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Wind and wave energy potential in southern Caspian Sea using uncertainty analysis

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ABSTRACT

In this paper, uncertainties in determining the offshore wind and wave energies were considered to estimate the wind and wave energy potentials in the southern Caspian Sea. For this purpose, 11 years of ECMWF data in 210 points were collected in the study area for the analysis. First, a SWAN model for wave modeling was performed and then, the wave and wind energies were calculated using conventional analysis. Next, the uncertainties in air density, wind speed, wind speed distribution parameters, wind turbine power performance, peak wave period, significant wave height in each peak wave period, and wave energy converter were considered and a Monte Carlo simulation for 1000 years was conducted for uncertainty analysis. Results showed that uncertainty analysis results in almost 9% lower average wave power density and 7.3% less exploitable energy than conventional analysis. In addition, wind power density computed by uncertainty analysis was on average about 4% higher than that obtained with the conventional analysis; however, the exploitable wind energy resulting from uncertainty analysis was 3% lower than the values computed by conventional analysis.

1. Introduction

One of the most accessible renewable energy is wind. In this regard, a lot of studies and investigation have been carried out on wind resource assessment of various locations [1–9]. Various capable sites are currently investigated and many of them are operating [10,11]. On the other hand, land limitation and competition in using wind sources as well as new technologies in engineering [12,13], have caused many countries to establish offshore wind farms [5,8,10,11,14,15]. Stepping to offshore regions has negative aspects such as more expensive marine foundations and electrical grid connections. However, next to the mentioned disadvantages, other advantages such as higher wind speeds, less turbulence and less effect on social life are motivating factors to develop offshore wind farms [11].

Wave energy is also another source of renewable energy, which is accessible for countries connected to the seas. Similar to wind resource assessment, many studies have been carried out to investigate the wave energy potential in various regions [15–21]. Moreover, additional research has been conducted to investigate wave energy converter technologies [22–25].

According to mentioned background, Table 1 presents the global wind and wave energy potential as well as installed capacity in year 2013 to harness wind and wave energy [26–31]. The offshore regions have wind capacity of almost 4.4 times higher than onshore regions; however, the percentage of generated power from onshore and offshore wind resources are 17.3% and 0.1% respectively. The wave energy resources were also estimated where the installed capacity was less than 1.0%.

Iran as a developing country, is mostly dependent on fossil fuels [32,33]. The first constructed onshore wind farm in Iran started to work at Manjil in 2003 [34,35]. By 2009, Iran generated 91 MW out of 33000 MW electricity generation from wind farms in Manjil and Binalood [35,36]. These numbers show that less than 0.3% of electricity generation is achieved from the wind resources. In this regard, many researchers have studied the potential of wind energy harnessing in different regions of Iran [35–41], with some focusing on onshore wind resources in different parts of the country based on observed data from meteorological stations in different cities [32,42,43].

Most of the previous studies on wind energy assessment were carried out based on meteorological data observed from several stations during some years [35,36,40–42,44]. However, meteorological stations might have limitations such as limited

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Table 1
Global wind and wave energy potential and installed capacity in the year 2013.

Energy source	Capacity (GW)	Installed (GW)
Wind energy (onshore)	7877	~10
Wind energy (offshore up to 200 m depth)	1792	310
Wave energy	2985	<30

measurement regions or missing data because of inaccuracy.

Iran is surrounded by three huge seas in northern (Caspian Sea) and southern parts (Persian Gulf and Gulf of Oman), and these water bodies have not been studied deeply from an offshore wind energy viewpoint, since the available data are limited in these regions. Furthermore, there is no operating wave energy converter project so far; however, long coastlines in southern and northern parts of Iran make it feasible to harness the wave energy for different purposes [45]. Regarding the wave energy assessment of Iranian seas, many studies have been conducted [2,19,20,46] using numerical methods to solve mathematical models in order to generate the wave characteristics.

Wave and wind energy are dependent on several parameters with uncertainties based on the various situations. These uncertainties may occur in air density, where it may change as a function of water vapor pressure and temperature on the sea surface in different seasons. Also, sea surface roughness which is a function of wave height, has important effects on wind speed. Hence, addressing the uncertainties of these leading parameters helps to estimate a more accurate energy potential in the region.

The first step to address the uncertainty is to know probability models for important parameters. For this purpose, analyzing the observed data during the past years and identifying the wind filed characteristics (as a source of the wave) and probability models for multiple simulations can help. In this regard, observed parameters, which are important for wind and wave resource assessment can be analyzed to establish probability models. These models are helpful for the uncertainty analysis of wind and wave fields as well as power generations [47,48]. Implementing uncertainty analysis helps to obtain an accurate enough estimation and assessment of wind and wave energy resources.

For the wind resource assessment, the wind speed at the turbine hub height directly depends on surface roughness [8,48]. Most of the uncertainty analysis carried out on wind resource assessment have been for locations in onshore regions, where the surface roughness is almost constant and only depends on the terrain [47,48]. However, in offshore regions, the surface roughness is a function of wave height [49]. Moreover, most of the sea waves are induced by wind [50]. Therefore, the hub height speed and wave height are coupled for determining the wind and wave energy potential, respectively.

This research focused on offshore wind and wave energy potentials of the southern Caspian sea in the north of Iran, as an offshore energy resource to complete the previous assessments of Iran's wind and wave energy resources [32,42]. Wave energy potential in the southern Caspian Sea has been studied before [20], however, uncertainties in determining the wave energy have never been considered in the previous studies. However, as discussed before, considering the uncertainties results in more accurate energy potential estimates. Therefore, in this paper, a coupled method is provided for the analysis of wind and wave energy potentials simultaneously. For this purpose, the previous observations were used to establish the probability models for important parameters of wind and wave. Then, these probability models were used for long term couples wind-wave simulation to better estimate the wind and wave energy potential.

According to “Wind Resource Assessment Handbook” by NREL, it cannot be claimed that a site is completely representing an area. Furthermore, no sensor can measure the data with complete accuracy, and finally, no data can completely reflect the future condition of wind in almost 30 years lifetime of a wind farm; however, by decreasing the magnitude of uncertainties, the results and conclusion can provide useful information [51]. The minimum monitoring period should be at least one year, which is useful for understanding the diurnal and seasonal changes. In addition, with a long-term data monitoring system such as an airport, the interannual variability of the wind can be estimated [51]. This handbook mentioned that “the data recovery for all measured parameters should be at least 90% over the program's duration. In order to compute wind resource assessments using a conventional method, most of the literature used short to mid-range periods of time such as 1–10 years [3,4,35,36,40,41,44]. However, after introducing the concept of uncertainties in wind resource assessments, short to mid-range data were used for quantifying the uncertainties of wind resource assessments [47,48]. By referring to the AWS Scientific [51], one single number cannot be presented as sufficient years of data monitoring, however, according to current paper and other references [47,48], when the duration of the available data increases, the accuracy of wind resource assessment increases as well.

In this research, an 11 years (1992–2003) ECMWF (European Center for Medium-Range Weather Forecasts) data over 210 points were used in the southern Caspian Sea. The ECMWF data in southern Caspian Sea was previously validated with local wind measurements [20]. The data were analyzed in each point, and probability models were established for uncertain parameters. At the first step, probability distribution of wind speed at 10 m height was extracted and used as SWAN (Simulating WAve Nearshore) model [52] input in order to simulate the peak wave period and significant wave height. The SWAN model was utilized completely based on the model previously performed and verified by Kamranzad et al. [20] in southern Caspian Sea. The results of wave modeling using SWAN were used to find the probability distribution of the peak wave period at the specific point. Then, the uncertainty of sea surface roughness-which directly affects the wind speed estimation at turbine hub height was estimated using peak wave period and significant wave height. Until now, similar studies have concentrated on onshore sites, where the surface roughness depends only on the terrain. In the current research, sea surface roughness, which is dependent on wind speed, wave period and wave height was considered through a coupled procedure. In addition, air density during 20 years was observed in four different points in the region and probability model for air density was established. The wind and wave energy potential can be estimated by determining air density distribution, wind speed distribution at hub height and wave characteristics.

In order to estimate the exploitable wind and wave energies, uncertainties in power generation of turbine and wave energy converter were used to estimate the annual energy production (AEP) in each point. This paper used a Monte Carlo simulation to simulate this procedure for 1000 years according to hourly power generation data to estimate the average AEP in each point. The results obtained from uncertainty method were compared with those of conventional methods. The differences resulting from conventional and uncertainty analysis can be used for more accurate decision making in renewable energy projects. In the scale of giant water bodies such as seas or oceans or a region in a specific sea (e.g. Southern Caspian Sea), the small difference between the conventional and uncertainty analysis will result in a large difference in the generated power. Finally, a geographical information system (GIS) tool was used to present the results and also discuss the renewable energy feasibility and sustainability in the region.