Spatial Management for Solar and Wind Energy in Kuwait

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Abstract: Kuwait situated at the northwestern part of the Arabian Gulf experiences severe arid environmental conditions. Kuwait is facing many challenges in the sustainable development of the energy sector. These challenges are: deposited dust, increase of carbonate and mud percentages in dust, lower solar radiation, high relative humidity and low wind speed. These challenges that affects more the photovoltaic (PV) power stations were carefully monitored in order to special manage the solar and wind energy in Kuwait. Using 14 weather stations, solar radiation, wind speed and directions were monitored during the period (2010-2017). The annual deposited dust represents one of the highest in the region with 216 t km-2 as an average in 2009-2010 and 339 t km-2 in 2010-2011. Also, carbonates and mud content within deposited dust represent the highest percentages compared to the surrounding regions. The annual power production of wind farms in Kuwait is 2.3 times higher than PV unit with similar capacity. Finally, maps that were produces for all environmental challenges for solar and wind energy in this present paper show that the northwestern regions of Kuwait are the most appropriate areas for setting up a wind and/or a PV power stations.

Keywords: Management, solar, wind, energy, Kuwait

1. Introduction

Wind and solar energy is likely to spread globally more than any other energy source in the middle of current century [1]. Wind and solar energy is environmentally clean, abundant, a renewable source of energy and quiet [2]. Solar and wind as a sustainable power source is conquering the peak among different energy sources and being increasingly used in multiple applications [3]. Many environmental challenges in arid regions disturb the photovoltaic panel such as air pollution, shadow and aerosols [4]. Dust, relative humidity and low solar radiation have a negative effect on photovoltaic technologies in the Arabian Gulf region [5], the Gobi **Error! Reference source not found.** and the Taklimakan [7] deserts. The understanding these environmental challenges at a particular geographical spot is essential for setting up any sustainable power systems and for evaluation of their efficiencies and output [8]. Also, the awareness of these challenges is a necessity for modeling and designing of all wind and solar systems [9] and helpful for climatology, air quality and atmospheric energy balance studies [10] [11]. These challenges being frequent in environment, thus active and passive solutions are liable to be applicable in arid areas matter to their specific conditions [12]. The sustainable development in the perspective of solar energy development and social community engagement in the Middle East are deliberated along with the need for progress of the human capital necessary to address sustainable solar energy challenges from a practical and social point of view [13]. Furthermore, wind energy potential challenges require cautious evaluation of wind properties such as its frequency distribution and mean wind speed [14] (Fig. 1)

Fig. 1. Photovoltaic cellsafter single dust storm (left) and wind turbines in Kuwait (right).

The Gulf Co-operation Countries (GCC) that include: Bahrain, Qatar, Saudi Arabia, Emirates, Kuwait and Oman have a high load peak and risk of electricity shortage, as well as the consuming hydrocarbon resources to meet up the increasing demand for power [15]. Launching sustainable and environmentally clean power systems in Kuwait will show the way to a modern electrical network, more capable power supply, more job opportunities, better global image and cleaner environment [16]. Among the variable sustainable energy alternatives, photovoltaic energy enforces itself as the leading practice in the GCC **Error! Reference source not found.**. Kuwait mean solar intake is roughly 9-10 hr/d with mean diurnal solar insulation that is able to reach to 7.0 kWh/m^2 [18]. On the other hand, dust is a frequent challenge in desert **Error! Reference source not found.** and marine **Error! Reference source not found.** environments in Kuwait. The annual average total dusty days is 255 days in Kuwait **Error! Reference source not found.** which might work as a challenge for photovoltaic power generation in the Middle East. There are less dusty days in southern Arabian Gulf in relationship to the northern part **Error! Reference source not found.**. For that reason, this will lay Kuwait as an ideal site to study the extensive influence of weather and dust challenges on wind and photovoltaic power generation [23]. While most of the studies in the region explore the potential sites to launch photovoltaic power units via availability of solar radiation; environmental challenges such as dust that affect the efficiency of photovoltaic panels have not much been investigated. Therefore, this study aims to ascertain the potential feasibility to initiate photovoltaic and/or wind energy systems and to identify the best locations.

2.Study Area

Kuwait is characterized by a windy and arid environment with extreme variations of diurnal air temperature. The meteorological records (1958 to 2017) shows the evaporation rate and mean air humidity percentage are 6,060 mm/yr and 55.3%, respectively, while the summer (June-October) mean temperature is 37.4°C. The rainfall is low and variable with 113.8 mm as mean annual. The northwesterly and northerly are the prevailing wind in Kuwait representing approximately 60% from the all wind directions **Error! Reference source not found.**. Other wind directions act with less frequency/shorter durations and lower wind speeds. The mean wind speed in Kuwait is 4.8 m·s^{-1} [16].

3.methodolgy

The basic principles of this research are to monitor the environmental challenges for sustainable energy using the data from 14 meteorological stations in Kuwait. These challenges are as follow:

- Wind speed and direction at 10m
- Wind speed and direction at 30m height
- Solar radiations

In addition to challenges obtained from 47 monitoring sites within Kuwait (Fig. 2) for:

- Deposited dust
- Carbonate percentages in dust
- Mud percentages in dust

The dust trap is designed according to US geological Survey design and 47 trap were manufactured at KISR. Samples were collected in a monthly basis for two years (September 2009 to August 2011). Using sieve (0.063 mm), mud was separated from sand, while carbonates percentages was obtained from all samples using 10% hydrochloric acid to find the total weight loss before using the acid and after. These methods will allocate a decent delineation to mud and carbonates percentages in the dust from the 47 sites. Using the ArcGIS S/W software, the collected data was stored as GIS layers, and geo-statistical interpolator (Simple IDW technique) was conducted to create the mean distribution maps.

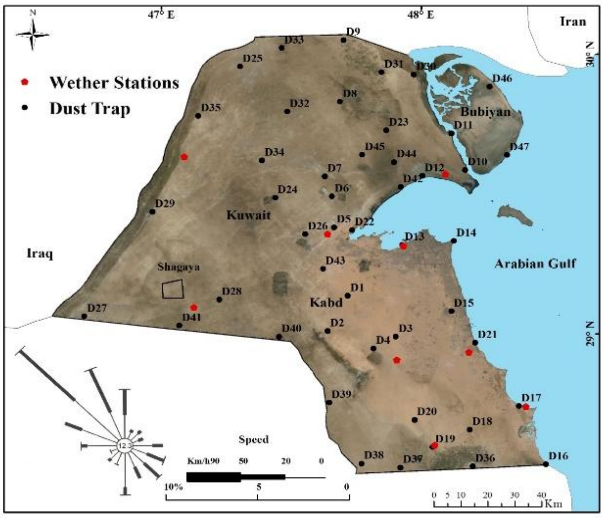

Fig. 2. Location map for weather and dust monitoring stations with average wind rose for Kuwait.

4.results and discussion

4.1.The Average Annual Dust

The annual accumulated dust ranges are 149-576 t km^{-2} (average is 339 t km^{-2}) in 2010-2011 and 10-1065 t km^{-2} (average is 216 t km^{-2}) in 2009-2010. The dust allocation map was illustrated based on the mean annual dust deposition for two years 2010-2011and 2009-2010 (Fig. 3). This map demonstrates significant inclination in dust deposition over the two annual periods. The maps spot specific zones with more than 350 t km^{-2} and other zones with low dust deposition in Kuwait, but the zones with high dust deposition appears to expand to cover more spaces in 2010-2011 in contrast to 2009-2010.

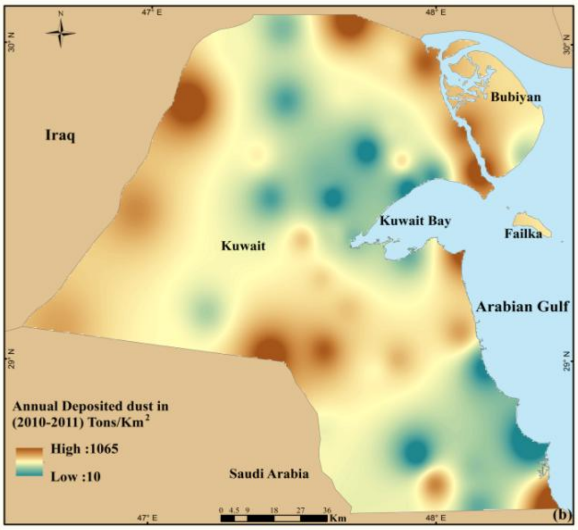

Fig. 3. Maps for annual deposited dust in 2010-2011.

Dust grains can act as a disturber to the economic systems, mainly via the off-site costs increase. Dust accumulated on solar cells, combined with scarcity of water in the arid regions to clean PV-energy units will put an additional cost of cleaning. Dust was revealed to degrade the power delivery, which in roll leads to a decrease in energy production of photovoltaic panels by 15% to 30%. Energy drop can be 100% during dust storms or high humidity. The efficiency of the photovoltaic is a main reason impacting the power generation cost. LCOE turns down exponentially as the efficiency of the photovoltaic panels is low.

4.2.Wind Energy and Solar Photovoltaic (PV)

From 14 meteorological stations in Kuwait, the wind power density distribution map at 10m and 30m height demonstrate higher values to the northwestern parts of Kuwait as being occupied by *Centropodia sp.* and *Stipagrostis sp.*, which are known to have the lowest efficiency in trapping mobile sand and dust among all native plants in Kuwait. During 1974, the northwestern areas were occupied by*Haloxylon salicornicum* with higher ability in trapping 9.73 m^3 mobile sand and dust per single plant (Fig. 4). This change in vegetation cover causes the formation of a wind corridor (of high speed wind) on the northwestern and the western parts of Kuwait creates some challenges to photovoltaic power generation, but advantages for wind energy generation. These challenges are represented in the formation of thinly crusted carbonates and/or mud film on the PV panel surfaces due to aeolian deposits (sand and dust) (Table 1). The described vegetation change in the affected area is more suitable for wind-derived energy compared to the photovoltaic as the efficiency of photovoltaic units will drop due to sand and dust coverage. The northwestern parts of Kuwait are the more and most suitable sites for setting up a wind energy unit. This was also supported by the final results from the wind power density (W/m^2) maps at 10m and 30m (Fig. 5 and 6).

Fig. 4. Huge areas covered by Haloxylon salicornicum as efficient plant in trapping mobile sand and dust.

The collected data of the mean annual solar radiations in Kuwait are geographically demonstrated. The mean annual solar radiation varies (223 Wm^{-2} to 246 Wm^{-2}). The northwestern areas in Kuwait show the highest solar radiation in contrast to other parts (Fig. 7). Testing the potential feasibility in Kuwait for setting up wind and/or solar power stations and relying on one year's operation of wind and solar units with the same capacity in Kuwait, the results confirmed that wind power production goes beyond the industry needed limits. Wind energy was allied with high capacity factors during the monitored time (12 months), resulting in an annual energy generation that is 2.3 times above than that of photovoltaic panels. The mean efficiency loss within photovoltaic units is around 45% due to environmental challenges.

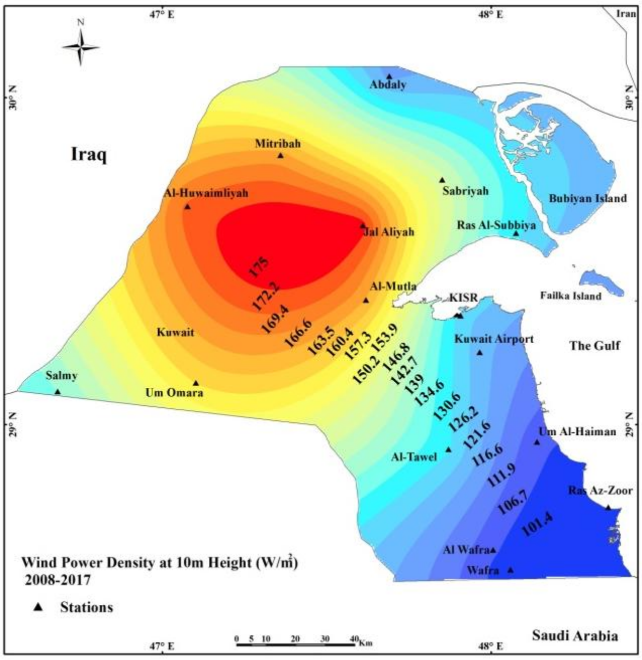

Fig. 5. The wind power density (W/m2) at 10m obtained from 14 weather stations.

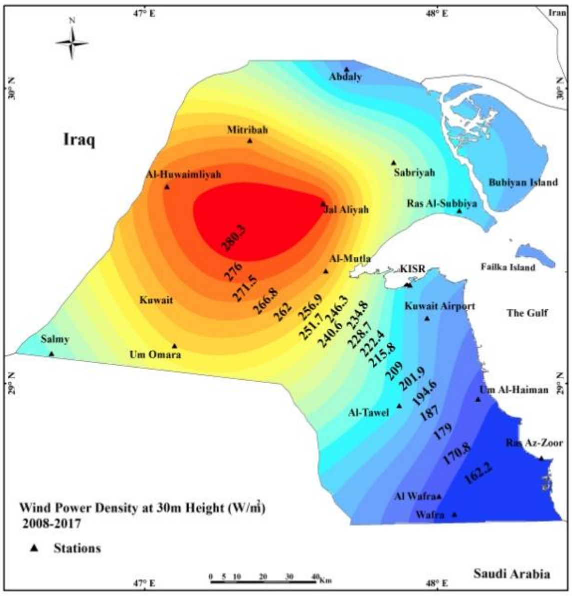

Fig. 6. The wind power density (W/m^2) at 30m obtained from 14 weather stations.

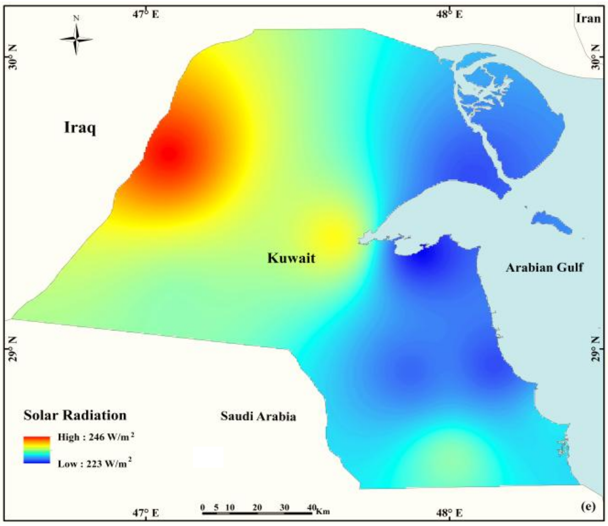

Fig 7. Maps for average solar radiation in Kuwait and the red color represent the best for PV unit station.

TABLE I. MUD AND CARBONATES PERCENTAGES IN KUWAIT COMPARED TO SURROUNDING REGIONS.

Sector	Source	M	Carbon
Kuwait	Present study	6	45
Ahwar-Iraq	**Error! Reference source not**	9	80
Manamah-	**Error! Reference source not**	8	41
West Empty	**Error! Reference source not**	6	13
Ain-Emirates	**Error! Reference source not**	4	52
Dubai-Emirates	**Error! Reference source not**	8	45
Amman-Jordan	**Error! Reference source not**	7	68
Tripoli-Libya	**Error! Reference source not**	8	27
Biougra-	**Error! Reference source not**	8	46
Cartagena-	**Error! Reference source not**	9	0
Cairo-Egypt	**Error! Reference source not**	9	34
Bald Hill-	**Error! Reference source not**	9	0
Average		7	38
Maximum		9	80
Minimum		4	0

5.conclusion

Kuwait puts forward optimum conditions for the expansion on the wind and solar power solution to improve power generation. The government lately recommended a scheme for the expansion of photovoltaic power generation with a more motivated vision to act a wind and solar power exporter. Conversely, the establishment of photovoltaic power stations in Kuwait should take in aspect vital environmental challenges, which contain humidity, solar radiation, dust fallout, and carbonates and mud within dust. There are many researchers mentioned the socioeconomic effect of dust [35, 36, 37]. Therefore, control measures future studies should be conducted. This research paper has clearly identified the environmental challenges that can influence the performance of solar photovoltaic technologies in arid zones. After one year of operation it was shown that wind energy records numbers far more than the industry needed limits. This was allied with the high capacity factors throughout the year. The change in density and type of native vegetation from high to low efficient plants in controlling Aeolian activities plays a major role in increasing intensities of environmental challenges to sustainable energy in kuwait. The northwestern zones of Kuwait are the most proper locations for wind power unit.

6.Acknowledgment

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