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A multicriteria decision making approach for evaluating renewable power generation sources in Saudi Arabia

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A B S T R A C T

Renewable energy sources are seen as potential alternatives for future energy generation and fossil fuel consumption. In this paper, we propose a multicriteria decision making approach based on analytical hierarchy process for evaluating five renewable power generation sources namely: solar photovoltaic, concentrated solar power, wind energy, biomass, and geothermal. The criteria used can be categorized as technical, socio-political, economic, and environmental criteria. A case study for Saudi Arabia is provided as a major oil producer and global supplier. The results of our study show that solar photovoltaic followed by concentrated solar power are the most favorable technologies followed by wind energy. The performance of each renewable energy resource per end-node criteria is presented and sensitivity analysis is conducted to observe how the overall rankings of alternatives change with respect to the priority weights of each criteria. By implementing energy mix policy, Saudi Arabia can preserve its finite energy resources for the future to back its strong economic and industrial growth. The findings of this research will help the prioritization of RE sources portfolio towards enhanced sustainability and development.

Introduction

Energy is an essential factor for societal development and prosperity nowadays. The diversification of energy sources is vital, particularly for oil-dependent and developing countries, in order to achieve more secure supply options, create more jobs, and contribute to sustainable energy and development. The Gulf Cooperation Council (GCC) consists of six member states: Saudi Arabia, United Arab Emirates (UAE), Qatar, Bahrain, Kuwait and Oman. In recent decades, these countries received significant economic growth due to the wealth generated from plentiful hydrocarbon reserves. This development has been combined with unparalleled growth in urbanization, infrastructure and industrial expansions. Since 1970, the region's population has grown by sixfold including migrant workers from Asia and other countries [1]. Nowadays, several GCC economies are ranked among the highest electricity consumption per capita countries globally (see Fig. 1) [2].

The Kingdom of Saudi Arabia is the world's largest oil producer and exporter, producing an estimated average of more than 11 million barrels per day (bbl/d) and exporting an estimated 8.6 million bbl/d in 2012 [3]. Although it is the global leader in oil production and exports, Saudi Arabia is also the largest oil-consuming country in the Middle East; in 2012, it consumed more than 3 million bbl/d of oil, essentially for electricity generation, water desalination, and transportation [3]. According to the Organization of the Petroleum Exporting Countries (OPEC), petroleum exports accounted for 90% of total Saudi export revenues in 2011 [4]. At the same time, Saudi Arabia is ranked second in the world in terms of subsidy levels for domestic energy prices [5].

Due to a rapidly growing population and economic development along with subsidized prices of gas, water, and electricity in the Kingdom, the overall demand for energy used in power, transportation, and desalination is estimated to increase dramatically from 3.4 million bbl/d in 2012 to 8.3 million bbl/d of oil equivalent in 2028, unless alternative energy initiatives are deployed and energy efficiency is improved [6]. Such progressively high-energy consumption led to establish Saudi Energy Efficiency Centre in 2010 to publicize rationalization awareness and enhance energy consumption efficiency which will support and preserve the national wealth of energy resources [7].

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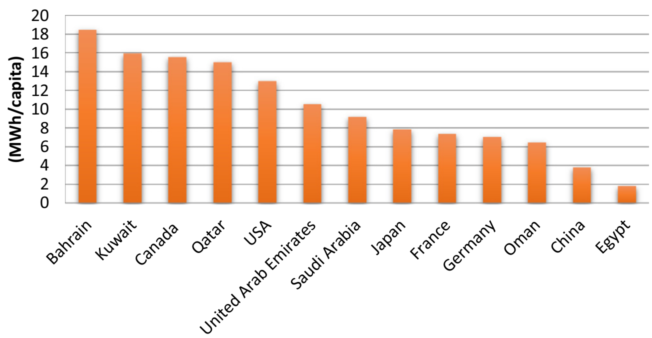

Fig. 1. Electricity consumption per capita in selected countries [2].

Furthermore, the Kingdom's leaders are well aware of the fact that heavy dependence on oil is not a good strategic decision; therefore, the King Abdullah City for Atomic and Renewable Energy (K.A.CARE) was established to introduce sustainable development and make remarkable diversifications in terms of energy resources. Saudi Arabia has pushed back its long-term renewable energy (RE) plans to 2040 instead of 2032 due to the need for more time to decide which domestic RE sources to use for the portfolio based on Bloomberg report [8].

In this paper, we present a multicriteria decision making (MCDM) approach for prioritizing and ranking RE technologies in the electricity production sector of a developing country in order to facilitate proper planning for sustainable development. To the best of our knowledge this is the first work prioritizing RE resources from different aspects including economic, technical, socio-political and environmental criteria in the context of Saudi Arabia. Moreover, this research identifies to what extent each alternative energy technology contributes to the sustainable energy mix profile. Different resources were used to define the criteria in the model, including a literature review, stakeholders' inputs, and the Saudi vision for the energy diversification announced by K.A.CARE.

Renewable energy potential and opportunities

The total available power generation capacity in the Kingdom reached 69,761 MW in 2013 [9]. The power generated is based 100% on fossil fuels (oil and gas). The number of customers increased from 4.5 million in 2004 to 7 million in 2013 for Saudi Electricity Company (SEC) which is the major electricity supplier (74%) in the country [9]. SEC spends more than 40 billion riyals on energy projects annually [10]. Owing to the population increase, strong economic and industrial growth, and high levels of price subsidization, the electricity demand is projected to grow significantly. According to government estimates, the anticipated electricity demand in the Kingdom is expected to increase from 80 GW by 2020 to more than 120 GW by 2030 [7]. K.A.CARE has recommended the utilization of renewable and atomic energy progressively to meet the expected demand, such that half of all electricity production would come from non-fossil fuels in 2032 [11].

Saudi Arabia is one of the most enriched countries with natural resources and has the potential to take advantage of abundant RE resources to meet a significant share of the Kingdom's energy needs and provide an efficient energy future [13]. In addition, harnessing RE to supply electricity to consumers in Saudi Arabia will have significant environmental benefits. The following subsections provide details of potential RE resources, including solar energy, wind energy, geothermal energy, and biomass energy, with their potential for electricity generation in Saudi Arabia.

Solar energy

The Kingdom has significant potential to exploit solar energy owing to its location, large unused area, and daily solar radiation availability. Solar radiation in the Kingdom is considered to have one of the highest rates globally with an average global horizontal irradiance (GHI) of 2 MWh/m^2/year, which is higher than the average global solar radiation in one of the leading countries in solar energy, Spain (1.6 MWh/m^2/year) [14,15].

Rahman et al. [16] studied long-term mean values of sunshine duration and global solar radiation on horizontal surfaces over 41 cities in the kingdom. The results show that the overall mean of yearly sunshine duration in the kingdom is 3248 h and the GHI varies between a minimum of 1.63 MWh/m^2/year at Tabuk in the northwest of the kingdom and a maximum of 2.56 MWh/m^2/year at Bisha in the southwest. However, the minimum solar radiation is higher than the average GHI in Germany and many other European countries. Furthermore, the pattern of global solar radiation intensity and sunshine duration follows the electricity demand pattern, which could be the most favorable RE generation option to meet demand, especially during the summer season when the demand peak is highest due to significant rises in domestic demand for air conditioning [15]. Since 1960, significant experience has been gained and lessons learnt in the area of solar energy from different studies and research programs conducted in the kingdom [15,17]. Fig. 2 depicts the long-term annual average global horizontal irradiance (GHI) and direct normal irradiance (DNI) obtained from the SolarGIS database [18].

Two solar energy technologies are considered in this study, including solar photovoltaic (PV) and concentrated solar power (CSP) which is also known as concentrated solar thermal. CSP technology deploys reflectors or mirrors in order to concentrate solar radiation to heat transfer fluid that is used to generate electricity. On the other hand, solar PV technology utilizes a PV-effect phenomenon existing in semiconductor material in order to convert solar energy directly into electricity. Unlike CSP, PV technology works in the presence of both direct and diffuse solar irradiation. Solar PV is commercially more mature technology than CSP with total installed capacity of 175 GW compared to 4 GW for CSP worldwide [19]. Due to massive scale production and technology advancement, the upfront cost of PV system has significantly decreased in the past few years while the upfront costs of CSP are considerably high. Since the end of 2010, the electricity cost generated from PV has halved while PV module costs have decreased by 75% [20]. In addition, the maintenance costs associated with PV power plants are minimal compared to other power utility systems as a result of the absence of mechanical parts. It is essential to note that for aired environments, the impact of dust on PV modules efficiencies should be considered. Al-Jawah [21] assessed the cleaning systems for PV power plants in Saudi Arabia to improve selection among cleaning alternatives. PV is suitable to cover peak demand during sun hours. However, storing energy through batteries is expensive for large scale utilities. CSP on the other hand is anticipated to witness increase levels of installation in the following decades. The International Energy Agency (IEA) anticipates that the installed capacities of PV will keep increasing to cover peak demands before the significance of cheap thermal storage associated with CSP systems play its role to facilitate CSP covering 11% of total global installed capacities of all generation sources in 2050 [22]. In addition, CSP technology is suitable for hybridization in which CSP could be combined with steam generation sectors of existing or new conventional power plants. This also serves the ability of these systems to take advantage of backup fossil fuels to cover base loads and reduce fluctuation [23].