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Assessment of Dust Properties in Ma'an Wind Farms in Southern Jordan

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Abstract

Many wind turbines have been deployed in different regions of Jordan; most are located in southern Jordan, which has a desert climate. In one of these farms near Ma'an city, the operators noticed a frequent temperature increase (+2°C) due to clogged air nacelle filters during the dust period, which caused decreasing cooling efficiency. This led to the frequent shutdown to protect the turbine parts and replace filters. In contrast, this approach reduced the estimated total annual energy production by 6.4 million kWh. This work has carefully investigated wind farm sites to verify the sources and concentration of dust in the atmosphere around the farm. Also, the dust collected from the used (replaced) filter was analyzed by X-Ray Diffraction (XRD), sieves, and X-Ray Fluorescence (XRF) at Al- Hussein Bin Talal University and Asia Center in Amman laboratory. The results showed that Calcium (Ca) constituted 90% of the chemical elements in the dust sample collected from the filter. Also, the dust particles, which have a size of < 297 μm, could be passed through the filter. Indeed, the dust characteristics are similar to the dust sources surrounding the wind farm, which is evidence of the apparent influence of these sources on the wind farm. These filters must capture contaminants that affect the cooling system, and must be durable enough to withstand high airflow, heat, and U.V. radiation. Moreover, at the end of this study, the authors proposed recommendations to reduce dust effects, thereby reducing shutdown periods and additional maintenance costs.

Keywords: Dust analysis, Wind turbine, Air filter, Wind turbine performance.

1. Introduction

Global energy demand will increase by 4.6% in 2021. Therefore, Solar, wind, and ocean energies play an essential role in coping with growing energy needs and reducing fossil-fuel consumption and greenhouse gas emissions [1-6]. Among all the renewable energy sources, wind energy is the fastest-growing renewable energy source of its sustainability, availability, environment friendly, and cost-effectiveness. According to Global Energy Review 2021 [7], wind energy was introduced as the most significant increase in renewable generation, growing by almost 17%, significantly higher than in 2020. This type of renewables plays a vital role in the decarburization of the power sector [8, 9]. In 2020, 82.5 GW of new wind turbine power capacity was added, representing 33.2% of the total power generated from renewable energy [10]. Wind energy share of worldwide power generation is expected to increase to 14%, whereas Solar photovoltaics can grow to 7% by 2030 [11-14]. As is the case in many countries, Solar and wind–derived electrical generation has become increasingly important in the Jordan power grid. Indeed, the southern region of Jordan has one of the highest Solar irradiance levels globally of 4-7kWh per square meter, coupled with more than 300 days of sunshine. Moreover, this area possesses a high potential for wind energy resources, with annual average wind speeds exceeding 7m/s (at 10m height) in some regions [15,16].

Jordan's government invested 1.4$ billion in the energy sector to 20% of the energy mix, which Jordan plans to reach by 2020 [15,9]. Many wind farms have been commissioned from 2013 to 2021. Most of them were located in southern Jordan. This includes the Tafila (117 MW), Ma'an farm (66 MW), Al-Rajef project (82 MW), Shobak project (45 MW), Al-Fajeej Project (89 MW), Mas project (100 MW), Daihan project (51 MW), El-Abour project (51 MW) and an additional 100 MW from the third round of direct offers 2020–2021. Jordan is expected to generate 600–1000 MW from wind between 2019-2021 [17].

Generally, wind turbines are installed in various environments; thus, the equipment (electronic and control) that supports wind turbines must operate efficiently and probably under extreme conditions. Blowing sand and dust for inshore, rain, and salt fog for offshore turbines is a significant concern for wind turbine equipment. These contaminants can cause electronic failure and production power loss. The accumulation of dust is one of the major

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concerns for wind turbine equipment [18]. These contaminants can cause the increasing temperature inside the nacelle, which causes the failure of the wind turbine's electrical, electronic, and mechanical parts.

Many aspects have been studied in the literature to overcome the temperature increase in wind turbine nacelle [19]. For instance, many airflow configurations have been investigated [20,21]. Also, the distribution of temperature fields of the internal components of the wind turbine has been analyzed [22,23]. Other studies have been conducted on the current cabin cooling system to inspect the thermal performance of these systems under extreme temperatures [24-26]. A further aspect that has been studied is the influence of the working environment of wind turbines on heat generation [27-30].

The accumulated dust is one of the severe working environment aspects that causes the increasing temperature inside the nacelle to block the air circulation. However, there is a shortage of studies assessing wind turbine performance and the environmental impact on its performance [31-34]. Most of the previous studies have concentrated on the effects of dust accumulation on the blade surface roughness and its influence on the performance of wind turbines. This is because a few of these studies have been briefly reported in the literature to protect intellectual property in a competitive market environment. On the other hand, the impact of the dust accumulated in the nacelle filter on reducing the effectiveness of the internal ventilating system of the wind turbines also needs more investigation. As well known, wind turbine filters must capture contaminants while allowing adequate airflow to ensure equipment within the turbine remains cool. The air filter must also be durable enough to withstand high airflow, heat, and U.V. radiation. According to the statistics of Ma'an wind farm, the number of unit shutdowns caused by the over-temperature of components due to accumulated dust exceeds 60% of the total number of abnormal shutdowns.

In Ma'an wind farm, the accumulated dust removal is a costly process. It is usually treated through (manual dust removal), carried out by the operation and maintenance personnel on the top of the wind turbine. This requires workforce and material resources, long downtime, limited dust removal, and heat dissipation. One novelty of the current investigation is to assess the significance of the filter clogging, which is responsible for entering the fresh air into the turbine's nacelle. This study will help mitigate dust's negative impacts on turbine operation. In this context, this study aims to investigate and classify the accumulated dust collected from the nacelle filters and the area around the farm. Then, the authors present some recommendations to reduce accumulated dust removal costs.

2. Case study

The case study is Ma'an wind farm located in southern Jordan, near the Al-Hussein Bin Talal University campus (latitude: 30° 16' 9.7" and longitude: 35° 41' 50.1"). This location is known for having a large wind potential capacity. It has average wind speeds of about (5-7) m/s at 10 m height, as shown in Fig. 1 [35]. In addition, it has good infrastructure and electrical grid connections. Therefore, it was chosen for deployed wind turbines. Fig. 2 illustrates the wind turbine location. This wind farm works 40 wind turbines with 97 rotor diameters and total nominal power of 80 MW[36].

Although of these advantages, Ma'an has a desert climate and rare rainfall with an average of 44 mm a year only. Additionally, this city has many stone crushers, where Ma'an stone is considered a high-quality building stone in the Middle East. The development projects are underway in this city. Thus, the construction projects are becoming close to the wind farm.

According to these circumstances, wind farm operators have started to report increases in the internal temperature of the nacelle due to the air filter collaging. Fig. 3 illustrates the air filter used in the Ma'an farm.Fig. 3(a) the new air filter that would be fixed in place of the blocked one shown in Fig. 3(b). When the air filter is clogged with dust, as shown in Fig. 3(b), this leads to shutting down of the wind turbine frequently to clean the filter and protect the internal components of the wind turbine from the increasing temperature. Therefore, it became essential to identify dust sources that impact the rising temperature of the wind turbine. Theoretically, wind farm operators noticed that the dust directly impacts the nacelle air filter blocking. Practically, no investigation has been done on this dust type and its characteristics or source.

3. Dust Analysis Methodology

To investigate and classify the accumulated dust collected from the nacelle filters and the area around the farm. The method followed in this work is developed as illustrated in Fig. 4. Initially, some critical measures must be used to create parallel datasets of the turbine's status, ambient temperature, and turbine active power. The dataset contains data for four periods in the year 2021 during regular turbine operation in summer when temperatures and dust accumulation are the highest.

The dust collected from the wind turbine air filter (D-T) has been used to analyze the mineral percent, chemical composition, and size of particles. These tests have been conducted by using X-Ray Diffraction (XRD), sieves, and X-Ray Fluorescence (XRF) inside the laboratory of Al-Hussein Bin Talal University; see Figs. 5(a) and 5(b). The second test was conducted to determine the particle size of the dust collected from the air filter. This test was carried out at the laboratory of the Asia Center in Amman. The various sizes of sieves used in this test are shown in Fig. 5(c). The dust collected for a year from the environment around the farm by a particle matter device is shown in Fig. 5(d). It is used to measure the concentration of dust by weighing dust trapped in the filter.

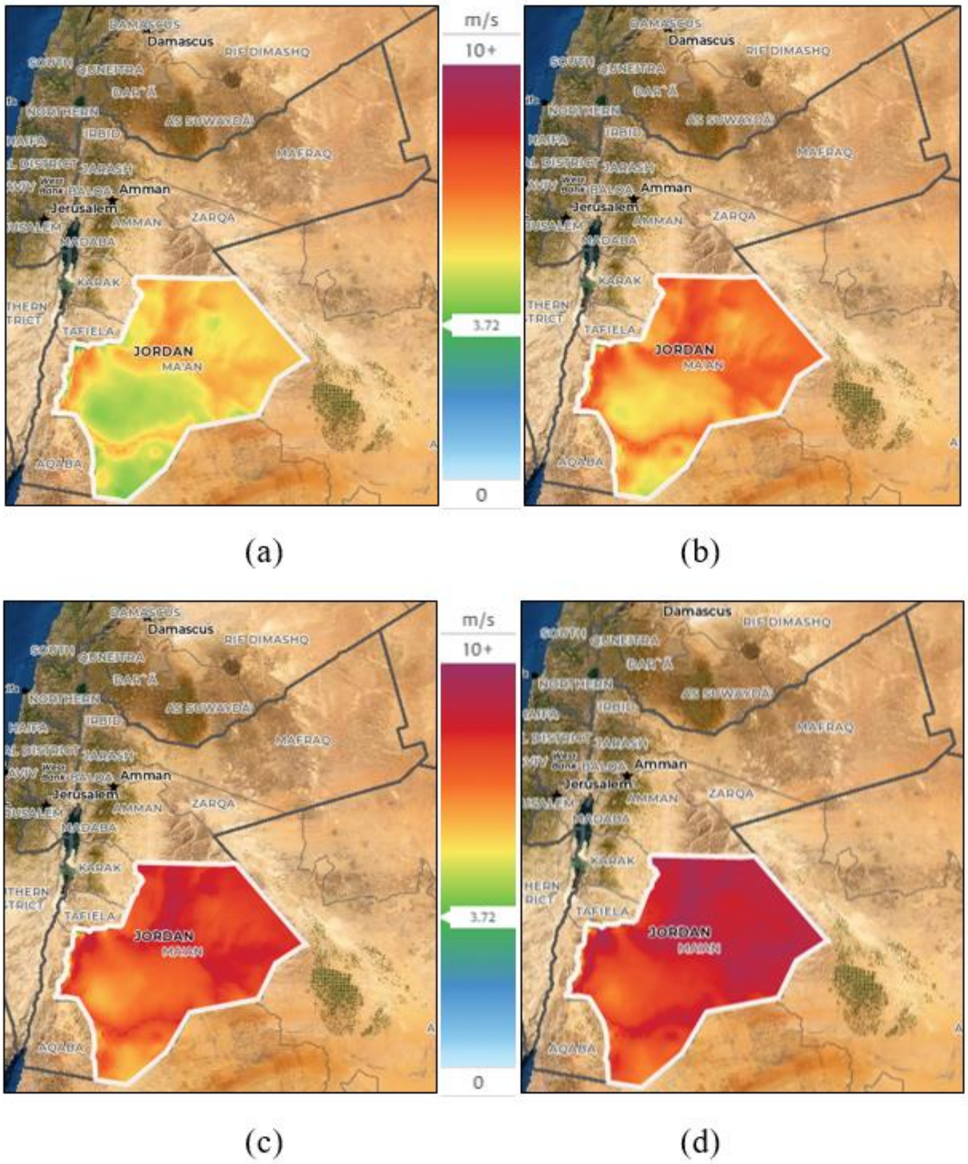
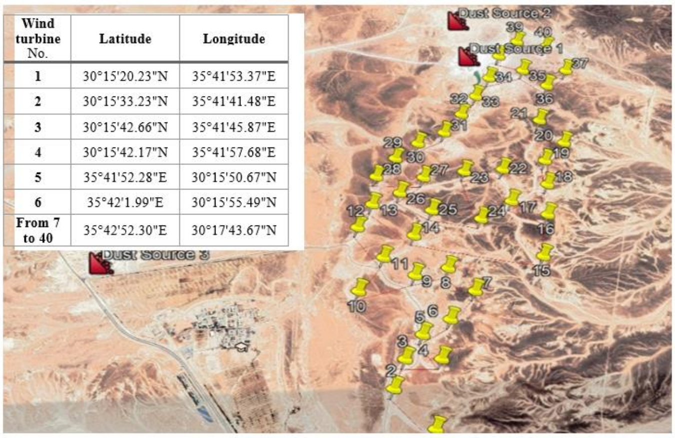
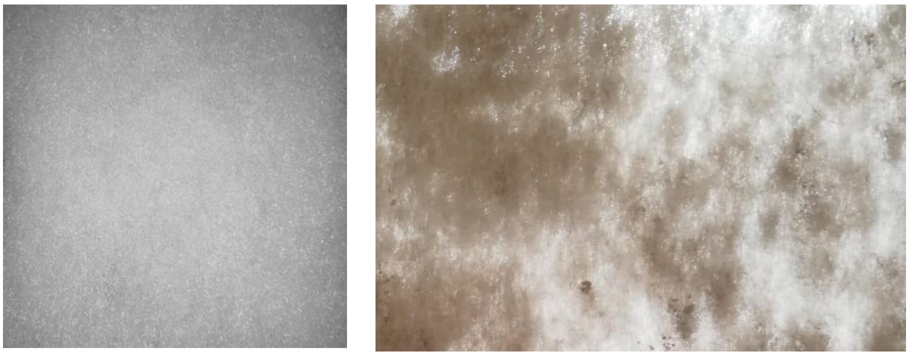


Figure 1. Mean wind speed in Jordan at altitude (a) 50 m; (b) 100m; (c) 150m; (d) 200m.



Wind turbine No.	Latitude	Longitude
1	30°15'20.23"N	35°41'53.37"E
2	30°15'33.23"N	35°41'41.48"E
3	30°15'42.66"N	35°41'45.87"E
4	30°15'42.17"N	35°41'57.68"E
5	35°41'52.28"E	30°15'50.67"N
6	35°42'1.99"E	30°15'55.49"N
From 7 to 40	35°42'52.30"E	30°17'43.67"N

Figure 2. Location of the Ma'an wind farm in southern Jordan.



(a) (b)

Figure 3. The air filter used in the Ma'an wind farm; (a) the air filter before it was used, (b) the air filter after it was blocked of dust.

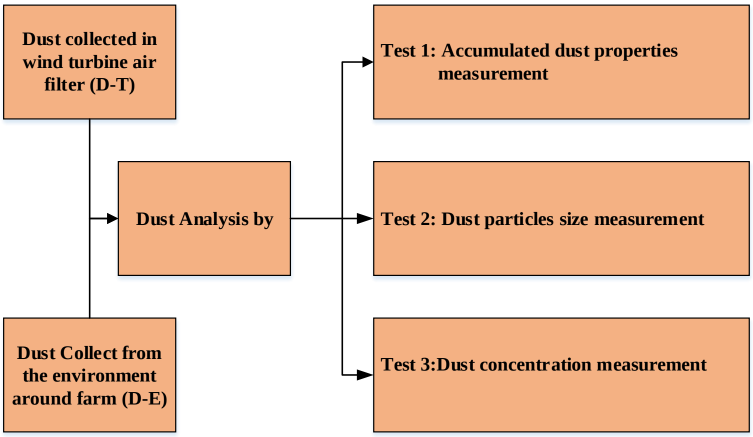
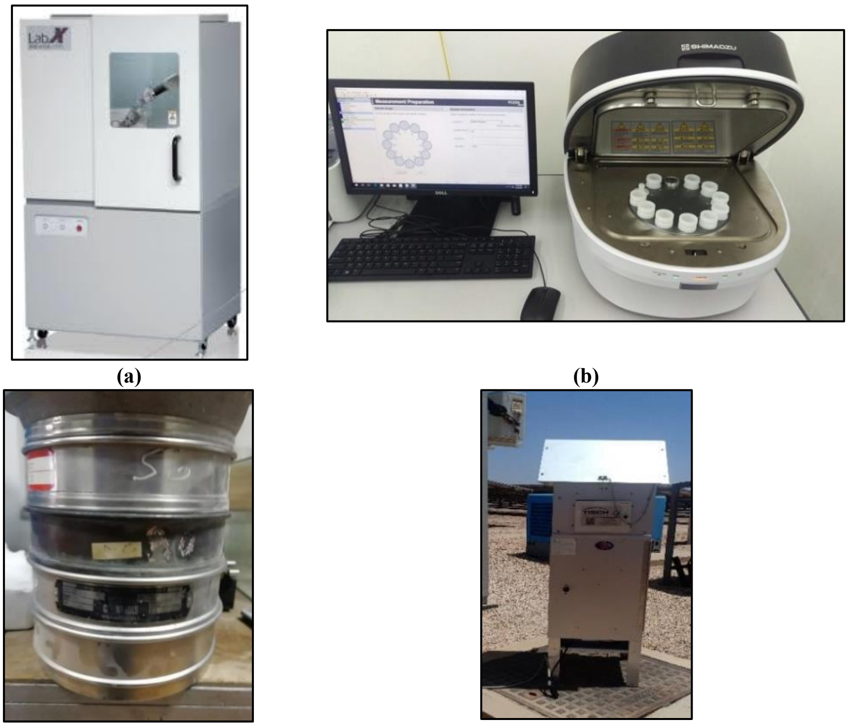


Figure 4. Method of Analysis.



(a) **(b)** **(c)** **(d)**

Figure 5. Instrumentations used in dust investigation; (a) X-Ray Diffraction (XRD)-LabX-6100; (b) Particles Matter Device; (c) X-Ray Fluorescence (XRF)-EDX 7000 (d) Sieves

4. Results and Discussions

The results in this section are limited to the dust specimens collected during four periods in the year 2020 during regular turbine operation in summer when temperatures and dust accumulation are the highest, as described in Section 3.

4.1. Dustchemical content analysis

The chemical content of the dust particles collected from the air filter (D-T) was investigated in the first analysis stage. This analysis has been conducted using X-Ray Diffraction (XRD) device (Fig. 5(a)). In this test, the molecular structure of crystalline dust material has been ascertained by diffraction x-rays through the dust sample. Figure 6 summarizes the test results. This figure indicates that the most dominant element was Calcium (Ca), which reached about 90%, and Silicon (Si) 6.10%. The reason of the high Ca content in the dust sample could be the stone crushers spread around the wind farm as the calcium is abundant in limestone and gypsum used in construction (see Fig.2, Dust source 1, and Dust source 2).

On the other hand, a comparison has been conducted between the chemical composition elements performed in this work and the dust analysis conducted in a previous study on dust accumulation on solar Photovoltaics [37, 38]. Fig.7 shows the comparison result. This figure illustrates variations between the chemical components of the dust accumulated in the wind turbine filter (D-T) and the dust sample collected over the PV panels (D-PV). The Ca reaches about 90% in D-T, while Ca is present at about 57.3% in the D-PV. However, the rest of the chemical components (e.g., S.I., Fe, ..etc.)in the D-PV specimen has a higher percentage than the D-T sample.

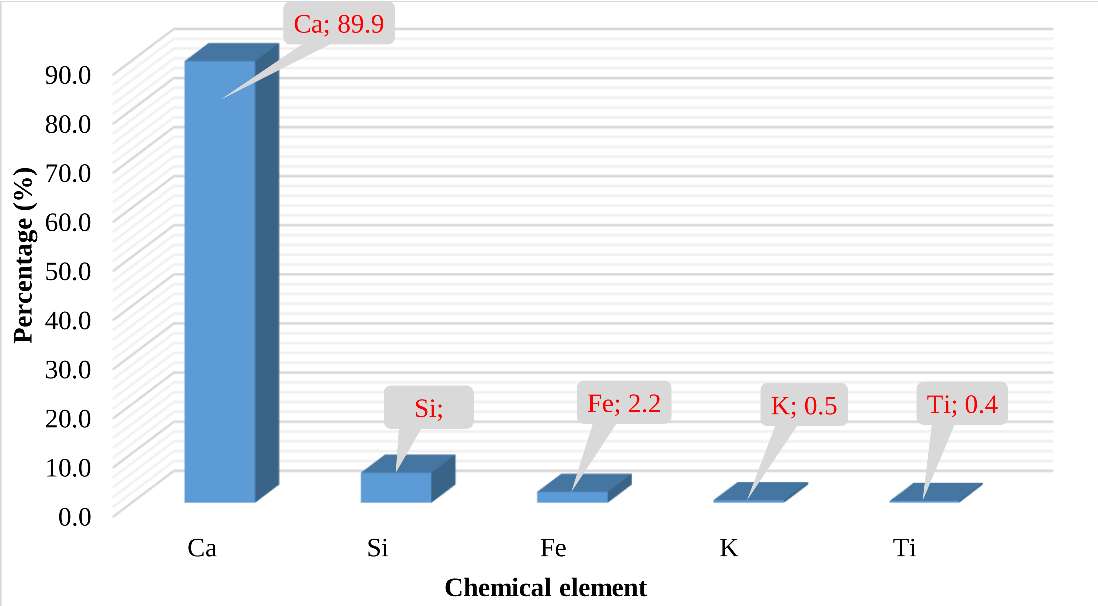


Figure 6. The chemical composition of the sample collected from D-T.

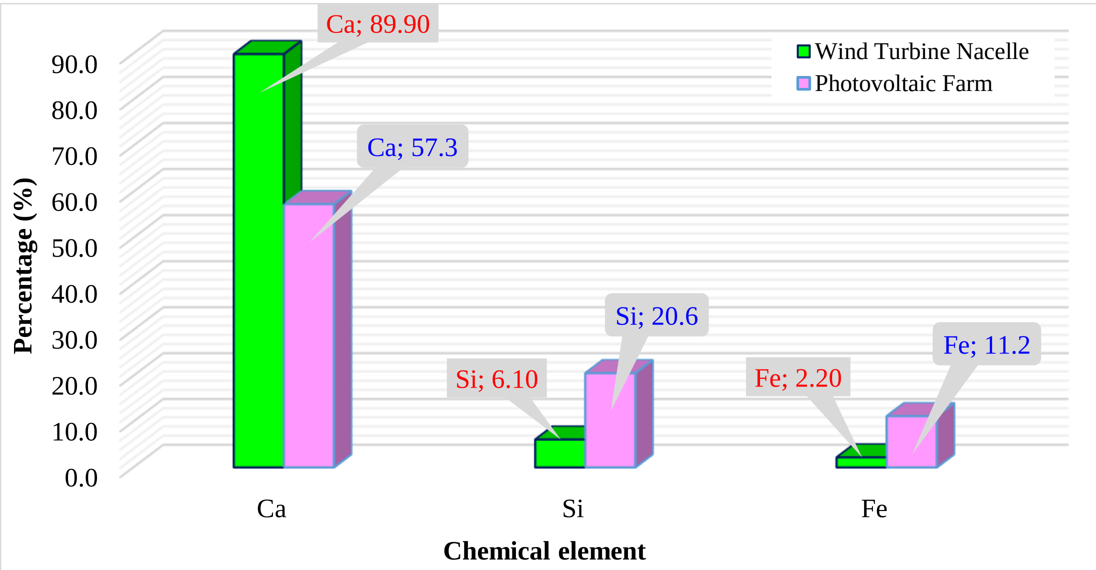


Figure 7. Comparison of the chemical elements between the samples collected from D-S and the D-T.

4.2. Dust particle size measurement

In this test, the accumulated dust particle size has been analyzed using different sieve sizes (See Fig.5.(c.)). The results of this test are illustrated in Table 1. The results showed that the dust particle size of about 149 µm was the most available in the dust sample with about 43.7%, then 74µm and 177µm, about 21.7% and 19.9%, respectively. The results of this test also illustrate that the current filter used in the wind farm can trap dust with a particle diameter of 74 to 590 µm. However, most of the dust particles (85%) trapped by air filters have a diameter of 74 to 177 µm.

Further, the current air filter is less efficient in trapping the dust with a particle diameter smaller than 297 µm. Accordingly, a part of dust particles (~< 297 µm) could be passed through the filter, damaging the wind turbine's internal component. Therefore, the concentrations of dust in the atmosphere with particle size (~< 74 µm) have to be studied.Accordingly, the dust particles with particle size (~< 74 µm) have been classified according to the international classification in Table 2. It is important to note that these results have been collected over four different periods during 2020, as presented in Section 2.

Table 1. Dust particle size trapped at the air filter (D-T)

Sieve number	Sizes of sieve opening (µm)	Weight (%)
30	590	2
40	420	9.8
50	297	2.9
80	177	19.9
100	149	43.7
200	74	21.7

Table 2. The average concentration of dust air particles

Particles Matters	Period 1	Period 2	Period 3	Period 4
PM2.5	21 µg/m^3	32 µg/m^3	71 µg/m^3	17µg/m^3
PM10	55 µg/m^3	80 µg/m^3	128µg/m^3	43µg/m^3

4.3. Effect of dust accumulation on the turbine performance

In literature [39,40], the nacelle temperature significantly impacts the turbine's productivity. Indeed, increasing temperatures inside the nacelle damage some turbine parts, such as the control unit, and decrease the lubricating oil efficiency. This frequently shuts down the turbine for maintenance work, thus reducing production. In this work, the temperature has been observed in the Ma'an wind farm for different periods in 2020. It has been found that the nacelle environment temperature rises by 14°C due to the air filter clogging due to dust accumulation. This issue often happens when the dust level is high in the atmosphere, as in Table 3.

According to the study periods, the wind turbine productivity reduced to 2000.6 kW when the dust concentration rate in the environment was high (71µg/m^3). In comparison, it was 2012.5 KW at an ambient temperature of about 27.9 but a low dust concentration rate of about (14 µg/m^3).

Many factors, like wind speed and direction, could impact wind turbine productivity. However, this study also proved that the increase in dust levels in the atmosphere directly affects wind turbine productivity and could be a significant factor, especially in a region like Ma'an city.

Table 3. The value of turbine productivity with the concentration of dust in the atmosphere

Period	Max average active power (kW)	Dust concentration rate (µ*g*/*m*^{3})	Ambient temperature (°C)
Period 1	2010.10	21	21.4
Period 2	2009.00	32	21.2
Period 3	2000.60	71	27.3
Period 4	2012.50	14	27.9

5. Conclusion

A good nacelle environment and reasonable nacelle temperature are robust guarantees for the safe operation of wind turbines. This study provided a detailed analysis of the dust accumulated in the wind turbine air filter on the Ma'an, southern Jordan farm. A chemical content variation was observed in dust particles collected from the wind turbine air filter. Also, the chemical content of the dust collected from the wind turbine air filter and the PV panels was similar but at different proportions. This study also proved that when the dust level is high in the atmosphere, the temperature increases inside the nacelle. Accordingly, productivity decreased during this period.

In the desert environments like southern Jordan, where most of the renewable energy projects are located (e.g., Solar farms, Wind farms), it is vital to maximizing power production. This needs a proper management of maintenance operations to keep the turbine nacelles operating normally. Despite dust accumulation negatively affecting wind turbine production, there is a shortage of studies on accumulated dust on the increasing temperature inside the wind turbine nacelle. According to the results of this work, the nacelle air filter needs frequent cleaning to allow the fresh air to complete the nacelle ventilation cycle and prevent too much dust accumulation, which is conducive to significant losses. In addition, the nacelle environment can be effectively improved, and the cabin temperature can be reduced by installing a proper filter. According to the dust particle size found in this work, another recommendation could be the possibility of using a backwash technique to clean such filters. This study could be helpful in the operation and maintenance of the wind turbine in a desert region like southern Jordan. However, further investigation is still needed to determine a suitable cleaning technique according to the weather conditions.

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