Optimization of ON-grid hybrid PV/wind system for a cement factory in Kuwait using HOMER pro software

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Abstract

The reliance on a single energy source leads to many problems, i.e. cost and unsustainable operation. Hybrid renewable energy systems (include more than one energy source) has been effectively shown as a feasible choice to overcome these problems. The main purpose of this research is to carry out a techno-economic optimization to minimize the size of the system with lower cost and higher reliability. This proposed ON-grid hybrid PV/wind energy system is designed to supply the electrical power of a cement factory in Kuwait. To achieve this purpose, the Hybrid Optimization of Electric Energy (HOMER Pro) software was utilized to carry out the optimization process. The results of this study show that the cost of electricity energy generated by the hybrid PV/wind energy system is equal to $0.082/kWh which is much lower when compared to the conventional fuel power plants in Kuwait which is approximately $0.12/kWh.

Keywords: photovoltaic energy; wind energy; hybrid system; renewable energy; LCOE; optimization; HOMER

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1 INTRODUCTION

Kuwait is one of the major oil exporting countries, but it consumes a huge amount of its natural hydrocarbon sources to meet the increasing electrical energy demand. Predicting the future national electrical demand and energy resources optimization are essential requisites to have a balanced energy policy. This increase in electricity consumption was largely due to increases in population and per capita consumption as well. The total electrical energy consumption in Kuwait has increased significantly during recent decades. It is necessary for any country to have a diversity of energy resources. Therefore, a great attention toward renewable energy is mandatory for all countries worldwide. Solar and wind energy systems are frequently utilized individually to produce electric energy, but both have advantages and disadvantages. For example, daily solar radiation and weather fluctuations affect the performance of solar systems; and wind speed fluctuation, affects the wind turbine power system efficiency [1]. Single energy sources (solar, wind, biomass, water) suffer from many drawbacks, particularly intermittent production. This main drawback can be overcome by considering more than one energy source which are termed as hybrid energy systems.

Numerous studies have been carried out to provide simulation and optimization analysis of different types of renewable energy systems to understand the dynamic behaviors of these systems. The reported research work on optimization of renewable energy systems (wind, solar, bioenergy, geothermal, and others) can be

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classified into two main groups: single source systems and hybrid energy systems. Most of the reported literatures in Kuwait were considering the single source systems studies. Althuwaini and Philbin [2] examined the specifications of solar power plants in Kuwait and conducted techno-economic optimization of photovoltaic (PV) and concentrated solar-thermal power (CSP) of 100 MW power plants. They found that Al-Wafra in Kuwait was the optimal location for their power plants. Hajiah *et al.* [3] carried out a theoretical evaluation of ON-grid (PV) 100 kWp systems in two main sites in Kuwait, namely, Al-Wafra and Mutla. Al-Salem and Al-Nassar [4] utilized statistical techniques to examine the wind speed values at three islands (Bubiyan, Failaka and Um-AlMaradim) sited in the north, mid- and south of Kuwait territorial waters. Khajah and Philbin [5] conducted a techno-economic numerical investigation using the RETScreen software of the viability of employing electrical power production from wind in Kuwait. Economic analyses of 80 kW solar PV ON-grid to produce electrical energy were investigated utilizing HOMER and MATLAB/Simulink Software's by Sekhar [6]. Teshnizi *et al.* [7] carried out a theoretical investigation of supplying electrical energy to a residential house in five cities in Qatar (Abu Samrah, Ar-Ruways, Doha, Duhan, and Musayid) using HOMER software and weather 20-year data. Charabi and Abdul-Wahab [8] utilized HOMER Pro software to evaluate the wind energy potential in the north and south of Oman and to present a guidance on the optimum wind turbines to meet the power needs of each area. They measured six different standard wind turbines and conducted a comparative study regarding the performance and the cost of energy produced.

The hybrid energy systems, particularly PV and wind, were studied by numerous researchers. These works were focused on optimizing total power productivity, increasing system reliability, and lowering system costs. Alturki and Dayil [9] considered the viability of hybrid power PV/wind as a system for supplying residential buildings with electrical power in Riyadh city, Saudi Arabia. Makbul *et al.* [10] carried out an optimization analysis of the feasibility of wind turbine and PV hybrid system energy for electrical energy in the west region of Saudi Arabi utilizing MATLAB and HOMER software. A grid-tied hybrid PV/wind energy system was optimized using HOMER software to meet a public load demand of 15 MWh/day and a peak load of 2395 kW in four different cities in Saudi Arabia was reported by Alharthi et al. [11]. Kharrich *et al.* [12] considered the techno-economic optimization of the hybrid renewable energy systems in different regions of Morocco using the PSO algorithm. Kabir *et al.* [13] investigated the viability of hybrid ON-grid PV/wind/diesel engine to overcome the deficiency of electrical power for remote regions in Bangladesh. Konchou *et al.* [14] presented an optimal design of a hybrid (PV/wind/battery/diesel engine) energy system to supply electrical energy to the community multimedia center in Makenene, Cameroon. A techno-economic viability study on an ON-grid distributed energy system for a big technical institute was carried out by Suresh *et al.* [15]. They emphasized minimizing the electricity consumption from the public grid by generating the ultimate possible renewable energy with an integration of green vehicle transportation applications such as electric cars and green hydrogen gas, etc. which are essential for sustainability. Arun *et al.* [16] simulated and analyzed various hybrid energy systems including renewable and non-renewable sources using the HOMER Pro software. They found that solar PV and wind were the main renewable energy resources potential in Oman. A hybrid renewable energy system composed of PV modules and a wind turbine to meet totally or partially the demand of a ON-grid residential building was optimized using a genetic algorithm [17]. Al-Sarraj *et al.* [18] carried out a techno-economic optimization investigation of a hybrid power system for an urban ON-grid building in Iraq using HOMER software, and they found that the optimal hybrid system solution was ON-grid (PV/wind/battery) with sellback property.

Recently Riayatsyah *et al.* [19] carried out a techno-economic optimization examination of an ON-grid PV/wind/battery hybrid energy system for Syiah Kuala University (Sumatra Island) using HOMER software. Ahouar *et al.* [20] provided a comprehensive review of different criteria and methods utilized to obtain the optimal design of ON-grid hybrid PV/wind energy systems and concluded with hopeful future methods in this area.

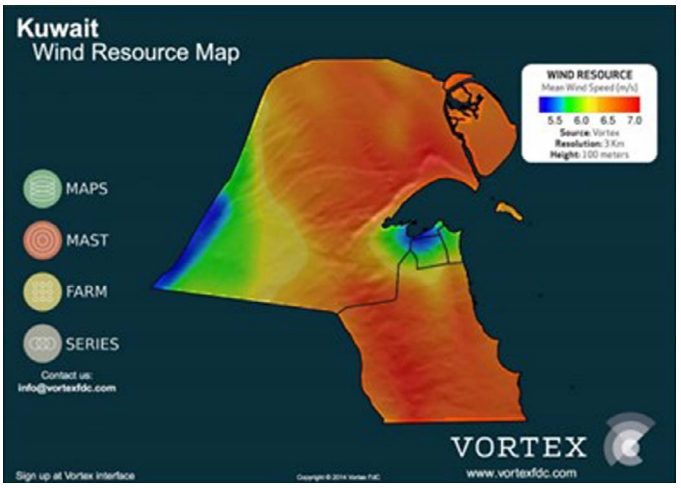

Figure 1. *Kuwait wind map.*

Table 1. *Location of the KMD 10 Meteorological stations*

Station	Station Name	Longitude	Latitude
1	Ahmadi Oil Pier	48.16153	29.05958
2	Beacon N6	48.20727	29.57306
3	Beacon M28	48.60239	29.51936
4	Julaia Port	48.28982	28.86466
5	Umm Mudayrah	48.77395	28.93628
6	Umm Almaradim Island	48.6528	28.67652
7	Salmiyah	48.1014	29.34619
8	South Dolphin	48.99495	29.41367
9	Qaruh Island	48.77435	28.81619
10	Sea Island Buoy	48.29861	29.11222

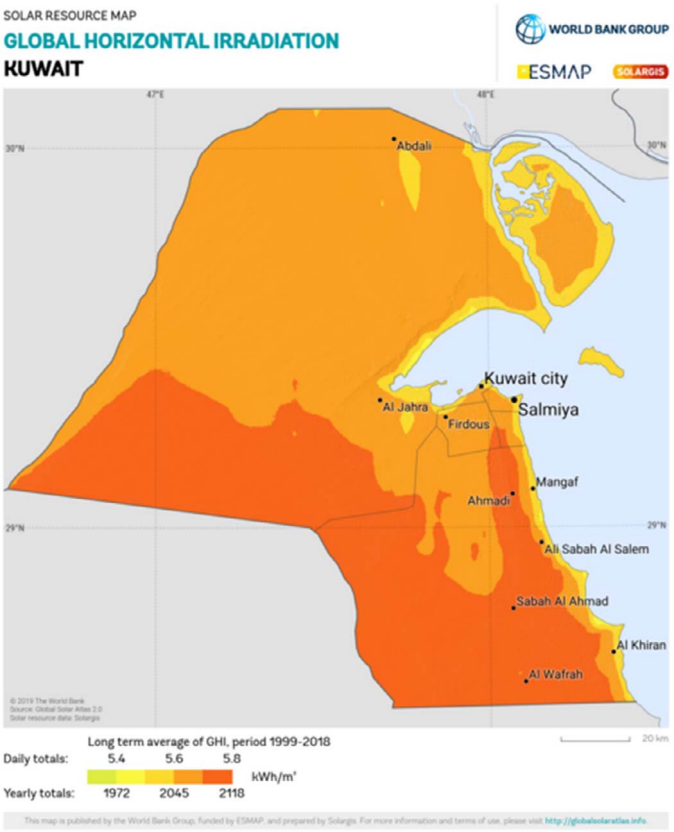

Figure 2. *Solar map of Kuwait area.*

Lawan and Abidin [21] presented a comprehensive review of previous research work on hybrid PV/wind energy systems and explored the main technical concerns on hybrid PV/wind energy systems with probable solutions arising from the integration process in ON-grid and OFF-grid approaches. Muhsen, H. *et al.* [22] conducted a theoretical investigation to design and optimize the performance of a small Horizontal-Axis-Wind-Turbine to get a power coefficient (CP) higher than 40% at a low wind speed of 5 m/s. They utilize two symmetric shape airfoils to obtain the final optimized airfoil.

Based on the above literature reviews, as no published research work studies the analysis and optimization of hybrid PV/wind energy system in Kuwait, this was the major drive of the present study. Therefore, the objective of this research is to carry out a techno-economic viability assessment of a hybrid PV/wind system for a cement factory in Kuwait using HOMER Pro software to obtain the optimal size of an ON-grid PV/wind system for the cement factory that meets the electrical demand effectively with a competitive cost compared the grid tariff.

2 METHODS AND MATERIALS

2.1 Wind potential in Kuwait

The average wind speed for Kuwait is shown in Figure 1. Wind speed data is available at coastal and offshore sites from ten wind measurement stations managed by the Kuwait Department of Meteorology (KDM) in the Directorate General of Civil Aviation. Table 1 shows the station's information as well as the period for which data is available. The information is based on the direction and the hourly mean wind speed at an elevation of 10 meters. For stations 1 to 9, the percentage of missing data over the recorded periods spans from 0.19 to 1.58%, with 11.3% for station 10. The data is well-maintained, and the DGCA and international consultants oversee quality control and assurance. As per the International Renewable Energy Agency (IRRA) data, wind potential in Kuwait amounted to 1605 hours per year more than 18% of the year hours. The highest potential wind power in Kuwait was found during the summer season which is also the peak electricity demand season [23].

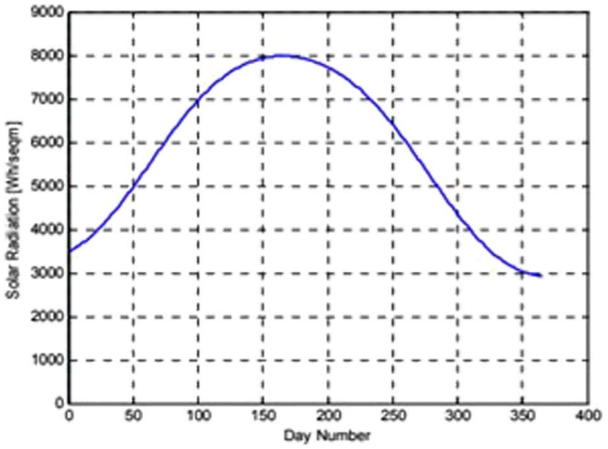

Figure 3. *Global solar radiation intensity daily variation on horizontal surfaces in Kuwait (Wh/m2).*

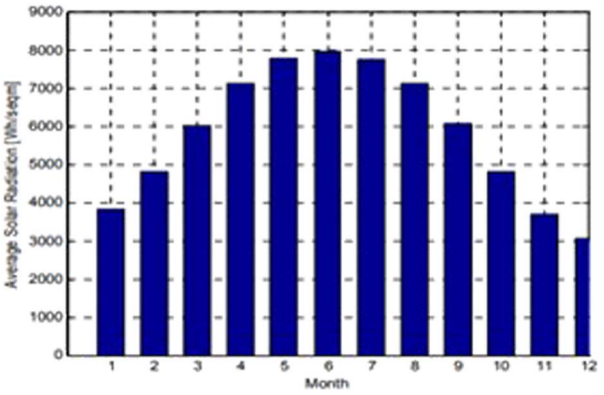

Figure 4. *Monthly mean solar radiation intensity on horizontal surfaces (Wh/m2/day).*

2.2 Solar radiations over Kuwait

The solar map for the state of Kuwait is shown in Figure 2. As illustrated in Figure 3, the daily solar radiation intensity on horizontal surfaces in Kuwait grew significantly from 3786.5 W.h/m² on 15 January to 7984.9 W.h/m² on 15 June and then rapidly reduced to 3691.6 W.h/m² on 15 November. Its peak values in the months of

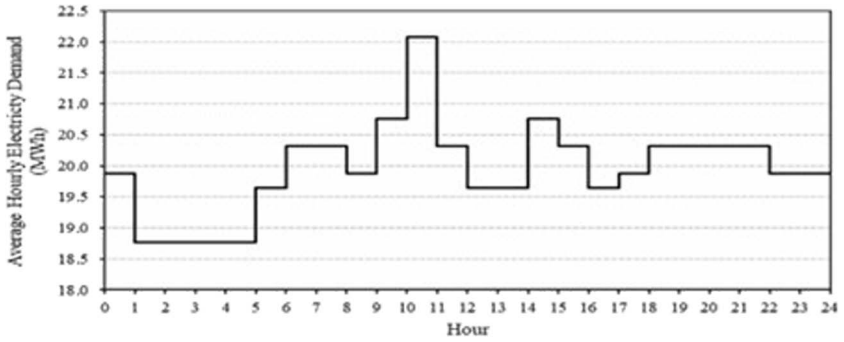

Figure 5. *The average hourly electrical energy demand of the cement factory.*

Figure 6. *Daily load profile of the electrical energy demand for the cement factory.*

Figure 7. *Monthly average wind speed (m/s) at a height of 20 meters in Al-Salmiya.*

April to August (for n ranging from 91 to 244), with the largest daily solar radiation occurring in June, as depicted in Figure 4. Because the solar altitude angle attains its maximum values during hot months in Kuwait (April–August), from 64.69° on 1 April to 83.85° on 30 June and again to 68.77° on 31 August, these results denote very good agreement between the computed data and the weather conditions. This clarifies the high temperature degrees in Kuwait during these months. The solar intake is about 9–11 hours per day in Kuwait, with an average daily solar irradiance of about 5.2 kWh/m²/day and can exceed 7.0 kWh/m²/day on some shiny days. This is equivalent to 1900 KWh/m²/year solar potential, evaluated in global horizontal irradiance. Therefore, Kuwait contains an abundance of solar energy capabilities.

3 MODELING SOFTWARE: HOMER

Hybrid Optimization Model for Electric Renewable (HOMER) is a computer software developed by the National Renewable Energy Laboratory (NREL). It is a powerful tool for simulation, optimization, configuration, and evaluation of various designs for distributed electrical power production and consumption plants. Additionally, the HOMER software helps in the modeling and optimal design of a hybrid energy system for power production to completely accomplish and meet the quality, continuity, and security of the electrical demand for remote regions. Understanding the electrical power demand besides the potential availability of solar radiation and wind in the region under consideration was the first required stage, as clarified in next parts of this paper.

The practical method utilized was for electrical energy production using a hybrid system that comprised PV and wind energy. The presented procedure contains the following phases:

- The study's rural community's energy demand was identified, field-surveyed, and analyzed.
- An examination of the wind and solar radiation potential in the factory's location is carried out utilizing HOMER software and Excel spreadsheets.
- A techno-economical evaluation of the proposed hybrid system for electrification of the cement factory at Al-Salmiya was conducted.
- Optimization analysis of different configurations of hybrid systems and their costs in power production using HOMER software to ensure the requirement of electrical energy to the factory.

- The best configuration choice of hybrid system that meets the electricity demand with highest quality and lowest cost was selected.

3.1 Collection and analysis of electric load curve data

The mean monthly electrical energy demand for the cement factory in Kuwait was obtained by comparing electricity bills of, and the average hourly load profile for, a typical cement factory obtained from similar factories. Figure 5 demonstrates the man-hourly demand of the cement factory under consideration. The

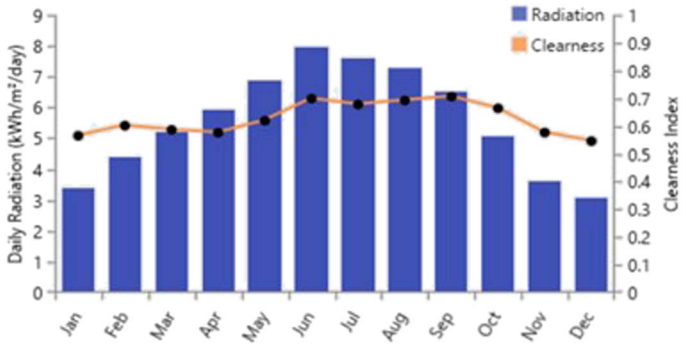

Figure 8. *Estimate of solar radiation potential in Al-Salmiya.*

Figure 9. *Estimated daily temperature in Al-Salmiya region.*

daily load profile of the electrical energy demand for the cement factory is depicted in Figure 6.

The predicted mean values of electrical energy demand were fed to HOMER software as input data to obtain the characterization of the power consumption of the factory at hand.

3.2 Solar and wind potential at Al-Salmiya region

The solar radiation and wind resources in the Al-Salmiya region obtained in this study for the site at hand were collected and then entered into the HOMER software as input data to perform the optimization process.

3.2.1 *Wind energy potential*

For this investigation, wind data were collected at an elevation of 20 meters and were fed into HOMER software, which allowed the monthly wind speed distribution to be seen throughout the course of the year, as shown in Figure 7. Most months the wind speed exceeds 5 m/s which is feasible for electrical power generation. Generally, the highest wind speed is observed in June and July, and the lowest wind speed is seen in January and April.

3.2.2 *Solar energy potential*

Figures 8 and 9 show the monthly solar radiation and daily air ambient temperature calculated by HOMER software. The daily and monthly mean solar intensity on horizontal surfaces in the Kuwait region varies from 3 Wh/m² in winter to 8 kWh/m² in summer. The monthly mean solar radiation during clear skies

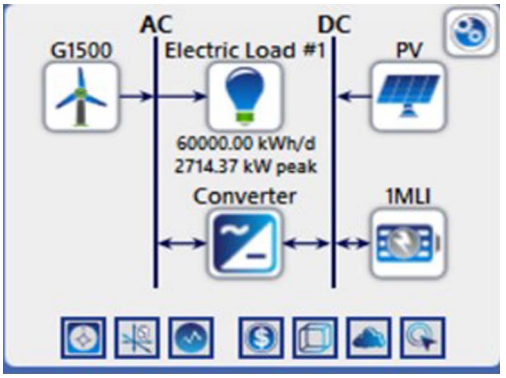

Figure 10. *The proposed system HOMER configuration.*

Table 2. *The NPC, LOCE and O&M costs for this project Al-Salmiya*

Total NPC:	57.086 M$
Levelized COE:	0.082$
Operating Cost:	0.696 M$

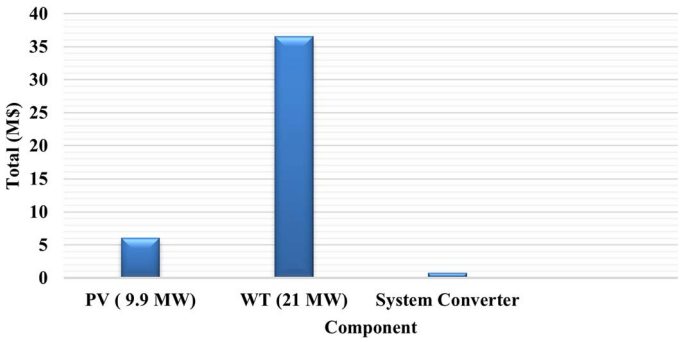

Figure 11. *Entire costs for the hybrid energy system in Al-Salmiya.*

on horizontal surfaces in the Kuwait region varies from 500–1042 W/m²/day. Thus, the Kuwait state possesses a viable solar energy source.

4 RESULTS AND DISCUSSION

4.1 Hybrid energy system configuration

Figure 10 demonstrates the intended system's overall constituent arrangement in addition to its HOMER model for several sensitivity values: ranges of power production capacity, energy cost, wind speed, and solar irradiation. The software structure contains all simulations and alternative configurations that were undertaken for solar PV module and wind turbines.

4.2 Techno-economic analysis of Al-Salmiya's results

The costs for this project in Al-Salmiya are depicted in Table 2 as NPC (net present worth), LOCE (levelized cost of energy), and O&M (operation and maintenance).

Table 3. *The capital, replacement, and O&M costs for the project in Al-Salmiya*

Component	Cap (M $)	Rep. M ($)	O &M (M $)	Fuel (M $)	Salvage (M $)	Total (M $)
PV (9.9 MW)	5.94	0.000	0.120	0.00	0.00	6.06
WT (21 MW)	32.25	10.28	0.576	0.00	- 6.536	36.571
System Converter	0.511	0.244	0.00	0.00	-0.0255	0.755
System	38.951	10.524	0.696	0.00	-6.562	43.386

Table 4. *The percentage amount of energy production by PV and wind in Al-Salmiya*

Production	KWh/yr	%	Consumption	KWh/yr	%	Quantity	KWh/yr	%
PV- Array (9.9 MW)	19 784 261	21.9	AC Primary Load	84 414 769	100	Excess Electricity	5 764 413	64.1
WT (21 MW)	70 414 921	78.1	DC Primary Load	0	0	Unmet Electric Load	56 194	0.0623
Total	90 199 182	100	Deferrable Load	0	0	Capacity Shortage	90 019	0.0998
			Total	84 414 769	100			
						Quantity	**Value**	**Unit**
						Renewable Fraction	100	%
						Max. Renew. Penetration	4489	%

The hybrid system capital, replacement, and O&M ('operation and maintenance') expenses are depicted in Figure 11 and Table 3. It is observed that the overall capital cost of the hybrid system reached 38.951 M$. The total replacement cost reached 10.524 M$, and the total O&M expenses reached 0.696 M$.

Table 4 compares the quantity of energy generated by solar panels and wind turbines. It can be observed that solar panels produce 21.9% and the wind turbines produces 78.1% of the total power generation.

5 CONCLUSIONS

This paper presents a techno-economic optimization investigation of a hybrid PV/wind renewable energy system to meet the electrical power demand of a cement factory sited at Al-Salmiya, Kuwait, using HOMER Pro software. It was obtained that the optimum sharing out of the PV generation and of wind turbine was 21.9% and 78.1% of the total energy production, respectively. The result achieved from the optimization provided the primary capital cost as 38.951 M$ whereas operating and maintenance cost is 27 840$/year and the total net present cost (NPC) is 43.386 M$. Finally, it was found that the energy cost of the proposed hybrid energy system is equal to 0.082$/kWh compared to 0.12$\kWh of Kuwait national electricity.

AUTHOR CONTRIBUTIONS

Mohammed Odat (Data curation [Equal], Formal analysis [Lead], Funding acquisition [Lead], Investigation [Lead], Supervision [Equal], Validation [Equal], Visualization [Equal], Writing—original draft [Equal], Writing—review & editing [Equal]), Ali Chamkha (Conceptualization [Supporting], Data curation [Equal], Formal analysis [Supporting], Funding acquisition [Supporting], Investigation [Equal], Methodology [Equal], Project administration [Equal], Resources [Equal], Software [Equal], Supervision [Equal], Validation [Equal], Visualization [Equal], Writing—original draft [Equal], Writing—review & editing [Equal]), Firas Obeidat (Data curation [Equal], Visualization [Equal], Writing—original draft [Equal]), and Mohammed Al-Hasan (Conceptualization [Equal], Formal analysis [Equal], Methodology [Equal], Resources [Equal], Writing—original draft [Equal], Writing—review & editing [Equal]).

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