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An optimal renewable energy management strategy with and without hydropower using a factor weighted multi-criteria decision making analysis and nation-wide big data - Case study in Iran

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In the present study, an optimal renewable energy management strategy (REMS) is proposed as a sustainable policy for non-fossil fuel-based centralistic energy policies. Accordingly, the demand load data and weather big datasets were analyzed using neural networks and analysis of variance, respectively. Biogas generation was modeled using a BSM2 dynamic model, and the available hydropower was evaluated in the form of a techno-economic assessment. A hybrid solar PV/wind turbine/biogas generator/hydroturbine/battery/inverter system was simulated as a gauge unit using the processed data to evaluate the potential of all renewable energies in Iran. The results were used to cluster Iran into various classes based on optimal green energy potential using a *K*-means algorithm. A factor analysis (FA) was performed using a big matrix consisting of 13 social, economic, environmental, and technical variables in all of Iran's provinces. Factor score coefficients were then employed in a mature multi-criteria decision making analysis technique to determine the order preference for an ideal solution (TOPSIS). These details were used to inform the REMS. The optimal hybrid renewable energy maps were generated and were combined with the FA-TOPSIS results to produce an action plan proposal. The results show that FA can explain 99% of the variance in the big data matrix. Iran can be efficiently clustered into five classes, while a four-stage action plan can assure sustainable development.

1. Introduction

Renewable energies have proven to be reliable solutions to the sustainability challenge in the last few decades. As a result, the global energy production includes a higher share of renewable energy sources (RES) than ever before. Several countries have been developing RES for various reasons [1].

Domestic fossil fuel deficiencies and high risks involved with nuclear energy have motivated investment in RES both in the Far East and Europe. Hence, South Korea and the European Union have committed to increase the share of green energy technologies to 98% and 27% by 2030, respectively [2,3]. However, the United States and China, two economic giants, have set more conservative policies aiming to meet, respectively, 12% and 20% of domestic energy consumption using RES by 2030 [4,5]. The Middle East enjoys large fossil fuel reservoirs and contributes the lowest global share of RES as they are estimated to represent only 16% of local requirements by 2035 [6]. The main concern around the developing Middle East is the lack of accurate renewable energy management strategies (REMS) in spite of diverse studies on the topic.

Previous studies focused on estimating the RES potential in developing countries using intelligent machine learning and advanced statistical or empirical models [7,8]. Mathematical models were then required to complement feasibility studies including economic aspects [9]. However, algorithm-based assessment approaches have overcome this problem and considered both aspects using techno-economic analysis. Techno-economic studies could include the technical restrictions of green energy production both in small regions and on large scales [10]. The analysis was often followed by environmental or social analyses to provide a vivid national vision of RES [11,12]. The technical, economic and social analyses were performed independently until Paliwal et al. [13] combined them to form a techno-socio-economic criterion for

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the optimization of various autonomous RES.

Systematic inclusion of various aspects in a combined model provided comprehensive insight into the pros and cons of green energies. However, most researchers focused on a single RES in large-scale studies. Wind and solar potentials were evaluated in industrial zones as examples of sectoral feasibility studies [14]. Solar GIS maps were prepared using an air clearness index and total sunshine hours [15]. A full review of all renewable and non-renewal energy sources was published, including energy scenarios in Iran [16]. Feasibility studies provided a good dataset for a single RES investigation until a simultaneous assessment of various RES was proposed [17]. The novel bottom-up assessment algorithm, DaSOSaCa, was capable of evaluating two or more RES under optimal conditions in a large region. Although the problem of optimal application of green energy on a large scale was solved by DaSOSaCa, the crucial human concerns of RES management remained unsolved.

Despite the fact that complex human and engineering factors are involved in green energy policies, few studies have considered the social, environmental and economic requirements of a population that must be met sustainably alongside the technical uncertainties and restrictions of costly weather-driven RES [18]. Merzic et al. [19] established four different transition models involving technical, economic, environmental and social parameters. Their investigation was a great step in energy management, although they focused on low carbon scenarios instead of zero emission systems. The complex problem of selecting renewable energy resources was studied in Turkey and flexible tools were employed to map out the situation [20]. A sustainable development plan was proposed in Iran based on hybrid RES using four major techno-econo-socio-environmental variables [21]. Although, the research stated that centralistic policies should be revised in Iran to achieve sustainable development, a remedy was neglected. It was because that a reliable action plan cannot be proposed analyzing only four major decision variables and ignoring hydropower as the second greatest energy source in Iran.

Thus, the aim of the current study is to propose a holistic management strategy all over Iran using optimal HRES with four available RES considering all technical, economic, social and environmental aspects by a novel flexible analysis. An optimal renewable energies-assisted action plan is proposed to meet the energy requirements in Iran sustainably for the first time. The flexible big data-based approach can aid the decision makers to shift the roadmap via a long-term monitoring. The dualistic HRES application, with and without hydropower, facilitates the conversion of hydro structures' performance if the present drought gets worse in the future. To the knowledge of the authors, a big data-based plan including sustainable development variables in Iran, is scarce.

The current paper consists of four major sections. First, a case study was briefly introduced and the characteristics of the studied sites were provided. Second, raw weather data were analyzed using analysis of variance to select a robust solar and wind data set. Available biogas was obtained using a dynamic model and the monitored hydropower data were obtained. The hourly annual demand load was predicted using a neural network algorithm. In the third section, optimal hybrid solar/wind/biogas/hydropower systems were simulated to obtain the technical and economic variables of renewable system installations at each site. The size of the renewable components and the corresponding costs were minimized while the simulation. In the fourth section, big data matrices were constructed to include more than 13 social, economic, environmental and technical variables and the whole country was ranked using a multi-criteria decision making analysis. For this, a factor analysis weighted technique for order-preference by similarity to an ideal solution (FA-TOPSIS) was detailed and employed. Finally, Iran was clustered using a *K*-means algorithm and an action plan was proposed using the generated hybrid maps and FA-TOPSIS results to form a holistic management strategy.

2. Case study

Iran is a large country located in the Middle East and it has a diverse topography. One fourth of its 1,648,195 km^2 area consists of arable lands, and the rest is covered by mountains, deserts, and highlands [22]. Various renewable energy scenarios can be defined in Iran because of the available climatologic diversity. Located in the world's solar belt, Iran enjoys 280 sunny days with 1800–2200 kWh/m^2 radiation per year. Feasibility studies show that wind energy and hydropower potential were initially estimated to be 6500 MW and 50,000 MW, respectively [6]. Biomass can also cover more than 6% of the domestic electrical and heat demand according to preliminary studies [23].

Iran holds 10% of the world's crude oil and 17% of natural gas reserves which are the fourth and second highest major reserves in the world, respectively [24]. The energy consumption per capita is approximately 10 times greater than the European Union [25]. Thus, the government has been encouraged to supply the required energy using its abundant fossil fuels. Therefore, more than 97% of the required energy is currently supplied by non-renewable sources and is transferred using an integrated national grid [26]. The current policy has to be revised for critical reasons including [17,21,27,28]:

- 70% of the generated net power is lost using on-grid power plants and an integrated transmission and distribution network, so distributed generation is a priority.
- Non-renewable power plants are the largest concentrated sources of air pollutants in Iran and these produced 528.6 million metric tons of CO_2 in 2009.
- Iran is committed to triple the renewable energies share by 2020. Governmental subsides are allocated and international funds have been committed for this purpose after the signing of the recent nuclear deal.
- Iran's government began an “economic reform plan” to decrease the 20 billion USD subsidies to the energy sector by 50% in 2010 and devoted a considerable share of the resulting income to RES and energy system optimization.
- A fossil fuel-based centralistic energy policy has been recognized as the major barrier to sustainable development. Here, a centralistic policy means devoting almost all national opportunities to metropolitan cities. Distributed HRES were suggested to overcome the dilemma.

An efficient action plan considering the potential of all renewable sources in an optimal manner is vital for Iran. The representative sites of Iran's 31 provinces as well as the six major water basins are shown in Fig. 1. The national boundaries and internal provincial borders are highlighted by bold and dotted black lines, respectively. There are 6 major water basins shown with different colors. The sites converge in dense areas of the northwest and this helps provide a better estimation of the population dispersion in Iran. Each province was studied using a representative site.

The representative sites are indicated with green triangles on the map and the relevant geographical data are summarized in Table 1. The renewable energy potential in each province was studied using meteorological data of the corresponding site. Iran's power department has divided the country into 16 electrical sub-regions. Each sub-region has a unique electric consumption pattern, so the divisions facilitate efficient management and operation of the national electrical grid [29]. The electrical sub-regions do not conform to political divisions. These electrical regions are