energy performance prediction [26,27].

Based on the literature review, it can be said, the previous studies are generally related to the technical analysis of the equipment that can be used in such a plant. Therefore, this study is different from the examples in the literature and aims to realize two purposes: The first objective is to propose a hierarchical model for selecting the most suitable location in Turkey for a first marine current energy plant and the second objective is to be the first study in literature with combining two methods (SWARA and WASPAS) in a new research area such as obtaining renewable energy from the sea.

2. Energy and its sources

Energy, which can be defined as the ability or capacity of the substance to do work, is one of the basic characteristics that show the development levels of countries. Energy has a great importance in meeting the daily basic needs, in the provision of services, in the production of products based on agriculture and animal husbandry as well as in industry. Table 1 and Fig. 1 represents distribution of net electricity consumption by sectors in Turkey.

According to Fig. 1, the net electricity consumption in industry has decreased with each year. On the other hand, the usage rate of electricity in commercial areas has increased in recent years. The electricity usage rates in remaining sectors do not show a significant change over the years.

Considering the development of civilizations, the technological equipment of the period discovered or developed in all phases of history depends on the energy resources used.

While only wind and water energy were used in the early ages, today there are lots of forms of energy production ranging from fusion reactions to nuclear power plants.

The concept of energy can be analyzed under three headings: renewable energy, nuclear energy and fossil derived energy. Natural gas, oil and coal are fossil derived energy sources. Nuclear energy is also a non-renewable energy because of the need for treated radioactive materials to meet the energy. Wind sourced, hydraulic sourced, biomass sourced, solar sourced, wave and tidal sourced and marine current turbine energy common in the oceans and seas are considered as renewable energy sources.

Another classification of energy types can be divided into renewable energy sources and non-renewable energy sources.

2.1. Non-renewable energy resources and their production in Turkey

Although the formation of non-renewable energy sources takes millions of years, they have a certain reserve in the nature and are depleted when they are used. According to Turkish Statistical Institute, Turkey produces about 70% of its electricity from non-renewable energy resources. The quantity of energy production and their energy resources are shown in Table 2 and Fig. 2.

According to Fig. 2., the amount of electricity obtained from environmentally friendly renewable energy sources is increasing day by day with the help of new researches and investments. On the other hand, liquid fuel usage rate has decreased significantly. It would not be wrong to say that the utilization rate of renewable energy sources will increase even more in the coming years with the developments regarding the return of investment and government incentives.

The types of non-renewable energy source used in the World today are as follows:

- *Coal sourced energy:* Coal is an organic rock that has the capacity to be burnt and has a very important and large share in electricity generation in the world [30,31]. It has been become the first and most used raw material with the discovery of steam machines. In addition to electricity generation, it is used in the iron and steel industry, in cement production processes and in the industrial sector to produce steam and to warm up in daily life. In the World, 40% of the total electricity production and in Turkey 32% of the total electricity production are provided from coal.
- *Petroleum sourced energy:* Petroleum is generally composed of hydrogen and carbon and contains a small amount of nitrogen, oxygen and sulfur. Global oil production in the World reached 97.4 million barrels/day in 2017, and in 2017, 33.7% of the World's energy needs was met with crude oil [32]. In order to meet increasing oil needs, Turkey tries to increase reserves with making lots of discovery researches.
- *Natural gas sourced energy:* Natural gas which is derived from crude oil is flammable, lighter than air and has no color or smell.

Table 1
Distribution of net electricity consumption by sectors in Turkey [28].

Year	Total	Household	Commercial	Government	Industrial	Illumination	Other
	(GWh)	(%)					
1980	20,398	21.5	5.6	3.0	63.8	1.4	4.7
1985	29,709	19.0	5.5	3.0	66.0	1.4	5.1
1990	46,820	19.6	5.5	3.1	62.4	2.6	6.8
1995	67,394	21.5	6.2	4.5	56.4	4.6	6.8
2000	98,396	24.3	9.5	4.2	49.7	4.6	7.7
2005	130,263	23.7	14.2	3.6	47.8	3.2	7.5
2010	172,051	24.1	16.1	4.1	46.1	2.2	7.4
2011	186,100	23.8	16.4	3.9	47.3	2.1	6.5
2012	194,923	23.3	16.3	4.5	47.4	2.0	6.5
2013	198,045	22.7	18.9	4.1	47.1	1.9	5.3
2014	207,375	22.3	19.2	3.9	47.2	1.9	5.5
2015	217,312	22.0	19.1	3.7	47.6	1.9	5.7
2016	231,204	22.2	18.8	3.9	46.9	1.8	6.4
2017	249,023	21.8	19.8	4.1	46.8	1.8	5.7

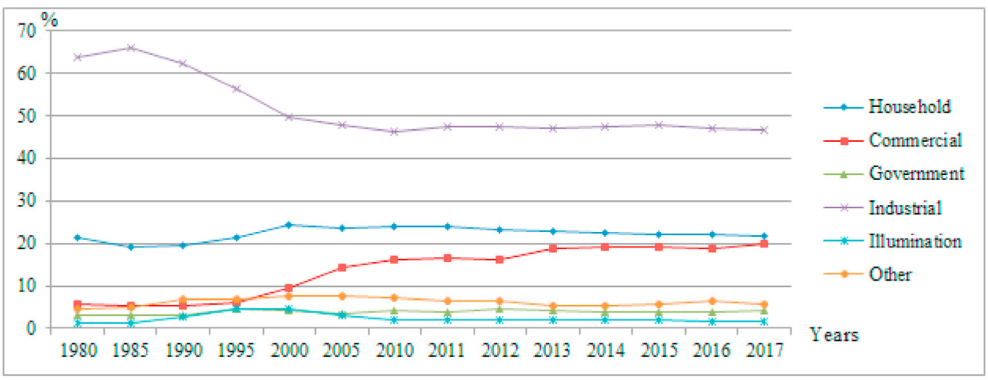

Fig. 1. Distribution of net electricity consumption by sectors.

Table 2
Electricity generation and shares by energy resources [29].

Year	Total	Coal	Liquid fuels	Natural gas	Hydro	Renewable energy and wastes
	(GWh)	(%)				
1980	23,275	25.6	25.0	–	48.8	0.6
1985	34,219	43.9	20.7	0.2	35.2	0.0
1990	57,543	35.1	6.8	17.7	40.2	0.2
1995	86,247	32.5	6.7	19.2	41.2	0.4
2000	124,922	30.6	7.5	37.0	24.6	0.3
2005	161,956	26.6	3.4	45.3	24.4	0.3
2010	211,208	26.1	1.0	46.5	24.5	1.9
2011	229,395	28.8	0.4	45.4	22.8	2.6
2012	239,497	28.4	0.7	43.6	24.2	3.1
2013	240,154	26.6	0.7	43.8	24.7	4.2
2014	251,963	30.2	0.9	47.9	16.1	4.9
2015	261,783	29.1	0.9	37.9	25.6	6.5
2016	274,408	33.7	0.7	32.5	24.5	8.6
2017	297,278	32.8	0.4	37.2	19.6	10.0

Natural gas, which can be used without process even when first extracted, can be stored and used in pipelines or in liquid form [33,34]. Recently, Turkey's natural gas resource exploration researches are being conducted with two hydrocarbon vessels on deep-sea.

- *Nuclear sourced energy:* In the production of nuclear energy; atomic nuclei fragmentation results in a very high amount of energy release with fusion reactions [35]. With the help of nuclear reactors following the reactions, this energy supplies the electrical energy, which is the most basic need of industrial and social life. Up to 11% of the World's overall electricity production is supplied through nuclear energy. Today, there are 453 nuclear power plants around the world, operating in 31 countries and 57 of them are still being built. Turkey is a country that has electricity and nuclear research capability that build nuclear power plant [36].

2.2. Renewable energy resources and their production in Turkey

The philosophy of energy production from renewable energy sources, which are found in nature and obtained result of natural

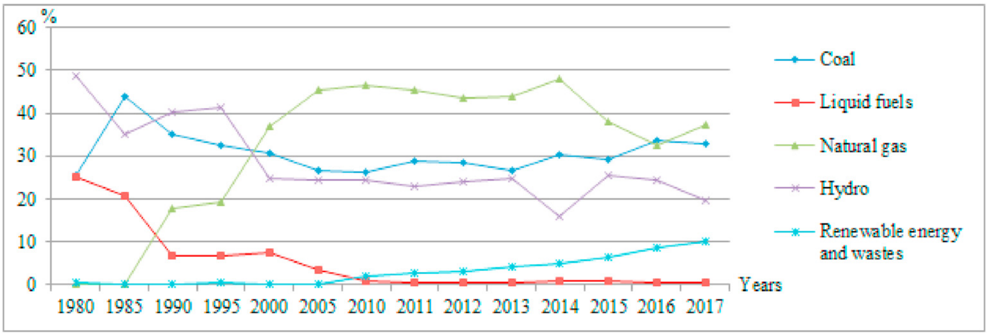

Fig. 2. Electricity shares by energy resources in Turkey.

processes, is based on the principle of obtaining positive benefit from the routine movements of the substances present in nature, namely the kinetic energies [37,38]. Renewable energy production resources, which offer a longer life compared to fossil fuels in terms of economic life, give a chance to human to meet their energy needs without dependence on raw materials.

With the increasing global awareness of global warming, most countries around the world are turning to nature-friendly energy and away from coal sourced energy production due to air pollution and serious health problems caused by this pollution. Renewable energy sources are seen as a chance for most people to solve the "Global Warming" problem. These resources are a great chance to prevent melting of glaciers, to prevent increasing the height of water, and to prevent the endangering of the lives of billions of people by correcting the wound caused by greenhouse gases in the atmosphere [39].

While wind and water mills are the first examples of renewable energy use in the world, recently it is possible to obtain environmentally friendly energy from many different sources. These resources can be listed as follows:

- *Solar sourced energy:* Solar energy is an eco-friendly technology based on obtaining energy from sunlight through the necessary equipment and systems. Solar energy is used in home-office heating, supply of hot water, electricity generation, thermal systems and solar cells. The production of electricity from solar energy is widely used in satellites, calculators, clocks, street lamps and traffic signaling applications. According to Turkey's Energy and Natural Resources Ministry's report, in Turkey annual sunshine duration according is 2741 h (7.5 h per day on average) and the annual total incoming solar energy is 1527 kWh/m^2 (daily average is 4.18 kWh/m^2) [40].
- *Wind sourced energy:* The winds are affected by the earth's rotation around its axis, surface friction, local heat distribution, topographic structure of the land and different atmospheric events in the wind direction. It is expressed by two parameters: speed and direction. Wind power plants, which are attempted to be built in high altitude areas for high efficiency, have high cost and construction problems [41,42]. Also these plants have disadvantages such as low capacity factors and variable energy production. According to Turkey Wind Energy Association report in January 2020, the installed capacity of wind power plants in Turkey in a total increase of 687 MW in 2019 rose to 8056 MW. There are 198 wind power plants in Turkey [43].
- *Hydraulic sourced energy:* Hydroelectric energy is obtained by converting the existing potential energy of water into kinetic energy. In hydroelectric energy plants, water is released from a certain height and the potential energy of water is converted to kinetic energy. The kinetic energy obtained is converted into mechanical energy by water turbines and mechanical energy is converted into electrical energy by generator system. Hydroelectric energy stations have two types such as storage capable (dams) and storage incompetent (river type). Today, there are about 597 hydropower plants in Turkey and the total production capacity of these plants is 26694.92 MW [44].
- *Geothermal sourced energy:* Geothermal resource, which is defined as underground heat, consists of hot water, steam and gases, which are composed of heat energy formed in the depths of the earth's crust. It provides energy supply by using in electricity generation and direct natural heating applications [45–47]. Turkey's geothermal energy derived 78% in western Anatolia, 9% in central Anatolia, Marmara region 7%, 5% in eastern Anatolia and other places in the region of 1% is located [48].
- Biomass sourced energy: Biomass can be defined as a species or total mass of living organisms of various species at a given time and is also considered an organic carbon. It is used in the production of plant resources, forest and forest products, animal and organic wastes, city and industrial wastes [49]. Biomass sourced energy production in Turkey has a very widespread usage. Biomass is used both as a biofuel in transportation and as a fertilizer for agricultural production. There is about 82 biomass power plants in Turkey and their total production capacity is 467.37 MW [50].
- *Hydrogen sourced energy:* The source of this energy is hydrogen. In energy systems where hydrogen is used as a fuel, the product thrown into the atmosphere is only water or water vapor [51]. Due to the depletion of fossil resources in the coming years, the use of hydrogen energy will increase Turkey should establish appropriate policies by planning the transition to the use of hydrogen [52].
- *Wave and Tidal energy:* Another way to obtain energy is to use waves. The potential energy of the waves is transformed into kinetic energy by the circular motion of water droplets [53,54]. Electricity production from wave and tidal energy is very limited. The reason for this is that the turbines need to be built close to too many waves in order to obtain high efficiency and that the wave energy turbines can be damaged in severe storms. Researches on wave and tidal energy in Turkey are continuing and there is no currently active facility.
- *Marine current sourced energy:* Energy can be generated from marine currents by using underwater turbines. The operating principle of water turbines is the same as wind energy, and kinetic energy, which consists of fluid movement and transfer, is converted into electrical energy [55]. Although the installation cost of the marine currents energy plant is high, this disadvantage will turn into an advantage over the years thanks to its long economic life [56,57]. In Turkey, Black Sea is higher than the

Marmara Sea. Due to this reason between these two leads to continuous water circulation. Also, the temperature difference and salinity differences between seas makes Turkey as a potential country for marine currents sourced energy production. Same as wave and tidal energy, researches on marine current energy are continuing and there is no currently active facility in Turkey.

Fig. 3 shows renewable energy resource examples available on different regions in Turkey.

3. Application of the combined SWARA&WASPAS method to a MCDM problem

Because of the increasing energy demand in recent years, the help of the technological competencies gives a chance to human for searching new energy production resources. The use of fossil-derived energy is very harmful to both humans and nature. Therefore, renewable energy sources that are harmless to nature and human beings, which derive their source from nature, also reduce the dependence of countries to each other about having energy. Marine current energy, which is one of the renewable energy sources, has become one of the most important research topics of recent years.

At this point, Turkey that is with three sides covered with sea has a high potential for marine current energy production. The location selection of the energy production facility planned to be built in the country is also the subject of this study. Within the scope of the study, a MCDM model consisting of 12 criteria was proposed, and 3 alternative areas identified in this model were evaluated with SWARA and WASPAS methods used respectively. While the weights of the criteria were determined by SWARA method, alternatives were ranked by WASPAS method and Fig. 4 demonstrates the schematic diagram of proposed solution methodology.

3.1. Problem definition

With its location advantage and energy needs, it is clear that Turkey can provide a better level of renewable energy production. In addition, made studies, taken steps in the country on the subject are promising for future generations and nature protection. However, despite all the satisfactory efforts in the country, which is surrounded by seas on three sides, unfortunately the necessary importance and opportunity has not been given to the marine current energy production.

In this study the problem is about the location selection for the planned marine current energy production plant in Turkey. The proposed research model is shown in Fig. 5.

3.2. Determination of decision criteria

While creating the proposed structure for the research model, renewable and non-renewable energy sources are examined in detail. Criteria to be taken into account in selecting the location for the planned marine current energy plant are determined.

The criteria that may be effective in location selection for the energy plant included in the study are shown in Table 3 together with their explanations and the literature sources obtained from.

3.3. Determination of alternatives

In recent years, state-funded feasibility studies have been carried out about marine currents energy production. With these studies, it is known that bottom currents consist of many factors such as different salinity rate of sea, temperature ratio and effects of wind regimes of region.

Dardanelles and Bosphorus are the most suitable alternatives which can provide the maximum benefit for the planned energy plant in Turkey. Therefore, 3 alternatives were identified and analyzes were conducted.

Dardanelles (A_1), Bosphorus/north (A_2) and Bosphorus/south (A_3) constitutes the marine currents energy production plant alternatives in the study.

A map of the alternative locations with the relevant data is shown in Fig. 6.

The Bosphorus connects the Black Sea with the Marmara Sea. It generally extends in the northeast-southwest direction and divides the city of Istanbul into two as the European Side and the Anatolian Side. The length of the strait is 29.9 km, the widest part is 3.6 km and the narrowest part is 698 m. There are two types of currents in the Bosphorus: surface and marine current. There is a continuous surface current especially from the Black Sea to the Marmara Sea [74,75]. This current flowing from north to south, from the throat surface, is at an average speed of 3–4 knots. The Bosphorus, which acts as a natural corridor between the two seas, is located between two different ecosystems and has a rich biological diversity.

Dardanelles connects the Marmara Sea to the Aegean Sea. The

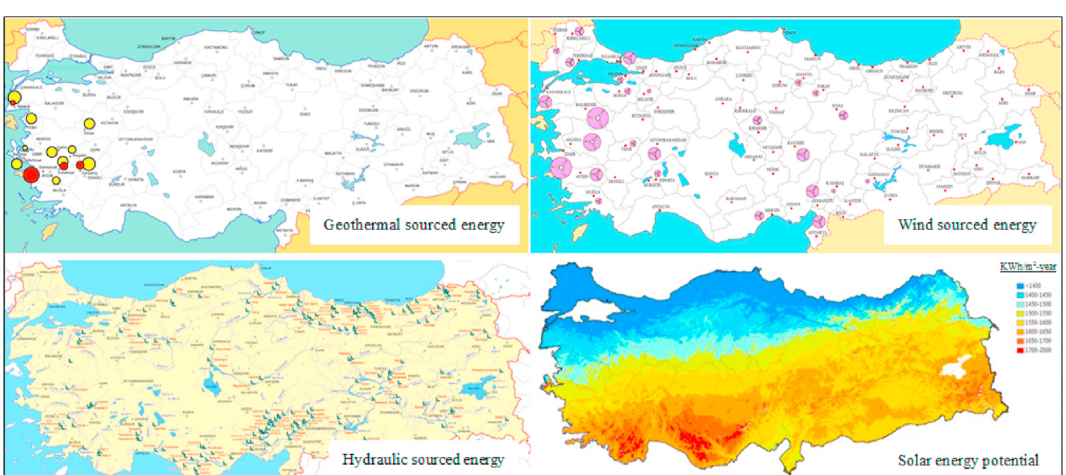

Fig. 3. Renewable energy resource examples available on different regions in Turkey [58].

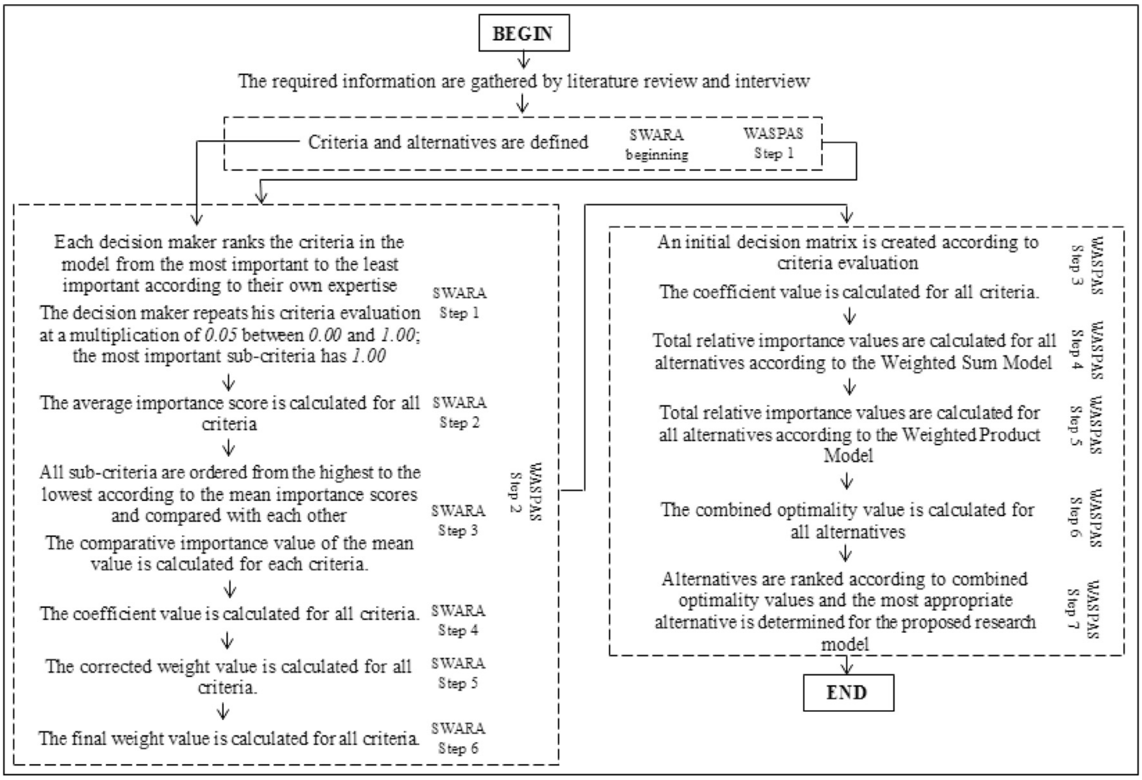

Fig. 4. The schematic diagram of proposed solution methodology.

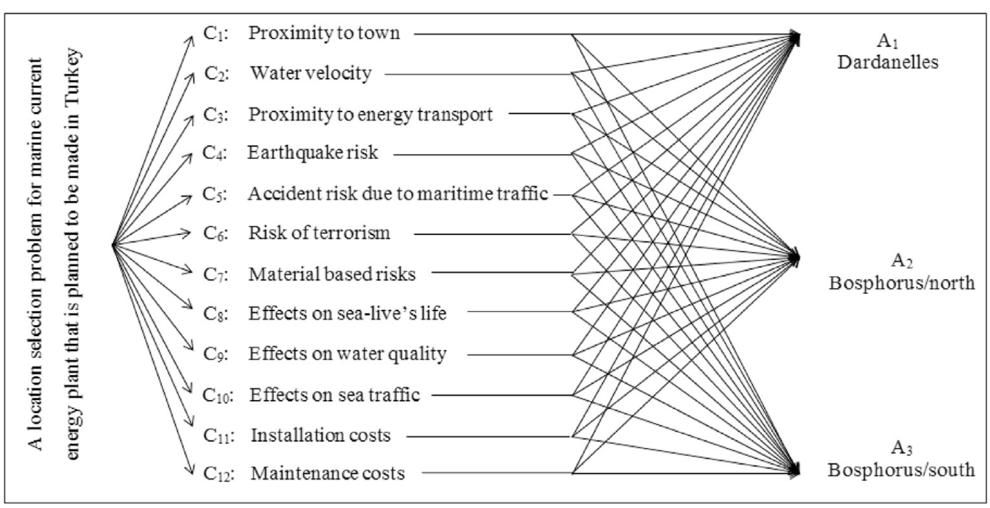

Fig. 5. Research model.

strait, which is approximately twice the length of the Bosphorus, is 61 km long and its narrowest point is 1.2 km and its widest point is 6 km. Dardanelles connects the Marmara Sea to the Aegean Sea. The strait, which is approximately twice the length of the Bosphorus, is 61 km long and its narrowest point is 1.2 km and its widest point is 6 km [75]. There are two major currents in the strait located to the north of the city of Çanakkale: The first is the surface current flowing from the Black Sea to the Aegean Sea, the second is the bottom current flowing from the Aegean Sea to the Black Sea, they flow in opposite directions to each other. There is always a steady current flowing from north to south in the Dardanelles. The current follows the geographical structure of the strait. The strait current starts at 1 knot in front of Gelibolu and increases towards the Aegean. Due to the hydrological structure of the Dardanelles is an important region that allows the species of fish, crustaceans and mollusks to live.

3.4. Assumptions

The aim of this study is to evaluate and rank three alternatives which are suitable for the applicability of technology in terms of criteria.

When evaluating the alternatives, it was accepted that the investments of the same size, same characteristics and the same

Table 3
Criteria of the research model and their explanations.

A location selection problem for marine current energy plant that is planned to be made in Turkey		
Criteria	Explanation	Resources
C_1 Proximity to town	It can be assumed that an economical structure can be established in the context of the energy transmission lines as the planned power generation facility will be close to the city. Generated energy can be converted to suitable voltage value for city and can be used easily and cheaply.	[59–62]
C_2 Water velocity	The marine current energy production facility takes advantage of the effect of the current and the high speed current provides high energy production. For this reason, the area with high current rate should be preferred for the plant that is planned to be established. The currents are mainly caused by sea temperature, salinity and altitude differences.	[60]
C_3 Proximity to energy transport lines	The marine current energy production facility should be close to the energy transport lines so that the produced energy can be transported with minimum transportation cost.	[63]
C_4 Earthquake risk	All of the marine current energy facility location alternatives planned to be established in the country is in the regions under the influence of earthquake fault lines. Planning and construction process should be managed according to this risk and additional precautions should be taken against any problems that may occur in the living areas where this energy production facility serves in case of a disaster.	
C_5 Accident risk due to maritime traffic	While evaluating alternative locations, the amount of sea traffic per square meter should be taken into consideration and the alternative with relatively low traffic should be preferred. In addition, where the water depth is reduced in the sea, the risk of collision of the lower parts of large tonnage vessels to energy production turbines is another risk to be evaluated under this criteria.	
C_6 Risk of terrorism	Renewable energy production facilities with their high cost and environmental benefits will always have the risk of terrorism. These are geopolitical structures that can be targeted in order to create crisis as a result of their high financial structure and importance.	
C_7 Material based risks	Against corrosion, the technological production equipment to be used for energy production in the facility to be established must have a structure that complies with the changeable conditions with its metallurgical structure and design.	[62,64]
C_8 Effects on sea-live's life	The type of oil used to increase the efficiency of turbines and the paints used for material equipment of power generation facility should not be of a chemical structure that would destroy the functioning of the natural habitat in the area where the turbine farm is located. This is a very important criterion for renewable energy sources, whose main purpose is to respect nature and eliminate existing pollution.	[62,63,65–67]
C_9 Effects on water quality	The impact of the planned power generation facility on the water quality is very important and it is aimed to prevent the negative effects of the facility on tourism and fishing.	[61,62,65,68,69]
C_{10} Effects on sea traffic	The alternative locations determined for the planned power generation facility are one of the most densely maritime regions of the country and the world. Although the power generation turbines do not have any traffic-enhancing effect under appropriate conditions, the presence of turbines in a narrow strait during construction and maintenance days may cause waiting and traffic.	[65]
C_{11} Installation costs	The installation costs of the facilities are high. Along with the research and development phase before the installation phase, the facilities have many outputs including field tests, material cost, energy batteries and power transmission lines. In addition, delays due to heavy traffic of the straits during the installation phase may cause additional costs.	[61,63,65–67,69–72]
C_{12} Maintenance costs	The maintenance costs of the facilities are very low. There is no additional cost after the completion of the installation, except for general system control.	[61,63,65–67,69,70,72]

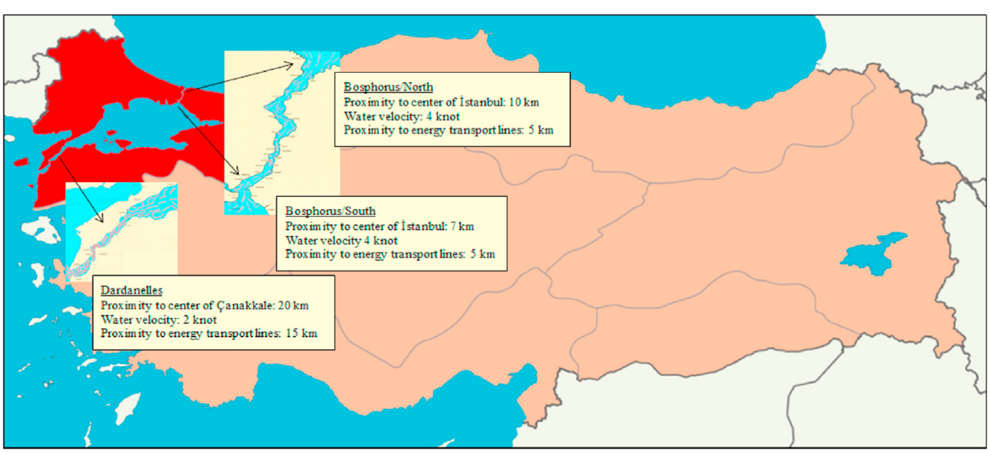

Fig. 6. A map of the alternative locations with the relevant data [73].

energy production capacity will be made.

4. Proposed solution methodology with combination of SWARA-WASPAS

In Turkey to be established marine current energy production plant location selection problem SWARA and WASPAS methods were used.

The SWARA and WASPAS methods provide ease of use, and shorten the processing time. With SWARA method decision makers achieve more objective results by not requiring using a defined scale while determining the importance of the decision criteria relative to each other. On the other hand, with WASPAS method decision makers can evaluate alternatives according to both subjective and objective criteria. In addition, the method can control the consistency in alternative rankings by conducting sensitivity analysis within its own operation.

With all these characteristics proposed solution methodology has been separated from other multi criteria decision making methods and preferred as solution method within the scope of study with these features.

4.1. The application steps of SWARA method

The "Step-Wise Weight Assessment Ratio Analysis" method was introduced by Keršuliene et al., in 2010. With this method, the criteria that should be used in the evaluation of alternatives are graded from the most important weight value to the less important value, and each criterion is voted by experts and the unimportant ones are eliminated [76].

The implementation steps of SWARA method, as schematized in Fig. 1, can be described as follows [7]:

Step 1: p_j^k is score that assigned to the *j.* criteria by *k.* decision maker ($j = 1, ..., n$; $k = 1, ..., l$; $0 \leq p_j^k \leq 1$).

Step 2: When the number of decision makers is indicated by *l*, $\overline{P_j}$ which is the average of the importance points assigned to the criteria by the decision makers is determined by the help of Eq. (1).

$$\overline{P_j} = \sum_{k=1}^{l} p_j^k \tag{1}$$

Step 3: s_j, represents the comparative importance value of the mean value for each criterion and indicates how important is the $(j+1)$. criterion according to the *j.* criteria.

Step 4: c_j is the coefficient value obtained by using Eq. (2). The coefficient of the criteria with the largest value of s_j is determined as $c_j = 1$.

$$c_j = s_j + 1 \tag{2}$$

Step 5: s'_j is the corrected weight value calculated by using Eq. (3). For the criteria which is in the first place of the ranking, $s'_j = 1$.

$$s'_j = \frac{s'_{j-1}}{c_j} \tag{3}$$

Step 6w_j is the final weight value calculated by using Eq. (4).

$$w_j = \frac{s'_j}{\sum_{J=1}^{N} s'_j} \tag{4}$$

4.2. The application steps of WASPAS method

The WASPAS method was developed by Zavadskas et al., in 2012. It combines the results of "Weighted Sum Model" and "Weighted Product Model". Alternatives are listed according to the value of the combined optimality criteria. However, the method is able to control the consistency in alternative rankings by conducting sensitivity analysis within its own operation.

The implementation steps of WASPAS method, as schematized in Fig. 1, can be described as follows [14,77]:

Step 1: Criteria (C_j) and alternatives (A_i) are determined ($j = 1, ..., n$; $i = 1, ..., m$).

Step 2: Weights of the criteria are determined by using one of the MCDM methods.

Step 3: In order to normalize the initial decision matrix, Eq. (5) and Eq. (6) are used for benefit based criteria (to be maximized) and cost based criteria (to be minimized), respectively.

$$\overline{x_{ij}} = \frac{x_{ij}}{max_i x_{ij}} \tag{5}$$

$$\overline{x_{ij}} = \frac{min_i x_{ij}}{x_{ij}} \tag{6}$$

Step 4: $Q_i^{(1)}$ is the first total relative importance value is calculated by Eq. (7) according to the "Weighted Sum Model".

$$Q_i^{(1)} = \sum_{j=1}^{n} \overline{x_{ij}} w_j \tag{7}$$

Step 5: $Q_i^{(2)}$ is the second total relative importance value is calculated by Eq. (8) according to the "Weighted Product Model".

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(\overline{x_{ij}}\right)^{w_j} \tag{8}$$

Step 6: Q_i is the combined optimality value calculated by Eq. (9). λ is the coefficient of combined optimality ($\lambda \in [0,1]$). If the Weighted Sum Model and Weighted Product Model approaches have equal effect on the combined optimality criteria, λ is equal *0.5*.

$$Q_i = \lambda Q_i^{(1)} + (1 - \lambda)\, Q_i^{(2)} \qquad \text{Eq. (9)}$$

Step 7: Each alternative is ordered taking into account the combined optimality value (Q_i). The alternative with the largest Q_i value is the best alternative and ranks first.

4.3. Application

In application phase, SWARA and WASPAS methods are used for solving the problem of selecting appropriate location for a marine current energy production plant planned in Turkey. With solution methodology, three alternative locations have been evaluated according to 12 criteria.

Step 1: First of all, a questionnaire was applied to three decision makers experienced in energy sources and renewable energy production and they were asked to list 12 decision criteria. In this ranking, the decision makers listed all the criteria by giving 1 to the criteria which is the most important and 12 to the criteria which is the most insignificant for them in location selection for the marine current energy production plant planned to be established. This ranking of the three decision makers for the criteria is shown in Table 5.

Following the ranking, the decision makers re-evaluated all

Table 4
Criteria ranking by decision makers and relative average importance scores.

Criteria		Decision Makers						Average importance scores ($\overline{P_j}$)
		DM_1	DM_2	DM_3	DM_1	DM_2	DM_3	
C_1	Proximity to town	1	3	3	1.00	0.90	0.90	0.93
C_2	Water velocity	2	4	4	0.90	0.85	0.80	0.85
C_3	Proximity to energy transport lines	8	6	6	0.45	0.75	0.70	0.63
C_4	Earthquake risk	5	5	12	0.60	0.80	0.35	0.58
C_5	Accident risk due to maritime traffic	9	10	8	0.40	0.45	0.55	0.47
C_6	Risk of terrorism	12	12	11	0.20	0.30	0.40	0.30
C_7	Material based risks	6	11	5	0.55	0.40	0.75	0.57
C_8	Effects on sea-live's life	7	7	9	0.50	0.60	0.50	0.53
C_9	Effects on water quality	10	9	10	0.35	0.50	0.45	0.43
C_{10}	Effects on sea traffic	11	8	7	0.30	0.55	0.60	0.48
C_{11}	Installation costs	4	1	2	0.75	1.00	0.95	0.90
C_{12}	Maintenance costs	3	2	1	0.80	0.95	1.00	0.92

Table 5
Ranking of average importance scores and c_j, s'_j, w_j values for all criteria.

Criteria	Average importance scores ($\overline{P_j}$)	The comparative value of the average importance scores (s_j)	Coefficient values (c_j)	Corrected weight values (s'_j)	Final weight values (w_j)
C_1	0.93	–	1.00	1.00	0.11
C_{12}	0.92	0.01	1.01	0.99	0.11
C_{11}	0.90	0.02	1.02	0.97	0.11
C_2	0.85	0.05	1.05	0.92	0.10
C_3	0.63	0.22	1.22	0.76	0.08
C_4	0.58	0.05	1.05	0.72	0.08
C_7	0.57	0.01	1.01	0.71	0.08
C_8	0.53	0.04	1.04	0.69	0.07
C_{10}	0.48	0.05	1.05	0.65	0.07
C_5	0.47	0.01	1.01	0.65	0.07
C_9	0.43	0.04	1.04	0.62	0.07
C_6	0.30	0.13	1.13	0.55	0.06

criteria between *0.00* and *1.00*, they gave *1.00* point to the criteria that they think is most important in solving the problem. Thus, p_j^k values were obtained for each criterion.

Step 2: Relative average importance score ($\overline{P_j}$) was calculated for all criteria using Eq. (1) and the results are shown with p_j^k values in Table 4.

Step 3: According to the relative average importance scores, all criteria were ranked from larger to smaller. For all criteria the comparative value of the average importance scores (s_j) were calculated and these values are shown in Table 3. All criteria were reordered according to their comparative importance as $C_1 > C_{12} > C_{11} > C_2 > C_3 > C_4 > C_7 > C_8 > C_{10} > C_5 > C_9 > C_6$.
Step 4: c_j coefficient value was calculated for all criteria by using Eq. (2).
Step 5: The corrected weights ($s_j^{'}$) were calculated for all criteria by using Eq. (3). In this calculation, for the first criterion s'_j value was equal to *1.00*.
Step 6: The final weights (w_j) were calculated for all criteria by using Eq. (4). The obtained c_j, s'_j and w_j values for 12 criteria are shown in Table 5.

Step 7: At the end of the calculations the alternatives were sequenced taking into account the combined optimality value (Q_i). The ranking of the alternatives was obtained as $A_2 > A_3 > A_1$. As shown in Table 8 having the highest Q_i value alternative A_2 is the most suitable alternative location for marine current energy production plant planned to be established in Turkey. This energy production plant should be built on the northern entrance to the Bosphorus according to the obtained results.

After calculating the weights of the decision criteria with the SWARA method, WASPAS method was used in the ranking of alternatives and three alternative locations were evaluated in terms of their suitability according to proposed model.

Step 1: Alternative locations (A_i, $i = 1, 2, 3$) that may be suitable for the marine current energy production plant were evaluated according to the criteria (C_j, $j = 1, \ldots, 12$). Among the criteria, water velocity (C_2) is a benefit based criteria and others are cost based criteria ($C_1, C_3, C_4, C_5, C_6, C_7, C_8, C_9, C_{10}, C_{11}, C_{12}$). The benefit based criteria should be maximized and the cost based criteria should be minimized.
Step 2: The SWARA method was used to determine the weights of criteria according to decision makers' evaluations. The obtained weights of the criteria are given in Table 5.
Step 3: After determining the criteria weights by SWARA method, initial decision matrix was created as shown in Table 7. These data regarding the location alternatives in this decision matrix were obtained through the characteristics of the alternatives. The values those the alternatives take for earthquake risk, accident risk due to maritime traffic, risk of terrorism, material based risks, effects on sea-live's life, effects on water quality, effects on sea traffic, installation costs and maintenance costs were obtained by the decision makers' joint evaluation between *1-5*. (*1 = the worst, 5 = the best*). In Table 6, proximity to town is expressed in km, water velocity is expressed in knot and proximity to energy transport lines is expressed in km.

After the creation of the initial decision matrix, the normalized decision matrix was formed by using Eq. (5) for benefit based criteria and by using Eq. (6) for cost based criteria. The obtained normalized decision matrix is shown in Table 7.

Table 6
Initial decision matrix.

Alternatives	Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
		min	*max*	*min*	*min*	*min*	*min*	*min*	*min*	*min*	*min*	*min*	*min*
A_1	Dardanelles	20	2	15	3	4	2	2	2	5	3	4	4
A_2	Bosphorus/North	10	4	5	3	5	3	4	3	3	4	4	5
A_3	Bosphorus/South	7	4	5	5	5	4	4	4	3	4	5	5

Table 7
Normalized initial decision matrix.

Alternatives	Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	Dardanelles	0.35	0.50	0.33	1.00	1.00	1.00	1.00	1.00	0.60	1.00	1.00	1.00
A_2	Bosphorus/North	0.70	1.00	1.00	1.00	0.80	0.67	0.50	0.67	1.00	0.75	1.00	0.80
A_3	Bosphorus/South	1.00	1.00	1.00	0.60	0.80	0.50	0.50	0.50	1.00	0.75	0.80	0.80

Table 8
$Q_i^{(1)}$, $Q_i^{(2)}$ and Q_i values of alternatives.

Alternatives		$Q_i^{(1)}$	$Q_i^{(2)}$	Optimality value of alternatives (Q_i)
A_1	Dardanelles	0.7964	0.7360	0.7663
A_2	Bosphorus/North	**0.8321**	**0.8163**	**0.8242**
A_3	Bosphorus/South	0.7906	0.7677	0.7791

Step 4: For each alternative, the total relative importance value ($Q_i^{(1)}$)was calculated by using Eq. (7) according to the Weighted Total Model. The obtained values are shown in Table 8.

Step 5: Then, for each alternative, the total relative significance value ($Q_i^{(2)}$) was calculated by using Eq. (8) according to the Weighted Product Model. The obtained values are given in Table 8.

Step 6: For each alternative, the combined optimality value was calculated by using Eq. (9). In the calculation of Q_i values, $\lambda = 0.50$ was assumed. Q_i values for all alternatives are shown in Table 8.

4.4. Findings

With SWARA method's application steps, the weights' of criteria were obtained for a proposed research model about location selection problem for marine current energy production plant planned to be established in Turkey. Among 12 criteria, the most important three criteria with weight ratio of *0.11* were proximity to city (C_1), maintenance costs (C_{12}) and installation costs (C_{11}).

After determining the weights of criteria by SWARA method and the order of alternative locations was obtained by WASPAS method. According to obtained results from made calculations, alternatives are listed from large optimality value to smaller values such as $A_2 > A_3 > A_1$. Thus, it was found that the northern entrance of Bosporus is the most appropriate location for marine current energy production plant planned to be established. This best alternative was followed by the Bosphorus/south (A_3) and lastly, the Dardanelles (A_1) took the third place.

In the calculations of the combined optimality value, $\lambda = 0.5$ was taken similar to the examples in the literature. Also the orders of obtained values of $Q_i^{(1)}$ and $Q_i^{(2)}$ were the same as the Q_i order. Because of this sequence, the results were found to be consistent and there was no additional consistency analysis required.

5. Conclusion

Due to increasing energy demand in the world, with the development of technology in recent years, many types of production related to non-renewable and renewable energy have been developed and production plants have been established. With the increase in energy demand, the increasing nature-based sensitivity and the fact that fossil derived energy resources have strategic importance among countries have increased the importance of renewable energy resources.

Though the discovery of marine current energy production that is one of the renewable energy sources was made many years ago, in Turkey there has not been achieved a significant improvement on the issue. Although Turkey is the one of the most suitable countries for the production of this type of energy, the researches have been made with more technical and economical perspectives on the subject. The effects of such a production plant on the nature and human life are not searched in the literature comprehensively.

With this point of view, in this paper a two-stage combined methodology of SWARA and WASPAS is proposed for the location selection of the plant where the production of marine current energy, one of the renewable energy resources, will be carried out.

Suggested solution methodology and calculation of the weight of the criteria determined within the scope of the proposed model were made to evaluate the alternatives. As a result of the solution, Bosphorus/north was determined as the most suitable location among alternatives for the marine current energy plant that planned to be established by the government within the framework of the determined criteria.

In the literature, there is no model to assess the problem of selection the most suitable location for marine current energy plant. Therefore, this study is the first in terms of the model and applied techniques which are established in the sectoral sense.

While in literature there are some researches about technical manner, the proposed model has contributed to the literature with its originality. According to European Commission's report, there is the potential to create 20,000 jobs throughout the supply chain of the marine energy sector by 2030 [78]. This paper can be helpful for the countries that plan to establish any kind of marine energy projects to be established.

In the future, it is possible to diversify the evaluations with different criteria that can be added to the model. On the other hand, the same problem can be solved with proposed model by different multi criteria decision making methods.

CRediT authorship contribution statement

G. Nilay Yücenur: Conceptualization, Methodology, Supervision, Writing - review & editing. **Ahmet Ipekçi:** Investigation, Methodology, Formal analysis, Writing - original draft, preparation.

Declaration of competing interest

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

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