INTERNATIONAL JOURNAL OF
COASTAL, OFFSHORE & ENVIRONMENTAL ENGINEERING IJCOE Vol.7/No. 4/Autumn 2022 (7-16)

Available online at: www. Ijcoe.org

Prioritize Renewable Energy Resources in Main Iranian Ports Area Using AHP Method

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ARTICLE INFO

Article History:
Received: 07 Oct. 2022
Accepted: 14 Feb. 2023

Keywords:
Solar Energy
Wind Energy
Wave Energy
Current Energy
Iranian main Ports

ABSTRACT

The use of renewable energies is inevitable due to the limitations of fossil fuels, pollution, and the global increase in energy consumption. Renewable energies are various, so selection and investment in the best option in each region are complicated and depend on multiple parameters. For this reason, this study has used Analytical Hierarchal Process (AHP) to prioritize renewable energy sources in Iran's main ports (located in the Caspian Sea, Oman sea, and the Persian Gulf). The AHP is among the most widely used methods in multi-criteria decision-making in many fields and can include different and contradictory criteria. Renewable energies, including solar, wind, wave, and current, have been analyzed in the main ports' area (5 km radius in sea and port hinterland). The results show solar (photovoltaic) and wave energies are the first and second priorities in all southern ports except Imam Khomeini Port. Imam Khomeini Port is the only port where the current energy is unignorable. In the northern ports, wind energy is the primary option for investment. Wave energy can be exploited only in the Shahid Beheshti Port of Chabahar, located on the Oman Sea shores and directly connected to the open sea. In the ports of Khuzestan province, the photovoltaic power potential is lower than in other southern ports despite the very high solar direct normal irradiation.

1. Introduction

Due to the increased population and industrialization of the countries, including developing countries like Iran, more countries use renewable energies. Countries worldwide seek clean energy resources to align their production and activities with environmental frameworks. Moreover, the regulatory requirements of each country direct legal institutions and private persons toward using this type of energy [1].

In recent years, Iran has aimed to use this kind of energy through the non-governmental investment of 126000 billion rials in clean energies. In the fifth strategic development plan, it is established that portion of renewable energy in supplying electricity becomes 10 percent of the country's electricity demand until the end of the plan. Nevertheless, renewable energies yet supply less than 1 percent of electricity demand in the country; until May 2019, total electricity generation by wind, solar, heat recovery, small hydro, and biomass power plants were 3.5 MWh [2]. Until May 2019, wind, solar, small hydro, and heat recovery energies included 45, 35, 16, and 2 percent of total electricity generation using renewable energies in Iran [3].

Iran has a great potential for employing renewable energies by having coasts of about 5800 km in the Persian Gulf, Oman Sea, and Caspian Sea. However, due to economic and sometimes technical reasons, the share of renewable energies in electricity generation is very low [4].

Harvesting energy from the sun does not require advanced and costly technologies; therefore, it is a useful resource to provide energy in most locations worldwide. Currently, solar energy is harvested by various systems, including photovoltaic, thermal, and refrigeration systems [3]. Among renewable energies, wind energy is one of the most known renewable energy types and based on plans given by the international energy agency, until 2050, about 5100 TWh of electricity generation in the world will be from wind energy [5]. Global installed wind-generation capacity onshore and offshore has increased by a factor of almost 75 in the past two decades [6].

Iran made valuable actions toward using wind energy by having various windy areas. Based on the available data, wind power plants of about 110 MW have been established in the country, and its electricity generation is transported to the electrical grid. Based on the atlas provided by SATBA (Iranian Renewable Energy & Energy Efficiency Organization), the obtainable energy from wind resources is estimated at about 18000 MW, showing the high potential and cost effectiveness of investment in wind power plants in the country [3].

Wave energy can be regarded as a centralized form of solar energy. Winds are created from temperature differences on the ground, and produce waves by flowing over ocean and sea. The transferred energy depends on wind strength, wind duration and fetch. The West coasts of the USA, Europe, Australia, and New Zealand have the most energetic waves in the world [7].

Tidal energy is one of the other renewable resources created from the earth-moon-sun system's cinematic and gravitational interaction forces. Harvesting tidal energy is done through two tidal stream generators (using tidal flow) and tidal barrage methods [8].

General policies of the country are to pay more attention to green ports that is required to increase the use of renewable energies in port operation. This shows the importance of harvesting clean energy in the country. Nowadays, this phenomenon is known as an energy portfolio. Due to its complicated and extensive parameters and components effective on energy policies in each country, standard methods such as mathematical modellings do not meet the requirements of this field. Therefore, multi-criteria decision analysis is used extensively by researchers to solve problems of this type [1].

In a research conducted by Taiebi and Sanaei (2015), feasibility of constructing a wind farm in Makran coast in 8 regions was studied. The main factors in this feasibility can be classified into three environmental factors, economic parameters, and human factors types. The environmental factors that have the main role in selecting the construction site of offshore wind farms include coast characteristics, hydrodynamic conditions of the region, and velocity and continuity of the wind flow in the desired elevation. In this research, wind energy is technically usable only when its velocity is between 5 and 25 km/h. In addition to wind velocity, the continuity of the wind flow and the percentage of days in the year when the minimum required velocity for turbine performance is available effectively define the wind turbine's construction site [9].

Szurek et al. (2014) aimed to determine the suitable sites in the land to establish wind farms in southwestern Poland using AHP analysis. In this evaluation, wind velocity is considered a minimum of 6 m/s and locating limitations such as distance from populated regions (a minimum of 500 meters), distance from the forest (a minimum of 250 meters), and others are taken into account [10]. Yue and wang (2006) studied the potential for using renewable energies such as wind, solar, and biomass in southwestern Taiwan by applying the hierarchy analysis method. Wind velocity (a minimum of 6 meters per second), distance from city (a minimum of 500 meters), distance from the village (a minimum of 250 meters), and distance from the environmentally sensitive area (a minimum of 250 meters) are some of these criteria [11].

Coasts in the south of Australia are one of the most potent regions in the world for electricity generation from sea waves. Therefore, some of the companies in Australia aimed to establish wave energy conversion devices in pilot points. One of the government's goals is to orient and organize these power plants. In this regard, Flocard et al. (2016) used multi-criteria analysis for zoning and selecting the best points for extracting wave energy on these coasts. In this research, the minimum significant wave height (Hs cut-off) is 1 meter, and the minimum operating power of the wave is selected as 10 kilowatts per hour. Also, a minimum distance from environmentally protected areas of 1000 meters, a minimum distance from sea oil and gas pipelines of 500 meters, and a minimum distance from shipping lines of 500 m are selected [12].

Morim et al. (2016) studied the wave energy power in New South Wales using 31-year predicted data from the SWAN model. In this research, in addition to classifying the wave energy power into seasonal and annual, the wave energy distribution based on its height and period are obtained in points with high energy potential. In these graphs, the height and period of the wave were divided into 0.5 meters and 0.5 seconds, respectively, and the duration of occurrence during the measurement is fitted in rectangles. Also, the color of each rectangle indicates the corresponding wave energy [13].

Lari et al. (2012) used Mike 21 spectral numerical modelling to estimate wave energy density in Anzali offshore area. In this study, harvestable energy density from wave, wave power, wave power density, and wind power density are computed at 0.66 kW/m^2, 2.187 kW/m, 125.53 W/m^2, and 10.396 W/m^2, respectively, and six Pelamis wave energy converters with a power of about 4.5 megawatts are suggested [14].

Saket and Etamadi Shahid (2011) used SWAN numerical modelling and 23-year statistics (1985-2007) of measured wind in the Chabahar weather station to compute changes in wave energy for the mentioned period and estimated the obtainable energy from the wave in mean annual value. Their results indicate that waves create the major portion of annual energy with a significant wave height of less than 1 meter and a period between 4 and 8 seconds for peaks. The mean annual energy obtainable in the Chabahar region is estimated to be more than 2 kW in unit wave width [15]. Bahmanzadegan et al. (2021) modeled wind-driven waves and estimated wave energy in

Chabahar Bay. The average of annual extractable power related to wind waves in the southern parts of Chabahar Bay was calculated from the order of 3 kW/m [16].

Iran is one of the capable countries in terms of receiving solar energy and mean annual sunshine hours of more than 2900 hours, and in the future, solar energy will provide a significant portion of the consumed energy in the country. Several projects and scientific activities have been conducted to select the proper point for constructing solar power plants in Iran and around the world. By examining most of these studies and comparing them with ecological and climate conditions, one unity of procedure can be achieved in this regard. Solar radiation and its received energy are one of the most crucial criteria in solar energy. Due to Iran's constant level of solar radiation, a simple map with a constant weight is entered into the hierarchy analysis. Some of the main criteria for locating solar power plants in Iran are physical land characteristics (elevation, slope, land stability, faults, mines, and sands), biological factors (vegetation and land use, environmental areas, and population of regions), economical-social factors (communication lines), technical factors (power lines and energy harvest), and infrastructures (special facilities such as airports, dams, refineries, gas and oil pipelines and power plants) [1-3].

Zabihian and Fung (2011) used tidal data to evaluate 36 sites with tidal energy potential. Based on their results, Mahshahr port has the greatest basins and is the best potent site for harvesting tidal energy. Also, in this study, it is mentioned that economic energy harvesting from tidal flows required a minimum velocity between 2-3 meters per second. Thus, due to low flow velocities in the Persian Gulf, harvesting energy in most areas is not cost-effective [17].

Mahmudof and Chegini (2014) evaluated the tidal renewable energies in Khur-e-Musa using CHOERENS and BOM numerical models. Hourly averaging in one month of flow energy in the model demonstrated that the highest flow energy value is 0.65 MWh. This research showed that according to the known technologies in the world regarding harvesting tidal wave energies, these values are lower than the minimum required value and are not economically feasible [18].

Kahak wind farm, floating solar power plants in Isfahan and Zabol, the thermal power plant in Yazd, and the wind power plant in Manjil and Binaloud are some of the projects conducted in the country to obtain renewable energy. Also, Imam Khomeini port special zone is one of the pioneer ports in the country in harvesting clean solar energy.

Some of the pioneer ports in deriving renewable energy in the world are the energy hub in Ireland, entailing Cork port and its surroundings in a land of 388 hectares, including energy infrastructures, Ostende port in Norway (known as energy port), Southhampton port in England by installing 2000 solar panels on the roof of buildings and Rotterdam port in the Netherlands with a total of 3100 solar panels.

Moreover, European Maine Energy Centre (EMEC) is the first centre in the world working on the development of tools and technologies for deriving electricity from tidal and wave flow energies. This centre is located in northeastern Scotland and has a great potential for harvesting renewable sea energies due to its 6.8 meters of wave height, 3.7 meters per second of flow velocity, and 12 meters per second of wind velocity [19].

Today, more than 90% of world trade is carried out through sea transportation. Therefore, the development of ports as the communication gateways of the country in the direction of sea-oriented development is mandatory. Also, the existence of efficient and active ports plays an essential role in the economic and industrial development of the country. The Persian Gulf is the world's energy bottleneck in the south of Iran, and the Oman Sea has direct access to open waters. In the north of Iran, there is the Caspian Sea, the best maritime communication route between Iran, Russia, Kazakhstan, Turkmenistan, and Azerbaijan. For this reason, Iranian ports play a vital role in the region's economic, commercial, and industrial development [20].

In this paper, hierarchy analysis is used to prioritize renewable energies in main country ports and for the optimal installment of facilities. This method is one of the most applied multi-criteria decision-making methods. In this method, the decision-making problem is broken down into its criteria, and therefore, the multi-criteria decision-making model is prepared in a hierarchy. Priority or relative importance of decision-making criteria is determined by pairwise comparisons [21, 22]. Also, due to the importance of decisions during the decision-making process, a combined structure of quantitative and qualitative parameters is created based on previous research, and the results were used by ArcGis 10.3 for zoning the use of renewable energies in the main ports [11, 23].

In summary, for each of the 13 main ports in the country, first, the priority of renewable energies in each port and then the relevantoptimal places are determined. For this purpose, the analytic hierarchy process (AHP) and ArcGis 10.3 are used. The studied energies are solar, wind, tidal and current energies.

2. Materials and methods

2.1. Location of the studied area and used data

In this research, the feasibility of using renewable energies in sea and land areas of 13 main ports in the country, including Shahid Beheshti, Jask, Shahid Bahonar, Shahid Rajaei, Lengeh, Asaluyeh, Bushehr, Imam Khomeini, Abadan, Khorramshahr, Amirabad, Nowshahr, and Anzali ports located at Oman, Persian Gulf, and Caspian seas are studied. For each port, the study area limits to a 5 km radius in the sea and port hinterland. Figure 1 shows the location of these ports on the map.

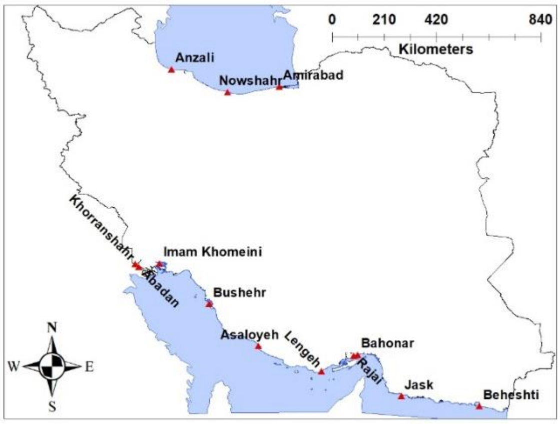


Figure 1. Location of 13 Iranian main ports as study area [24]

Since the feasibility and priority of using renewable energies in the main ports of the country are the main goals of this research, the preparation of basic data for each of these energies is required. These data include solar irradiation, wind, waves, and tidal data.

In the area of studied ports, the solar irradiation and wind data are provided by the world bank, accessible in websites Global Solar Atlas and Global Wind Atlas, respectively. Solar energy information includes photovoltaic power potential (Kwh), global horizontal irradiation (Kwh/m^2), diffuse horizontal irradiation (Kwh/m^2), global irradiation for optimally tilted surface (Kwh/m^2), optimum tilt to maximize yearly yield (º), and direct normal irradiation (Kwh/m^2) in Raster file with Spatial accuracy of 1 km in daily and annual mean values from 1999-2015 data. The utilized wind data has Spatial accuracy of 1 km at the height of 50 meters. The Global Wind Atlas provides both wind energy potential zone and frequency of occurrence of mean wind velocity and wind energy power in the ports' region.

For information required from waves, the data from buoy networks of ports and maritime organizations (PMO) in ports' area and Iranian Sea Waves Modelling (ISWM) during 1999-2003 with the spatial resolution of 0.125 degrees and a temporal resolution of 1 hour are used. For each buoy, there is at least one year of continuous data [25]. Noting that the D/L ratio is higher than 0.5, the deep-water conditions exist and relation $P = 0.49(H_S)^2T\_e$ can be used to compute wave energy power and relation $T_e = 0.9T_P$ can be used to calculate wave energy periods. In these relations, P is the wave energy power (Kw/m), Hs is the significant wave height (metre), T_e is the wave period (second), and T_P is the wave peak period (second) [17].

Based on the previous studies, it is evident that deriving flow energy in Iran seas is not economically feasible. Therefore, in this research, the flow energy is used only in Khur-e-Musa and based on 1-month flow modelling. Additionally, the tide stations of (PMO) in Khur-e-Musa are used.

2.2. Research method: Analytic hierarchy process (AHP)

The analytic hierarchy process is one of the most efficient decision-making techniques proposed by Al-saati in 1980 [26]. In this method, comparisons are performed pairwise, and different scenarios for managing decision-making are examined [22]. This process is a flexible, robust, and simple analytical technique and is applied when decision-making criteria are numerous, contradictory, and complicated and selection between choices is difficult [21]. In addition to simplicity and flexibility, controlling logical consistency of the judgements used in defining priorities, final rating of the options, and employing group ideas are the reasons behind using this method [27, 28]. The analytic hierarchy process begins with identifying and prioritizing decision-making components. These components include goals and criteria and possible options and indices that are used in prioritization. The analytic hierarchy process consists of 5 steps 1-Creating hierarchy, 2-Determining the importance coefficient of criteria and subcriteria, 3-Determining the importance coefficient of the kinds, 4-Determining the final points of options and 5-Examining the consistency in decisions that must be performed stepwise. The analytic hierarchy process includes identifying components and the connection between them. The structure is hierarchy component due to the fact that the decision-making components can be summarized at different levels. They are compared pairwise to determine the importance (weight) of the criteria and subcriteria. The basis of the judgement is a table with 9 quantities in which the superiority of criterion i to criterion j is defined based on the rating goal. In Table 1, the rating process of criteria is proposed [27, 29, 30]

Table 1. Ranking of criteria in AHP

Ranking (intensity of importance)	Definition	Description
1	Equal importance	In research, two criteria have equal importance
3	Slightly more importance	Experience shows that achieving a particular objective i is more important than j
5	More importance	Experience shows that achieving a particular objective i is more important than j
7	Greatly more importance	Experience shows that achieving a particular objective i is greatly more important than j
9	Absolute importance	Importance of i over j has been proven substantially
2,4,6,8	Mid-interval importance	This is true when middle importance is the case.

The desired options of this research to harvest energy in ports' area (land and sea) include 1-Coast wind energy, 2-Wind energy nearshore, 3-Solar energy on the land, 4-Floating solar energy, 5-wave and 6-Flow energy.

Since the initial purpose of this research is to prioritize the use of these energy resources in the main ports of Iran, first, a list of criteria and limitations effective in the decision-making process of this field was determined by examining the library documents and authoritative international references on energy management and planning. For the evaluation of these criteria and limitations, the analytic hierarchy process was used. Therefore, for pairwise comparisons, Delphi questionnaires were prepared, completed, and analyzed using international references and experts' opinions. After collecting all required pairwise comparisons, four following stages were performed for AHP calculations. First, a square matrix was formed in which rows and columns are decision-making criteria. In the second stage, the criteria were compared pairwise, and the importance of each as compared to the opposite criterion was determined using a number between 1 and 9. In this matrix, the main diagonal is always 1, and the values below the matrix diagonal are inverse of the values in above. Normalization of the pairwise comparison matrix (division of each number by the sum of its column) was conducted in the third stage. In the end, the average values in each normalized matrix row in the previous stage, which indicate the criterion's weight, were computed. In Table 2, a pairwise comparison matrix of the main criteria is given [23, 31, 32]. The consistency index and ratio were estimated for the pairwise comparison matrix. When the consistency ratio is less than 0.1, the matrix is consistent, and the weights' results are valid; otherwise, pairwise comparisons must be revisited [33].

Table 2: Pair comparison and final weight of renewable energies

	Wave	Current	Wind	Solar	Weight
Wave	1	1	1.2	1.3	.14
Current	1	1	1.2	1.3	.14
Wind	2	2	1	1.3	.23
Solar	3	3	3	1	.49
Inconformity rate: 0.02					

2.3. Criteria and limitations of renewable energies

To justify the extraction of renewable energies, the relevant power for each port must be computed. In this regard, for each renewable energy, first, the minimum acceptance criterion is determined, and then, the relevant limitations are defined based on the environmental and infrastructural conditions. These limitations and criteria are listed in Tables 3-6 for solar, wind, wave, and flow energies [12, 13, 27, 34-40].

After determining the criteria and limitations of each renewable energy, layers for each of the energies, solar, wind, wave, and flow, were outlined using ArcGis 10.3 and based on boolean algebra (zero-one logic). In this method, the input maps are combined using operators (AND, OR logical union and intersection) [23, 41].

Table 3. Limitation and criteria for selection of solar energy

Type	Parameter	Value
Criteria	Solar radiation	Minimum 4.5 kWh per m^2
	Panel slope	1-3%
Limitation	Distance from ecological areas	Minimum 2500m
	Distance from local airports	Minimum 2500m
	Distance from oil and gas transportation lines	Minimum 500m
	Distance from gravel grounds	Minimum 2000m
	Distance from electric grids	Minimum 100m
	Distance from protected areas	Minimum 2000m

Table 4. Limitation and criteria for selection of wind energy

Type	Parameter	Value
Criteria	Wind speed	Minimum $6ms^{-1}$ at 50m height and minimum $7ms^{-1}$ at 80m height
	Wind energy power	Minimum 200KW per m^2
Limitation	Water depth (marine turbines)	Maximum 40m relative to CD
	Distance from shoreline (Marine turbines)	Minimum 1000m
	Distance from shipping lines (marine turbines)	Minimum 1000m
	Distance from protected areas (marine turbines)	Minimum 1000m
	Distance from oil and gas undersea pipelines	Minimum 1000m
	Distance from ecological areas	Minimum 1000m
	Distance from airport	Minimum 2500m
	Distance from city	Minimum 500m
	Distance from bird migration routes	Minimum 500m
	Distance from power transmission lines	Minimum 250m
	Distance from road	Minimum 150m

Table 5. Limitation and criteria for selection of wave energy

Type	Parameter	Value
Criteria	Wave height	Minimum 4.5 KWh per m^2
	Wave power	Minimum 10KW per m
Limitation	Distance from protected areas	Minimum 1000m
	Distance from undersea oil and gas pipelines	Minimum 500m
	Distance from shipping lines	Minimum 500m

Table 6. Limitation and criteria for selection of water current energy

Type	Parameter	Value
Criteria	Minimum current peak speed in high water condition	2.5 ms^{-1}
Limitation	Distance from protected areas	Minimum 1000m
	Distance from oil and gas transportation lines	Minimum 500m
	Distance from shipping lines	Minimum 500m

Table 7. List of values of each parameter for wave, solar, wind and current energy

Parameter	Range of values	Rank
Wave power energy	<10 kW/m	0
	10< <20 kW/m	1
	20< <30 kW/m	2
	>30 kW/m	3
Solar energy power	<4.5 kWh/kWp	0
	1600 < <1650 kWh/kWp	1
	1650< <1675 kWh/kWp	2
	1700< <1725 kWh/kWp	3
	1725< <1750 kWh/kWp	4
	>1750 kWh/kWp	5
Wind energy power	<200 W/m2	0
	200< <300 W/m2	1
	300< <400 W/m2	2
	400< <500 W/m2	3
	>500 W/m2	4
Water current speed	< 2.5 m/s	0
	2.5< <2.6 m/s	1
	2.6< <2.7 m/s	2
	2.7< <2.8 m/s	3
	>2.8 m/s	4

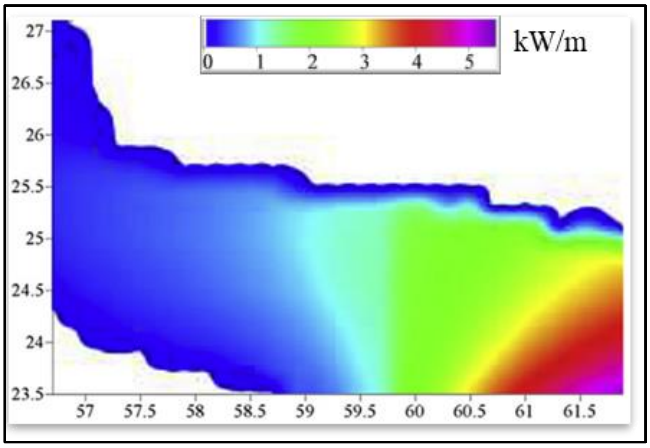
3. Results and discussion

The first step in determining the prioritization of renewable energies in each area is to define the power of each energy and deal with the criteria and limitations of each of them. The power of solar and wind energies is derived directly from the global wind atlas and global solar atlas. Table 8 shows the data for solar and wind energies. Additional to mean wind velocity, the percentage of total annual days in which wind had a velocity lower than 2 metres per second is effective in the calculation of the mean density of wind energy power. These data show direct solar irradiation is highest in Khorramshahr and Abadan, while photovoltaic power potential maximizes in Shahid Beheshti and Jask ports. Northern ports, especially Anzali port, have the lowest potential for harvesting solar energy. Regarding wind energy, Khorrahmshahr and Anzali ports had the highest and lowest mean wind power density, respectively. Despite the higher direct irradiation in Khorramshahr and Abadan ports in Khuzestan province, the photovoltaic power potential in these ports is not the maximum. One of the reasons for this is the reduced efficiency of photovoltaic systems due to high temperatures and pollution, and dust in these regions.

Table 8. power of wind and solar energy obtained from the long-term solar and wind World Bank information within the limits of each port.

Port	Wind Speed Average (ms^{-1})	Average Wind Power Density (Wm^{-2})	Photovoltaic Power Potential (Kwh/Kwp)	Direct Normal Irradiation (Kwh/M^2)
Amirabad	4.7	161	1389	1307
Nowshahr	3.6	123	1218	1052
Anzali	3.85	121	1201	990
Khorramshahr	7.12	411	1665	1841
Abadan	6.8	395	1685	1880
Imam Khomeini	6.62	351	1659	1827
Bushehr	5.65	273	1678	1814
Asaloyeh	6.21	399	1679	1725
Lengeh	5.4	217	1685	1620
Shahid Bahonar	4.8	260	1697	1660
Shahid Rajai	4.8	186	1693	1657
Jask	5.5	243	1754	1810
Shahid Beheshti	6.2	271	1770	1814

Regarding the wave and flow energy powers, the conducted modelling and calculations are used. In Figure 2, the zoning map of total (annual) wave power (KW/m) in Oman and Caspian seas based on Iranian Sea Waves Modelling is proposed. Wave energy in the Persian Gulf is lower than in Oman and Caspian Seas. As is evident, the highest wave power is in the Oman sea in the eastern region of the Sistan and Baluchestan coasts, and the highest wave power is in the Caspian Sea at the central coasts of the southern sea.



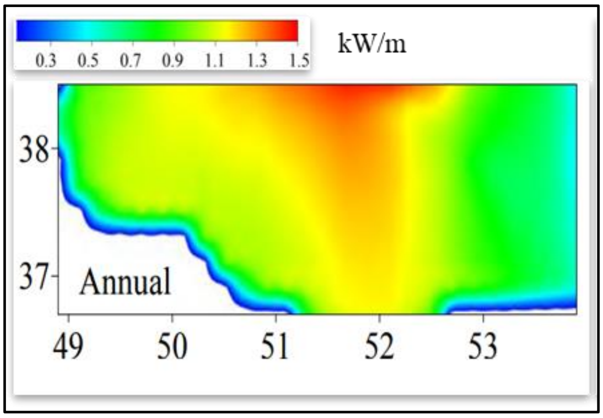


Figure 2. Annual map of wave energy power ($kW.m^{-1}$) of Oman Sea (top) and Caspian Sea (down) using (ISWM) data.

Additionally, the seasonal distribution graph of the mean density of wave energy (kW/m) and wave energy distribution graph (MWh/m/Year) were plotted based on the wave height (metre) and period (second) using the measurement data from wave buoy of PMO. In these graphs, wave height and period were divided into 0.5 and 1 second intervals, respectively, and their corresponding occurrence duration was fitted in rectangles of intervals in hours. Furthermore, the colour of each rectangle indicates the corresponding annual wave energy; its colour spectrum is shown on the left side of the graph. In Figure 3, the wave power matrix and in Figure 4, the mean seasonal density of wave energy and wave rose of buoy data in Amirabad port are shown. Based on this, the highest annual energy for waves were estimated to equal 1.8 MWh for a period of 4-5 seconds and a significant height of 1-1.5 metres. In the summer season, the maximum energy can be derived from waves. Also, 55.97 percent of wave measurement data had a height of fewer than 0.5 metres, and the dominant direction of waves was from the northwestern sector.

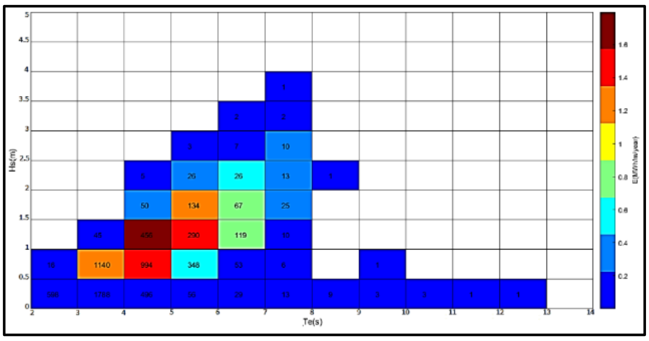


Figure 3. Matrix of characteristics of wave power based on height and period of the wave for Amirabad buoy.

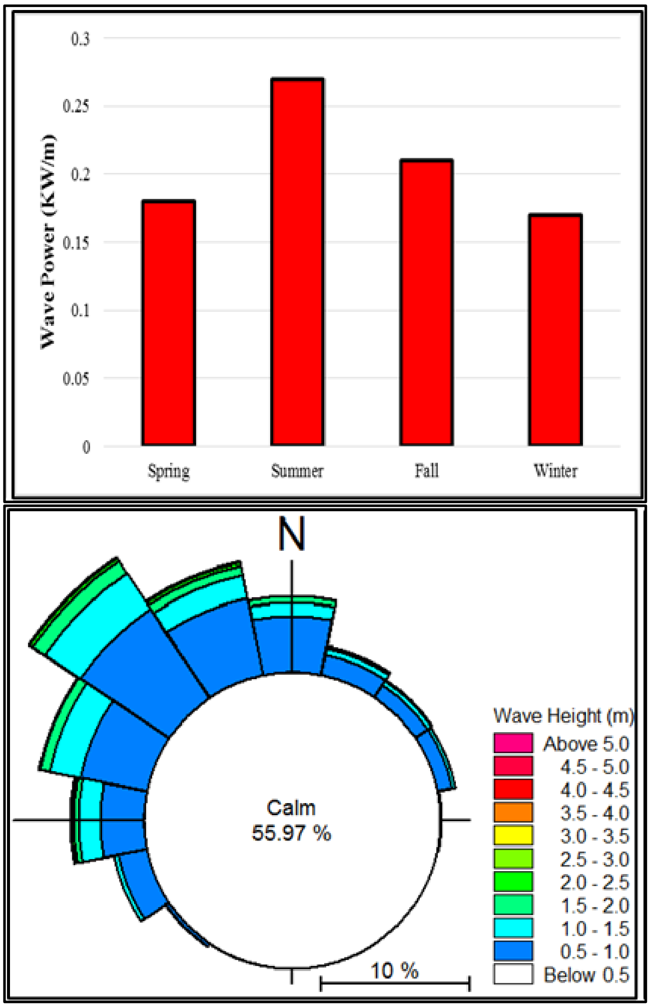


Figure 4. The seasonal average of waves' power (top) and wave rose (down), based on the Amirabad buoy measurement data

In Iran's seas, the flow energy does not have an acceptable power, except in the northwestern Persian Gulf. Energy extraction from this source is not feasible based on today's technology. In Figure 5, tidal current power density in the Persian Gulf (kW/m^2) and Khur-e-Musa (W/m^2) in the northwestern Persian Gulf are proposed.

By applying the predefined criteria and limitations for each energy (mentioned in previous section) to the hierarchical analysis model, the prioritization of renewable energy in studied ports is determined. The hierarchical analysis results have shown that in all southern ports, except for Imam Khomeini port, solar and wind energies are at first and second priority, respectively. Imam Khomeini port is the only port in the country with a potential for energy harvesting from tidal currents. In northern ports, energy extraction from wind is the first priority. In these ports, other renewable energies are not cost-efficient. The priorities for different sources of renewable energy in all 13 main ports have been shown in Table 9.

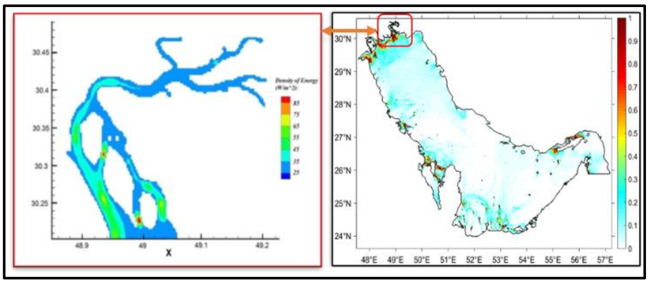


Figure 5. Current power density (kW/m2) of tides in Persian Gulf (right) and Khor Musa (left)

Table 9. priorities for different sources of renewable energy in all 13 main ports.

Priority	Beheshti	Jask	Lengeh
1	Solar-land	Solar-land	Solar-land
2	Solar-vessel	Solar-vessel	Solar-vessel
3	Wind-nearshore	Wind-nearshore	Wind-nearshore
4	Wind-land	Wind-land	Wind-land
5	Wave		
Priority	**Bahonar**	**Rajai**	**Bushehr**
1	Solar-land	Solar-land	Solar-land
2	Solar-vessel	Solar-vessel	Solar-vessel
3	Wind-nearshore	Wind-nearshore	Wind-nearshore
4	Wind-land	Wind-land	Wind-land
Priority	**Asaloyeh**	**Imam Khomeini**	**Abadan - Khorranshahr**
1	Solar-land	Current energy	Solar-land
2	Solar-vessel	Solar-land	Solar-vessel
3	Wind-nearshore	Solar-vessel	Wind-land
4	Wind-land	Wind-land	
Priority	**Anzali**	**Amirabad**	**Nowshahr**
1	Wind-nearshore	Wind-nearshore	Wind-nearshore
2	Wave-research	Wave-research	Wave-research

After determining the renewable energy prioritization in each port, the best location for establishing a power plant for each type of energy is determined in layers using ArcGis 10.3 software and applying limitations. Then, by overlapping these layers, the renewable energy extraction map was obtained for each port. Figures 6 and 7 show the renewable energy extraction map for two Shahid Rajaei and Lengeh ports (as samples). During the preparation of these maps, all defined criteria and limitations for each energy mentioned in the previous section are considered.

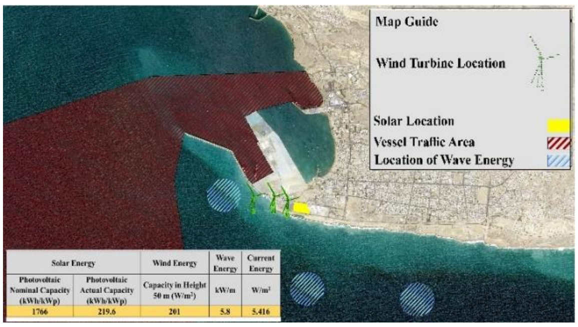


Figure 6. Renewable energy layout map for Shahid Beheshti port

Figure 7. Renewable energy layout map for Lengeh port

4. Conclusions

The results of this research have shown that in southern ports of the country, except for Imam Khomeini port, energy harvesting from solar and wind resources are the first and second priority, respectively. In Khuzestan province ports, despite high direct solar irradiation, the photovoltaic power potential is lower than other southern ports due to the reduced efficiency of photovoltaic solar cells in high temperatures and dust in the area. Therefore, Khuzestan province ports are not in priority among southern ports' in terms of solar energy extraction. In northern ports, due to cloudy weather, solar energy harvesting is inefficient; therefore, using wind force is the main option in these ports.

Among Iran's seas, only the eastern section of Oman sea, which has direct access to the open sea, has a high potential for wave energy, and therefore, Shahid Beheshti port in the Oman sea coasts is the only port capable of energy extraction from sea waves in industry scale. Shahid Beheshti, Jask, Shahid Bahonar, Shahid Rajari, Lengeh, Assaluyeh, Bushehr, and three northern ports of Amirabad, Nowshahr, and Anzali can only be used to derive wave energy on a research scale.

Although among Iran ports, only Imam Khomeini port has a tidal range (about 6 metres) capable of energy harvesting using a tidal barrage, according to nowadays technologies and economic costs, is not efficient. Nevertheless, tidal currents can be employed in this port and energy derivation from tidal currents is the first priority in Iman Khomeini port.

Noting that in this research, the defining limitations in the hierarchical analysis method is used in a 5 km radius in the sea and ports hinterland; the priority or arrangement of each energy may change by changing the region of concern for extracting energy.

Acknowledgment (Optional)

This research was done with the support of the Port and Maritime Organization (PMO) and the Darya-Bandar Consulting Company. We hereby thank them.

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