




## EFFECT OF DUST ACCUMULATION ON PERFORMANCE OF THE PHOTOVOLTAIC PANELS IN DIFFERENT CLIMATE ZONES

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### ABSTRACT

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With the increasing demand for energy globally and the need to reduce fossil fuels, paying attention to renewable and clean energy sources is necessary. Solar systems are viable among renewable energy sources for heat and electricity generation. In this study, an Off-grid solar system was investigated by considering the effect of climate conditions and environmental factors such as dust on the performance of PV panels. Performance and efficiency of PV system using PVsyst software in four cities of Iran (Mashhad, Abadan, Rasht, and Sanandaj) with different climates were presented. This study shows that most of the loss occurs in Sanandaj, with the cold and humid climate, which results show an 11.19% efficiency reduction. On the other hand, with its hot and humid climate, Abadan has an 8.33% loss due to the geographical location of this city in the vicinity of desert areas. With a temperate and humid climate, Rasht has a 2.27% decrease, and Mashhad, with a cold and dry climate, has a 2.19% decrease in yield.

**Contribution/Originality:** This research aims to identify and prioritize suitable locations for constructing photovoltaic power plants from the perspective of dust in Iran. In this regard, four cities of Mashhad, Rasht, Abadan, and Sanandaj were studied as representatives of the main climates of Iran in PVsyst software.

### 1. INTRODUCTION

The need to reduce non-renewable resources has made the importance of using renewable resources even more urgent. In this regard, electricity and energy production based on renewable energy are growing (Borzuei, Moosavian, & Farajollahi, 2021). Due to the lack of negative environmental impacts when using renewable energy technologies (Zahedi, Seraji, Borzuei, Moosavian, & Ahmadi, 2022). The importance of the environment increases the commitment and efforts of world politicians to reduce greenhouse gas emissions. Therefore, it increases the role of new and renewable energies (Mohseni, Moosavian, & Hajinezhad, 2022). One of the most common systems of generating electricity from renewable sources is photovoltaic panels that convert solar energy into electricity (Wu et al., 2020). Solar energy is one of the primary renewable energy sources; it is free, non-permeable, and clean and has various direct and indirect applications (Jaszczur, Hassan, Styszko, & Teneta, 2019). Solar photovoltaic energy systems can significantly meet the present energy demand and contribute to sustainable development (Borzuei,

Moosavian, & Ahmadi, 2022). For optimal efficiency, the installation of solar systems is determined according to their geographical location (latitude and amount of solar radiation) and installation design (slope, direction, and height of panels) to maximize sun exposure. Also, other dependent factors determine the system performance when these parameters are properly considered. Environmental factors such as wind, dust, and rainfall patterns significantly affect the performance of photovoltaic installations (Mani & Pillai, 2010). One of these important factors in this area is the dirty effect caused by the accumulation of dust on the surface of the module, which reduces the transparency of the PV coating glass over time and thus reduces the panel's efficiency (Maghami et al., 2016).

The effect of dust on solar power plants is one of the important factors that has always been considered from different perspectives (Pan, Lu, & Zhang, 2019). Dust is a minute solid particle less than 5 mm in diameter. Fine particles suspended in the environment, such as bacteria and fibers isolated from clothing and fabrics, are known as dust. Which sits on the surface of solar panels and gradually reduces the transfer coefficient (Costa, Diniz, & Kazmerski, 2018). Depending on the characteristics of dust (chemical properties, size, shape, weight, etc.) and climatic conditions (temperature, humidity, wind speed, precipitation) as well as the characteristics of the environment, the amount of dust settlement on the panel surface is different (Mekhilef, Saidur, & Kamalifarvestani, 2012).

One of the environmental factors directly related to the deposition of dust on the surface of solar systems is the direction and speed of the wind. Low-speed winds usually cause dust to settle, while high-speed winds have a different effect, removing dust on the surface (Gupta, Sharma, Pachauri, & Babu, 2019). However, the geometry of the PV system is concerning. The direction of wind movement can increase or decrease the dust settling on the panel surface in certain places of the PV system. The dust dispersion due to wind movements and the PV system's location depends on the dust's characteristics. A framework for understanding the various factors governing sedimentation/dust absorption is shown in Figure 1 (Mani & Pillai, 2010). It is easy to recognize that the phenomenon of dust settlement in PV systems is extremely complex and challenging to practically handle/comprehend in terms of all factors that affect dust settlement.

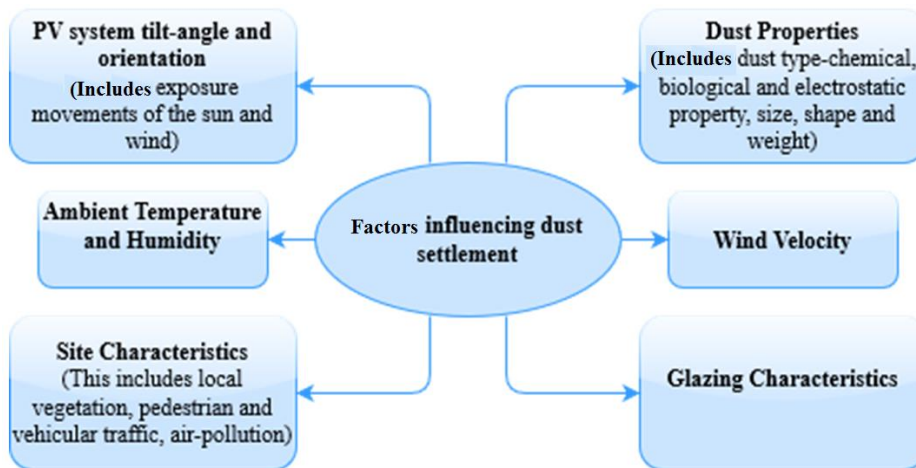


Figure 1. Factors affecting dust settlement.

## 2. BACKGROUND

Accumulating dust on the solar photovoltaic module (PV) can significantly reduce the solar radiation that reaches the surface of the cells and thus negatively affect the efficiency of electricity generated (Borzuei, Moosavian, Ahmadi, Ahmadi, & Bagherzadeh, 2021). Dust accumulation and its effect on system performance are uncertain that depend on the environmental conditions of the system and the amount and intensity of rain. It is generally negligible in moderate rainy climates and residential areas (less than 1%). Pollination is significantly lost in the rural agricultural environment during some seasonal activities (Kilci & Koklu, 2019). Increasing the rate of dust

accumulation leads to a decrease in PV performance due to a decrease in the glass coating spectrum and transferability (Kaldellis, Fragos, & Kapsali, 2011).

In another study, the conversion efficiency reduction of the PV system is 10%.16% and 20% for 12.5 g/m<sup>2</sup>, 25 g/m<sup>2</sup>, and 37.5 g/m<sup>2</sup> of dust density, respectively (Kumar, Sarkar, & Behera, 2013). Many research efforts in the past have focused on quantifying the soil effects on high-capacity solar power plant's performance and considering soil effects in the design of these systems (Al-Addous, Dalala, Alawneh, & Class, 2019).

In another research, Guo et al. Measured the performance of PV and the effect of environmental dust and climatic conditions in the region for seven months in Qatar. Their results showed that dust deposition on PV modules causes significant PV power generation efficiency losses (Guo, Javed, Figgis, & Mirza, 2015). In Emziane and Al Ali (2015), Accumulation of dust on the surface of the panels and its effect on light transmission for some of the samples tested in the Saudi desert found that light permeability has decreased to 84% due to dust settling. In the study, Benghanem, Almohammed, Khan, and Al-Masraqi (2018) Investigated the effect of dust accumulation on photovoltaic (PV) panels. Their results show that this dust causes the loss of 28% of the panels' output power during the 60 days (Benghanem et al., 2018). In a study to examine the performance of solar systems, Ghazi and his colleagues (Ghazi & Mustafa, 2013) found that dust varies in shape, size, and disruption; it comes mainly from the refineries and hurts the efficiency of solar systems. In Andrea, Pogrebnyaya, and Kichonge (2019), the results showed that the accumulation of dust on the polycrystalline silicon photovoltaic module has a negative effect on the output power of the short-circuit current. However, it does not significantly affect the open-circuit voltage. As a result, the module efficiency decreased to 64%, 42%, 30%, and 29%. Alnasser, Mahdy, Abass, Chaichan, and Kazem (2020) showed that the highest losses of production capacity are the time of collection of ordinary and white cement, sand, and plaster. Due to the small size of some of its particles, ordinary cement penetrates into the cracks and causes a significant reduction in production capacity (Alnasser et al., 2020). In Gholami, Alemrajabi, and Saboonchi (2017), the authors found that the amount of dust removed was less than that collected for such cases, which means a high density of accumulated dust. Bhaduri and Kottantharayil (2018) also proved that the soiling effect affects 16-18% of the efficiency. In Kazem, Chaichan, Al-Waeli, and Sopian (2020), panels' daily power losses and monthly efficiency reduction due to dust in some places are more than 1% and 80%, respectively Siyabi, Mayasi, Shukaili, and Khanna (2021). A study on the effect of dust in Oman concluded that 7.5% of the dust in the environment reduces electricity production by 5.6% in a month, and 12.5% of dust reduces 10.8% of electricity Gives results. Sarr, Cheikh, and Ababacar (2020) examined the power generated by the photovoltaic system, consumption, and other components related to PV production in four climatic regions of Senegal. In Memiche, Bouzian, Benzahia, and Moussi (2020) a study of the impact of environmental factors on the performance of solar panels in the Algerian desert concluded that the maximum power loss was 10.27%. Yadav and Bajpai (2017) also reported a 11.4% reduction in dust losses in one month by installing a 5 KVA photovoltaic power plant. In other study, Daher, Gaillard, Amara, and Ménézo (2018) Examined the performance of solar panels and stated that the dust loss rate was 0.03% during the rainy season and 14.23% during the hot and dry months.

The wind is one of the effective factors in reducing or increasing dust in the air and as wind speeds of more than 3 meters per second increase in the desert, dust and sand rise, reducing the amount of solar radiation that reaches the PV cells and reducing system efficiency (Kasim, Hussain, & Abed, 2019). The movement of the wind clears some of the sedimented particles on the surface of photovoltaic panels. The speed and angle of the wind movement determine this condition (Jaszczur. et al., 2019). If the wind is directed towards the surface of the PV panels, some of the dust particles collected on them will be removed by the wind movement.

In other words, the existing dust in the air is trapped due to the wind with very small diameters, and after the wind speed decreases, it settles and accumulates on the surface of PV panels (Varun & Manikandan, 2020). In Figgis (2016) B. In a study of a collector fixed on a building in Qatar, Figis examined the relation between wind speed and

dust deposition. This study showed that if the wind speed is less than 3 m / s, sedimentation is the main factor in accumulating dust in the collector area.

The surface of PV cells cools due to the speed of the wind, and their temperature also decreases. Also, the relative humidity of the environment will decrease, and as a result, its loss will be reduced. As wind speeds increase, more dust is dispersed and can increase the likelihood of being placed on panel surfaces (Rekhashree & Rajashekar, 2018). In order to install solar power plants in countries with arid climates, the effect of wind speed on dust deposition on the panels' surface was investigated to select the best geographical area (Kazem & Chaichan, 2019).

Another effective parameter in dust settling and deposition on the surface of the panels is the tilt angle. Several research efforts have investigated the direct relationship between stilt angle and soil subsidence to show the best tilt angle configuration to maximize energy production (Moosavian, Borzuei, Zahedi, & Ahmadi, 2022). It has been concluded that increasing panel tilt reduces dust subsidence on the surface (Conceição, Silva, Fialho, Lopes, & Collares-Pereira, 2019). In general, factors such as dust, wind, and humidity are highly dependent on the region's geographical location and climatic conditions, which directly affect the performance of solar (Moosavian, Borzuei, & Ahmadi, 2021). Climate change from one place to another worldwide has a similar effect on the performance of the PV module in different regions (Yaghoubirad, Azizi, Ahmadi, Zarei, & Moosavian, 2022). Dust is a unique problem that significantly affects the performance of photovoltaic modules in the Persian Gulf region and reduces efficiency (Said, Hassan, Walwil, & Al-Aqeeli, 2018). Many studies have analyzed and studied the effects of climatic factors such as dust, wind speed, and temperature on the performance of photovoltaic cells and the rate of reduction of their output power. In this study, a detailed analysis of the effect of dust on the performance of solar power plants has been targeted, considering the diverse climatic conditions and different climates of Iranian cities.

### 3. METHODOLOGY

Solar system performance analysis is studied to investigate the effect of dust on its efficiency in Iran. This country is located between the 29 and 41 orbits of northern latitude, and the solar radiation rate in Iran has been estimated at 1095-2410 KWh/m<sup>2</sup> per year. The mean radiation in Iran is higher than the global mean. Table 1 demonstrates the climate specifications and geographical coordinates of the four cities. These four cities have been selected according to different climatic conditions, cold-dry, temperate-humid, hot and humid, cold-humid, and various geographical locations. These climates are an example of the different climatic and geographical conditions of Iran, and their diversity in them makes the installation of solar systems require a separate study of environmental and climatic conditions.

Table 1. Köppen's climatic classification of Iran's cities (Raziei, 2017).

Name of Cities	Köppen climatic class	Latitude (N)	Long(E)	Average High	Average Low	Elevation
Mashhad	Cold semi-arid climate	36° 20'	59° 35'	21	7	1050
Rasht	Humid Subtropical Climate	37°27'	49° 59'	20.6	11.3	-8
Abadan	(Hot Desert Climates	30° 22'	48°15'	33	18	7
Sanandaj	(Humid Continental Climate)	35° 20'	47° 00'	21	5	1373

#### 3.1. PV System

In designing a solar system, the designer must consider the exact numbers for the size and type of solar panels. Design details increase energy production and improve the life of panels. Designing a system requires knowledge of solar systems and their components, area specifications, weather conditions, panel efficiency, etc. (Hasarmani, Holmukhe, & Tamke, 2019). Pvsyst is an extensive application program used for solar systems, which includes the required tools for investigating and research, sizing, simulation, and data analysis of PV systems designed to help architects, engineers, researchers, and ever students interested in research (Kalbasi, Jahangiri, Nariman, & Yari,

2019). PVsyst software defines solar systems as grid-connected, off-grid, pumping, DC networks, and databases (Verma, Yadav, & Sengar, 2021). PVsyst software has a great collection of meteorological data worldwide, allowing data entry manually if the database is not accessible. To obtain the appropriate size and design with technical and economic evaluation of the PV system, you must provide all the required software data. For example, (i) location, (ii) tilt angle, (iii) azimuth angle, (IV) PV module and inverter specifications, (v) shading, and so on. The output parameters of the PVsyst software simulation are as follows: (i) meteorological data, (ii) various efficiency and losses, (iii) performance ratio, (iv) energy production, (v) carbon emission balance, (vi) financial evaluation, and so on.

### 3.2. Off-Grid System

Off-grid systems include the main components of panels, batteries, controllers, and inverters (Li, Li, Zhu, & Ma, 2021). Solar modules produce direct current power. DC (direct current) power is channeled by the charge controller and charges the battery. The controller has dual functions to perform; one is to charge the battery, and the second is to prevent overcharging. Other accessories like cables are also required, which need to be ultraviolet safe and sensible for open-air applications (Kumar, Rajoria, Sharma, & Suhag, 2021). These systems are designed to meet daily needs and have sufficient battery capacity to supply power at night or on cloudy days (Spea & Khattab, 2019). Figure 2 shows an Off-Grid system.

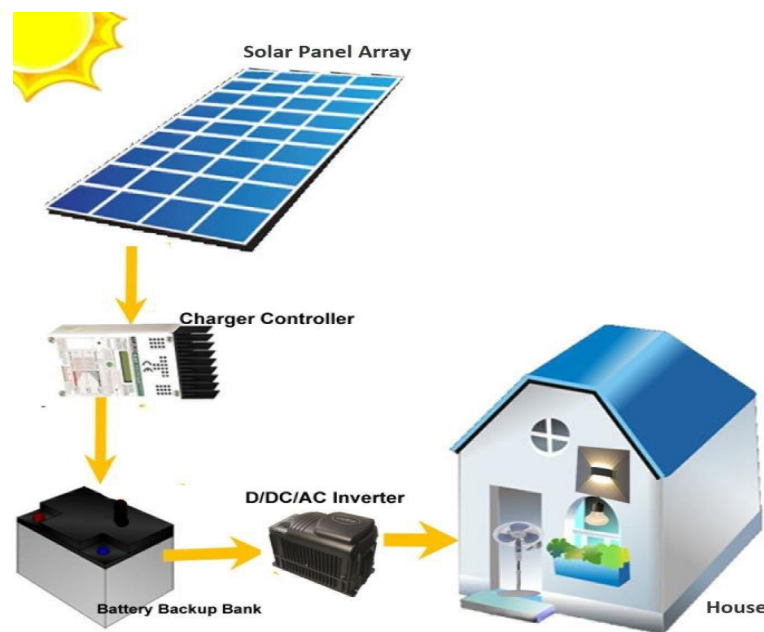


Figure 2. Off-Grid system.

## 4. MODELING

In order to investigate the effect of dust on the performance of panels in the region's climatic conditions, we consider an Off-Grid system for a consumer with a power of 2.9kwh/day, the specifications of which are listed in Table 2. The specifications of this solar system were modeled for each city in the software. Although the best orientation is to the south, these sites are in the northern region. Also, the optimal slope angle is set equal to the latitude to achieve maximum solar radiation. This affects the amount of dust that settles on the surface of the panels. After adjusting the tilt angle, the specifications of Table 2 were set to select the panel and battery. Information about dust and snowfall in each month of the year was considered using meteorological statistical data. Snow settling on the surface of the panels in winter, such as dust, prevents the passage of light and thus reduces the panels' efficiency. Therefore, it is considered in the settings related to dust losses. The DC and AC ohmic losses at standard test condition (STC), 1.5%, and array mismatch losses are 1%.

Table 2. Specification of solar PV panel.

PV module/Model	Si-poly
Manufacturer	HHV solar
Module power	230Wp 26 v
Number of modules in series	3
Number of strings	1
battery	Exide classic
Number in series	2
Number in parallel	2

The simulation steps in the software are summarized in Figure 3. According to this Figure, in the first step, the off Grid system is determined according to the geographical and technical conditions, and then the factors affecting the system efficiency are examined.



Figure 3. Simulation steps.

#### 4.1. Modeling Results

After simulating a photovoltaic system in PVsyst software, in order to investigate and analyze the effect of dust on the performance and efficiency of panels in different climatic conditions of each city, the results of these cities are classified and presented as follows:

##### 4.1.1. Mashhad

Due to the geographical location and cold and dry climate of Mashhad, the city is exposed to the dust of the deserts of Turkmenistan, which according to Figure 4, has the most significant impact on the performance of panels in summer and early autumn and reduces system efficiency. Also, a small number of snowy days are considered soil losses in modeling the solar system. According to Figure 5, the impact of sedimentation of both dust and snow causes a 2.2% reduction in the solar system's efficiency.

As a result of the analysis, the various losses expected when installing a photovoltaic power plant were obtained as a diagram of system losses. Production capacity and losses are shown in Figure 4.

PV array losses or collection losses ( $L_c$ ) are mainly classified into heat absorption losses and miscellaneous losses. Heat loss is caused by increased cell temperature of more than 25 degrees Celsius. System wiring, module quality, mismatch, shadows, MPPT error, and soli are miscellaneous losses. The PV system losses of the simulated result for Mashhad is 18.9%. System losses ( $L_s$ ): Inverters, incompetent battery systems, and inactive circuit elements cause losses for the system. The loss rate in the proposed system is 6.4%. The energy supplied to the user is 73.7%. According to the graph results, most of the panel losses are in summer and early autumn, the leading cause of which is dust settling on the surface of the panels. Fig 4 shows the system losses in different parts. The system's global horizontal irradiation (GHI) is 1694 Kwh/m<sup>2</sup>. The effective irradiance on the panels is 1839 Kwh/m<sup>2</sup>. The energy need of the user is 1073KWh. PV loss due to temperature is -9.84%, and soiling loss factor is -2.19%. As mentioned in the previous sections, air temperature is one of the environmental factors affecting the performance of solar systems. Therefore, two factors, temperature, and dust, simultaneously affect the reduction of system efficiency.

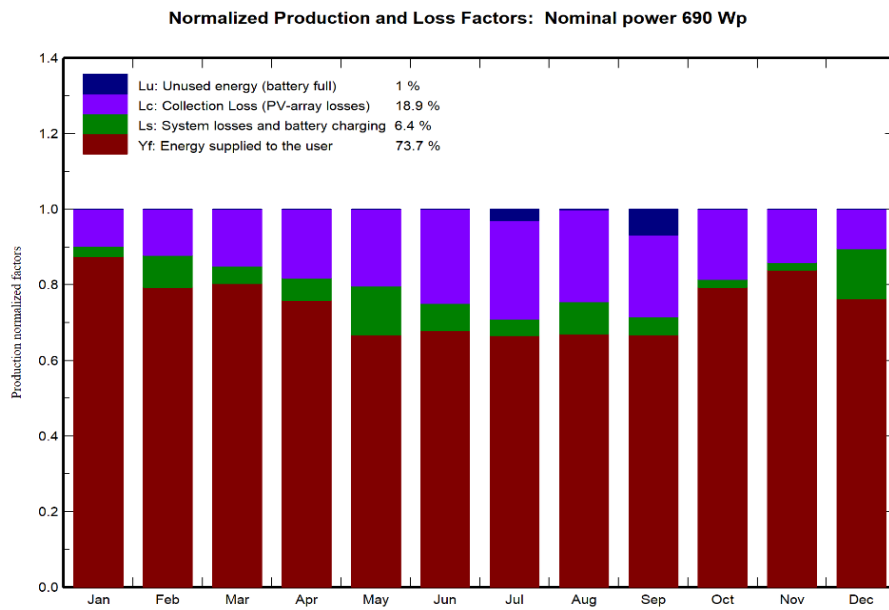


Figure 4. Normalized production and loss factors.

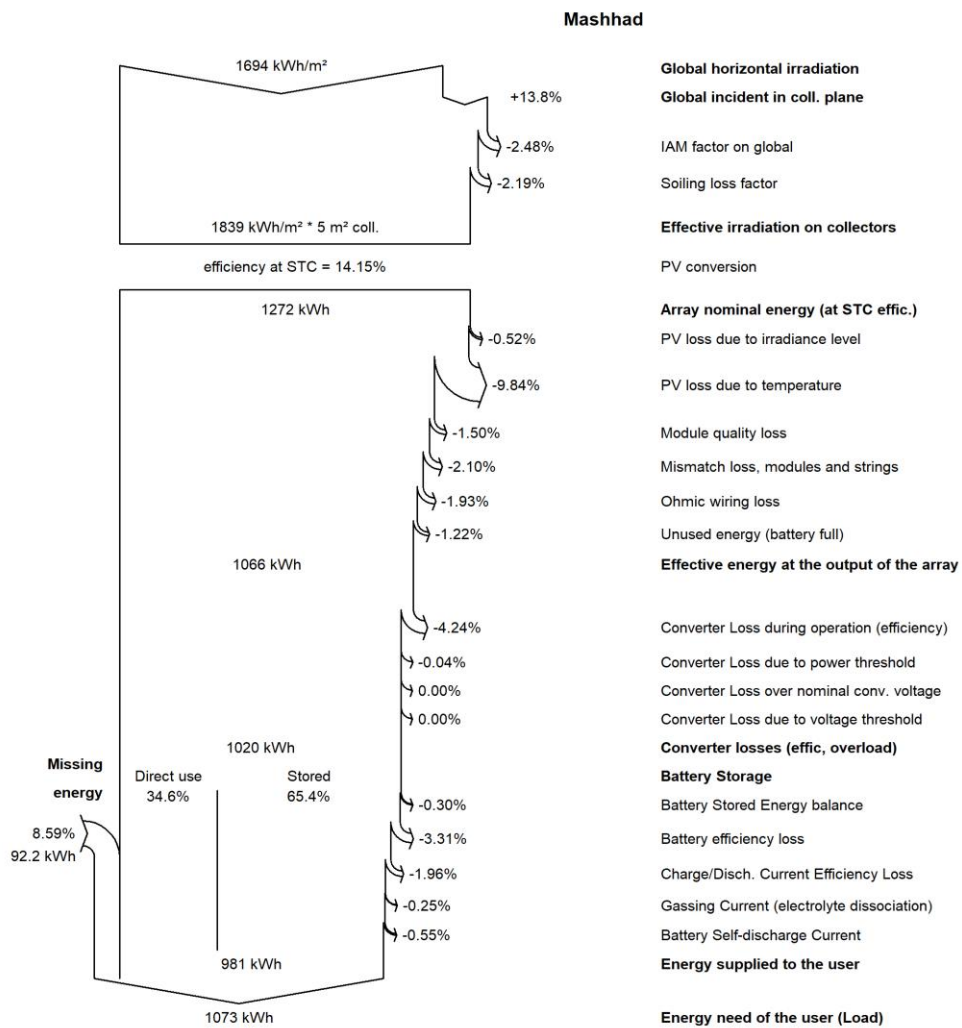


Figure 5. Loss diagram over the whole year.

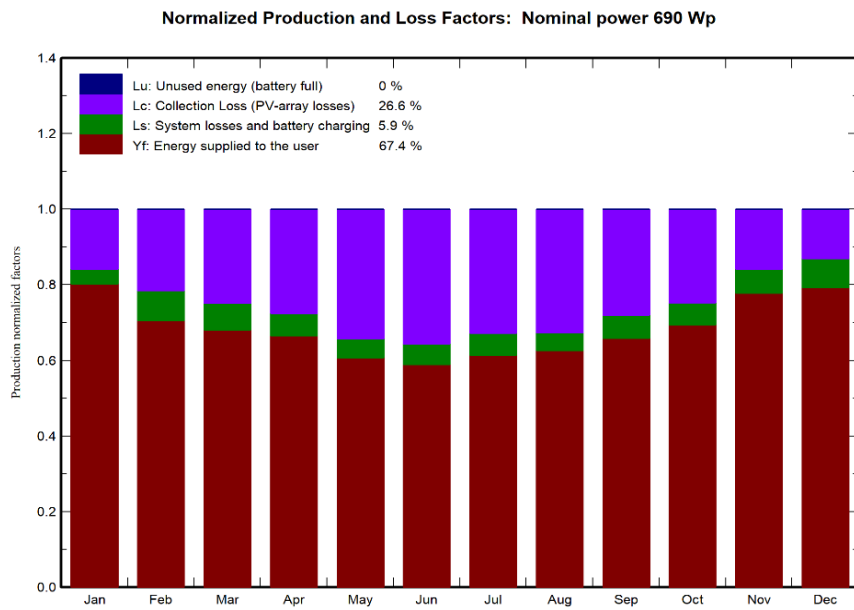


Figure 6. Normalized production and loss factors.

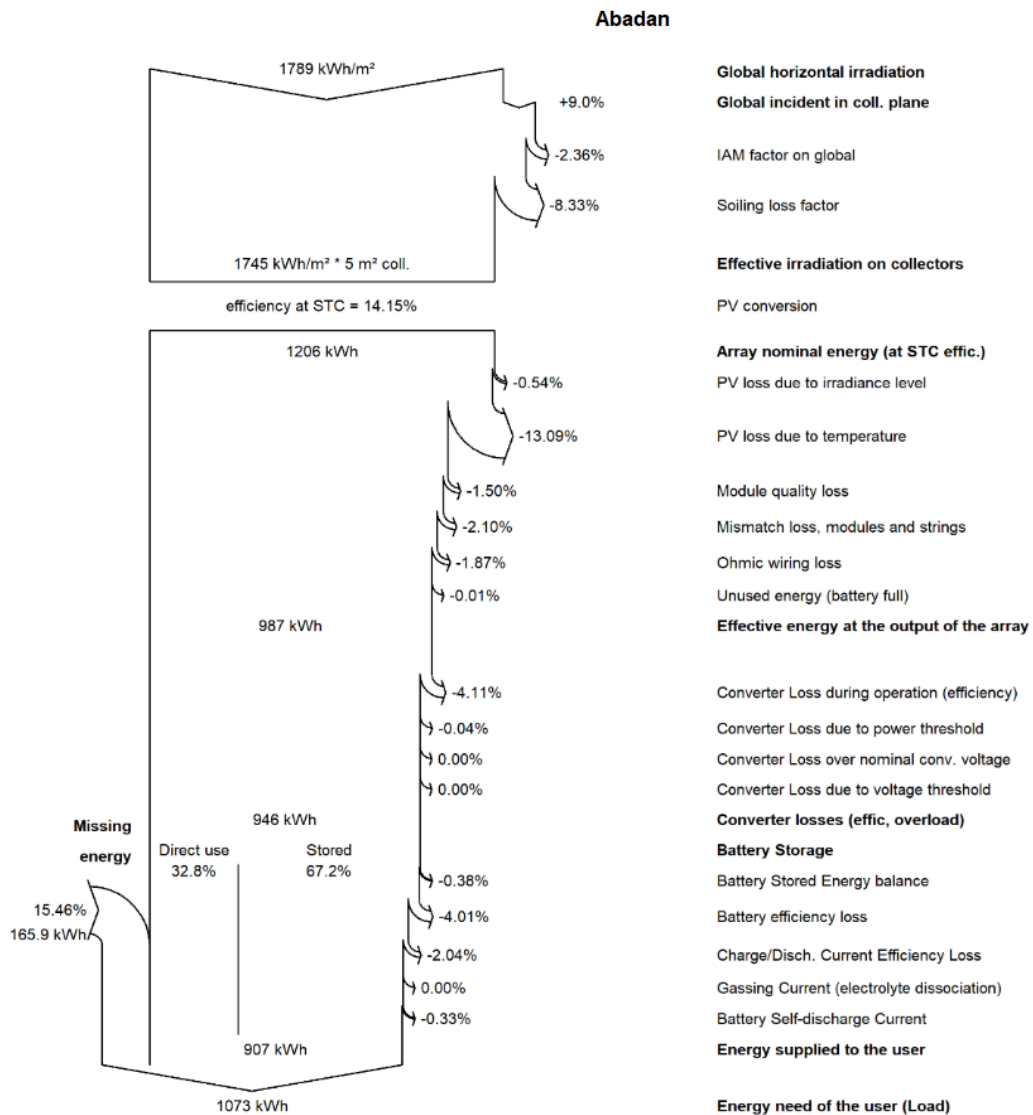


Figure 7. Loss diagram over the whole year.



4.1.2. Abadan

Abadan is one of the tropical regions in Iran and experiences several sand and dust storms annually. Due to the climatic conditions of this city, high temperature combined with dust affects the performance of solar systems and significantly reduces the output power. Figure 6. shows normalized production and loss factors. PV-array losses are 26.6%, and system losses are 5.9%. Most system losses occur from May to September because of the hot weather. For a year, different losses of the system for Abadan are seen in Figure 7. The GHI of the solar system is 1789 Kwh/m<sup>2</sup>. Also, the effective irradiance on the collectors is 1745 Kwh/m<sup>2</sup>. The energy need of the user is 1073KWh. PV loss due to temperature is -13.09%, and soiling loss factor is -8.33%. Based on these results, it can be seen that the amount of losses due to temperature and dust greatly reduces the power and efficiency of the solar system. Therefore, using the solar system in this area is not efficient.

4.1.3. Rasht

Rasht is located near the Caspian Sea, with a temperate and humid climate. Due to these conditions, the dust in this city is negligible. In winter, snowfall on the surface of the panels reduces the system's efficiency. The number of cloudy days is more than in other cities. Figure 8. shows normalized production and loss factors. PV-array losses are 17.33%, and system losses are 5.6%. The energy supplied to the user is 77.1%. The highest number of losses is in February and July due to snowfall in winter, hot weather, and dust in the air. Figure 9 shows the loss diagram of the proposed PV system for a year. The GHI for this city is 1290 Kwh/m<sup>2</sup>. For the intended system in Rasht, the effective irradiance on the surface is 1354 Kwh/m<sup>2</sup>. Loss due to temperature is -7.08%, soiling loss factor is -2.27%. The amount of losses due to dust in photovoltaic systems in this city is insignificant due to the city's high latitude. As a result, solar systems with desirable efficiencies and the least losses can be exploited in this city.

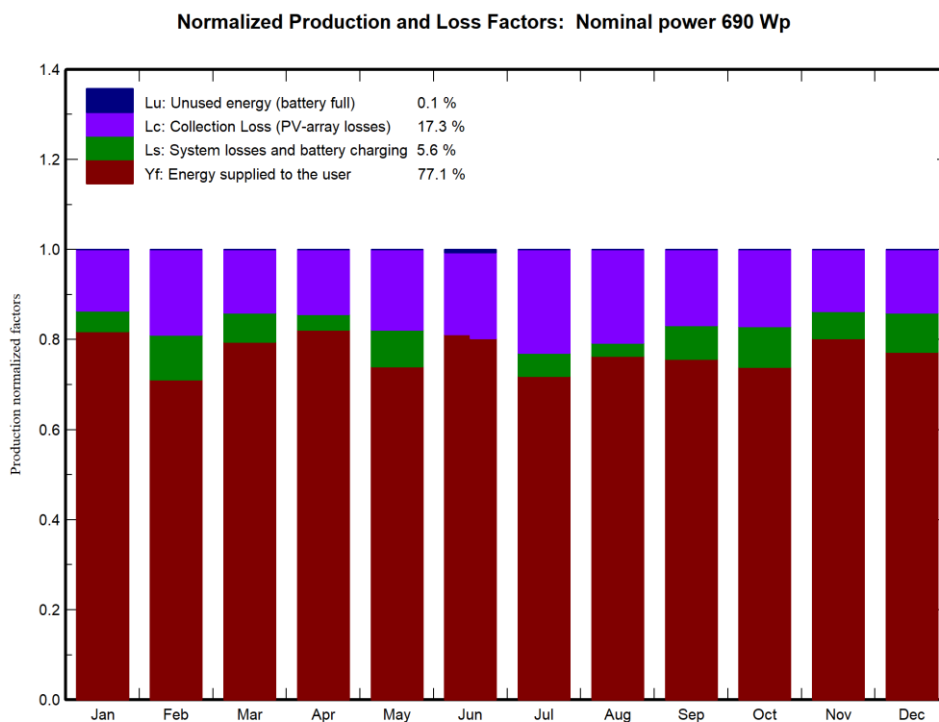


Figure 8. Normalized production and loss factors.

4.1.4. Sanandaj

Due to its geographical location and cold and humid climate, Sanandaj has a significant number of snowy days, but the dust in the city air is low and insignificant. Normalized production and loss factors are shown in Figure 10.

PV-array losses are 27.7%, and system losses are 6.4%. The energy supplied to the user is 63.5%. According to the Figure 11, most system losses occurred in February, mainly due to snowfall in the city. The amount of system losses in June is also significant, the most important reason being the ambient temperature. Like other cities for Sanandaj, the flow diagram for a whole year is shown in Figure 11. The GHI for this city is 1899 Kwh/m<sup>2</sup>. Also, the effective irradiance on the surface of panels is 1871 Kwh/m<sup>2</sup>. The energy need of the user is 1073KWh. PV loss due to temperature is -10.09%, and soiling loss factor is -12.95%. Based on these results, it can be seen that snowfall in winter on the surface of the panels and the ambient temperature significantly reduce the efficiency of the solar system.

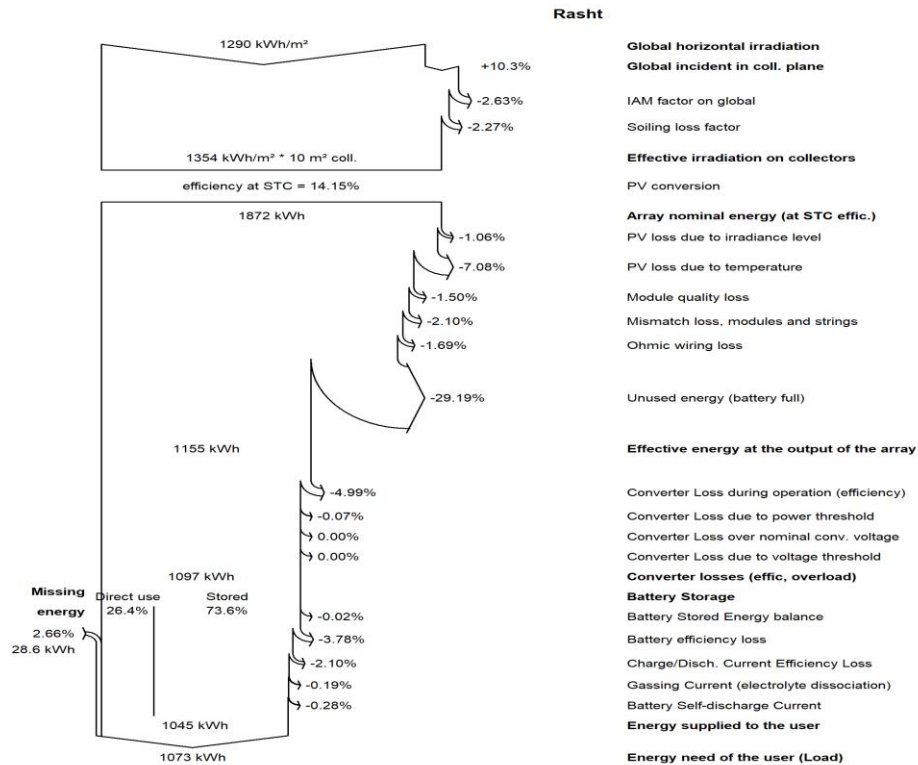


Figure 9. Loss diagram over the whole year.

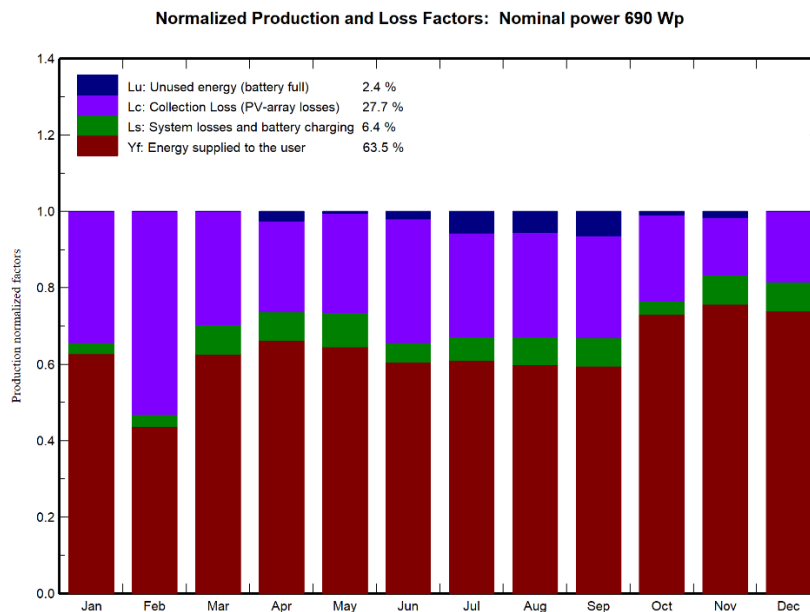


Figure 10. Normalized production and loss factors.

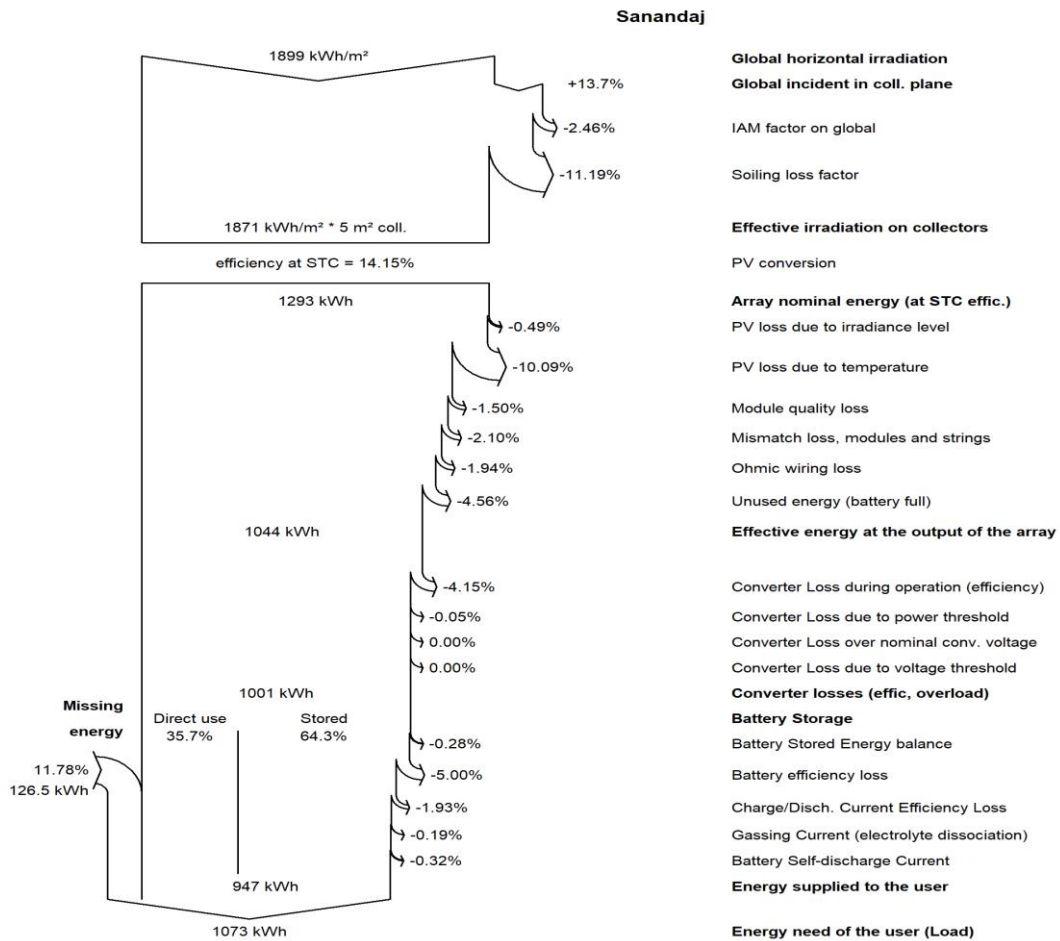


Figure 11. Loss diagram over the whole year.

## 5. CONCLUSION

In this research, the effect of dust losses on the performance of solar systems with an emphasis on different climates was studied and evaluated. For this purpose, four cities, Mashhad, Abadan, Rasht, and Sanandaj, were selected with cold and dry, hot and humid, temperate and humid, and cold and humid climates. According to the results of the study and modeling with software, it is observed that in cities with low latitude, hot climate, and low rainfall, such as Abadan, dust is an influential factor affecting the performance of solar systems. So that the amount of dust losses by 8.33% results in an efficiency reduction. Similarly, in cities with cold climates such as Sanandaj, winter snowfall on the panels' surface reduces the output power and thus reduces the system's efficiency by 11.19%. However, in cities with high latitudes such as Rasht and Mashhad, the cause of dust will not be a big problem. Rasht is one of the rainy areas that naturally cleans the surface of the panels, and as a result, the losses due to dust in this city are 2.27%. Dust losses in Mashhad are the lowest compared to other cities. In Mashhad, Soiling loss is 2.19%. As a result, Mashhad is a suitable option due to the geographical and climatic conditions, as a result of which the least effect of dust and snow subsidence was observed on the panel surface and disturbance in the performance of solar systems. As mentioned in the previous sections, the accumulation of dust in the environment and snow on the panels of the PV system prevents light rays from reaching the surface completely, reducing the system's efficiency. Dust and snow removal from panel surfaces should be done periodically so the system does not cause malfunction, and the solar system can continue to operate at full capacity.

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**Authors' Contributions:** All authors contributed equally to the conception and design of the study.

## REFERENCES

- Al-Addous, M., Dalala, Z., Alawneh, F., & Class, C. B. (2019). Modeling and quantifying dust accumulation impact on PV module performance. *Solar Energy*, 194, 86-102. doi:<https://doi.org/10.1016/j.solener.2019.09.086>
- Alnasser, T. M., Mahdy, A. M., Abass, K. I., Chaichan, M. T., & Kazem, H. A. (2020). Impact of dust ingredient on photovoltaic performance: An experimental study. *Solar Energy*, 195, 651-659. doi:<https://doi.org/10.1016/j.solener.2019.12.008>
- Andrea, Y., Pogrebnaya, T., & Kichonge, B. (2019). Effect of industrial dust deposition on photovoltaic module performance: Experimental measurements in the tropical region. *International Journal of photoenergy*, 2019, 1-10. doi:<https://doi.org/10.1155/2019/1892148>
- Benghanem, M., Almohammed, A., Khan, M. T., & Al-Masraqi, A. (2018). Effect of dust accumulation on the performance of photovoltaic panels in desert countries: A case study for Madinah, Saudi Arabia. *International Journal of Power Electronics and Drive Systems*, 9(3), 1356. doi:<https://doi.org/10.11591/ijpeds.v9.i3.pp1356-1366>
- Bhaduri, S., & Kottantharayil, A. (2018). Mitigation of soiling by vertical mounting of bifacial modules. *IEEE Journal of Photovoltaics*, 9(1), 240-244. doi:<https://doi.org/10.1109/jphotov.2018.2872555>
- Borzuei, D., Moosavian, S. F., & Ahmadi, A. (2022). Investigating the dependence of energy prices and economic growth rates with emphasis on the development of renewable energy for sustainable development in Iran. *Sustainable Development*.
- Borzuei, D., Moosavian, S. F., Ahmadi, A., Ahmadi, R., & Bagherzadeh, K. (2021). An Experimental and Analytical Study of Influential Parameters of Parabolic Trough Solar Collector. *Journal of Renewable Energy and Environment*, 8(4), 52-66. doi:[10.30501/jree.2021.261647.1172](https://doi.org/10.30501/jree.2021.261647.1172)
- Borzuei, D., Moosavian, S. F., & Farajollahi, M. (2021). On the performance enhancement of the three-blade Savonius wind turbine implementing opening valve. *Journal of Energy Resources Technology*, 143(5), 1-11. doi:<https://doi.org/10.1115/1.4049460>
- Conceição, R., Silva, H. G., Fialho, L., Lopes, F. M., & Collares-Pereira, M. (2019). PV system design with the effect of soiling on the optimum tilt angle. *Renewable Energy*, 133, 787-796. doi:<https://doi.org/10.1016/j.renene.2018.10.080>
- Costa, S. C., Diniz, A. S. A., & Kazmerski, L. L. (2018). Solar energy dust and soiling R&D progress: Literature review update for 2016. *Renewable and Sustainable Energy Reviews*, 82, 2504-2536. doi:<https://doi.org/10.1016/j.rser.2017.09.015>
- Daher, D. H., Gaillard, L., Amara, M., & Ménézo, C. (2018). Impact of tropical desert maritime climate on the performance of a PV grid-connected power plant. *Renewable Energy*, 125, 729-737. doi:<https://doi.org/10.1016/j.renene.2018.03.013>
- Emziane, M., & Al Ali, M. (2015). Performance assessment of rooftop PV systems in Abu Dhabi. *Energy and Buildings*, 108, 101-105. doi:<https://doi.org/10.1016/j.enbuild.2015.08.057>
- Figgis, B. (2016). Role of moisture in PV soiling. Paper presented at the Webinar, PVQAT Conference, # TG12-2.
- Ghazi, A., & Mustafa, F. (2013). Dust effects on the performance of PV street light in Baghdad city. Paper presented at the 2013 International Renewable and Sustainable Energy Conference (IRSEC).
- Gholami, A., Alemrajabi, A. A., & Saboonchi, A. (2017). Experimental study of self-cleaning property of titanium dioxide and nanospray coatings in solar applications. *Solar Energy*, 157, 559-565. doi:<https://doi.org/10.1016/j.solener.2017.08.075>
- Guo, B., Javed, W., Figgis, B., & Mirza, T. (2015). Effect of dust and weather conditions on photovoltaic performance in Doha, Qatar. Paper presented at the 2015 First Workshop on Smart Grid and Renewable Energy (SGRE).
- Gupta, V., Sharma, M., Pachauri, R. K., & Babu, K. D. (2019). Comprehensive review on effect of dust on solar photovoltaic system and mitigation techniques. *Solar Energy*, 191, 596-622. doi:<https://doi.org/10.1016/j.solener.2019.08.079>
- Hasarmani, T., Holmukhe, R., & Tamke, S. (2019). Performance analysis of grid interfaced photovoltaic systems for reliable agri-microgrids using PVsyst. Paper presented at the 2019 International Conference on Information and Communications Technology (ICOIACT).
- Jaszczur, M., Hassan, Q., Styszko, K., & Teneta, J. (2019). Impact of dust and temperature on energy conversion process in photovoltaic module. *Thermal Science*, 23(Suppl. 4), 1199-1210. doi:<https://doi.org/10.2298/tsci19s4199j>

- Jaszczur, M., Teneta, J., Styszko, K., Hassan, Q., Burzyńska, P., Marcinek, E., & Łopian, N. (2019). The field experiments and model of the natural dust deposition effects on photovoltaic module efficiency. *Environmental Science and Pollution Research*, 26(9), 8402-8417. doi:<https://doi.org/10.1007/s11356-018-1970-x>
- Kalbasi, R., Jahangiri, M., Nariman, A., & Yari, M. (2019). Optimal design and parametric assessment of grid-connected solar power plants in Iran, a review. *Journal of Solar Energy Research*, 4(2), 142-162.
- Kaldellis, J., Fragos, P., & Kapsali, M. (2011). Systematic experimental study of the pollution deposition impact on the energy yield of photovoltaic installations. *Renewable Energy*, 36(10), 2717-2724. doi:<https://doi.org/10.1016/j.renene.2011.03.004>
- Kasim, N. K., Hussain, H. H., & Abed, A. N. (2019). Performance analysis of grid-connected CIGS PV solar system and comparison with PVsyst simulation program. *International Journal of Smart Grid*, 3(4), 172-179. doi:<https://doi.org/10.20508/ijsmartgrid.v3i4.57.g64>
- Kazem, H. A., & Chaichan, M. T. (2019). The effect of dust accumulation and cleaning methods on PV panels' outcomes based on an experimental study of six locations in Northern Oman. *Solar Energy*, 187, 30-38. doi:<https://doi.org/10.1016/j.solener.2019.05.036>
- Kazem, H. A., Chaichan, M. T., Al-Waeli, A. H., & Sopian, K. (2020). A review of dust accumulation and cleaning methods for solar photovoltaic systems. *Journal of Cleaner Production*, 276, 123187. doi:<https://doi.org/10.1016/j.jclepro.2020.123187>
- Kilci, O., & Koklu, M. (2019). The importance of fixed and variable angle in solar power plants analysis. *International Journal of Applied Mathematics Electronics and Computers*, 7(4), 75-83. doi:<https://doi.org/10.18100/ijamec.653371>
- Kumar, E. S., Sarkar, B., & Behera, D. (2013). Soiling and dust impact on the efficiency and the maximum power point in the photovoltaic modules. *International Journal of Engineering Research & Technology*, 2(2), 1-8.
- Kumar, R., Rajoria, C., Sharma, A., & Suhag, S. (2021). Design and simulation of standalone solar PV system using PVsyst Software: A case study. *Materials Today: Proceedings*, 46, 5322-5328. doi:<https://doi.org/10.1016/j.matpr.2020.08.785>
- Li, J., Li, Y., Zhu, B., & Ma, X. (2021). Analysis of hydrogen production capacity of off-grid photovoltaic system based on PVsyst software simulation. Paper presented at the *Journal of Physics: Conference Series*.
- Maghami, M. R., Hizam, H., Gomes, C., Radzi, M. A., Rezadad, M. I., & Hajighorbani, S. (2016). Power loss due to soiling on solar panel: A review. *Renewable and Sustainable Energy Reviews*, 59, 1307-1316. doi:<https://doi.org/10.1016/j.rser.2016.01.044>
- Mani, M., & Pillai, R. (2010). Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations. *Renewable and Sustainable Energy Reviews*, 14(9), 3124-3131. doi:<https://doi.org/10.1016/j.rser.2010.07.065>
- Mekhilef, S., Saidur, R., & Kamalisarvestani, M. (2012). Effect of dust, humidity and air velocity on efficiency of photovoltaic cells. *Renewable and Sustainable Energy Reviews*, 16(5), 2920-2925. doi:<https://doi.org/10.1016/j.rser.2012.02.012>
- Memiche, M., Bouzian, C., Benzahia, A., & Moussi, A. (2020). Effects of dust, soiling, aging, and weather conditions on photovoltaic system performances in a Saharan environment—case study in Algeria. *Global Energy Interconnection*, 3(1), 60-67. doi:<https://doi.org/10.1016/j.gloi.2020.03.004>
- Mohseni, M., Moosavian, S. F., & Hajinezhad, A. (2022). Feasibility evaluation of an off-grid solar-biomass system for remote area electrification considering various economic factors. *Energy Science & Engineering*.
- Moosavian, S. F., Borzuei, D., & Ahmadi, A. (2021). Energy, exergy, environmental and economic analysis of the parabolic solar collector with life cycle assessment for different climate conditions. *Renewable Energy*, 165, 301-320. doi:<https://doi.org/10.1016/j.renene.2020.11.036>
- Moosavian, S. F., Borzuei, D., Zahedi, R., & Ahmadi, A. (2022). Evaluation of research and development subsidies and fossil energy tax for sustainable development using computable general equilibrium model. *Energy Science & Engineering*.

- Pan, A., Lu, H., & Zhang, L.-Z. (2019). Experimental investigation of dust deposition reduction on solar cell covering glass by different self-cleaning coatings. *Energy*, 181, 645-653. doi:<https://doi.org/10.1016/j.energy.2019.05.223>
- Raziei, T. (2017). Köppen-Geiger climate classification of Iran and investigation of its changes during 20th century. *Journal of the Earth and Space Physics*, 43(2), 419-439.
- Rekhashree, J., & Rajashekar, H. N. (2018). Study on design and performance analysis of solar PV rooftop standalone and on grid system using PVSYSY. *International Research Journal of Engineering and Technology*, 5(07), 41-48.
- Said, S. A., Hassan, G., Walwil, H. M., & Al-Aqeeli, N. (2018). The effect of environmental factors and dust accumulation on photovoltaic modules and dust-accumulation mitigation strategies. *Renewable and Sustainable Energy Reviews*, 82, 743-760. doi:<https://doi.org/10.1016/j.rser.2017.09.042>
- Sarr, A., Cheikh, M. F. K., & Ababacar, N. (2020). Analysis and feasibility of 50 kWp self-consumption solar photovoltaic system for four Senegalese typical climatic zones using PVsyst software. *International Journal of Physical Sciences*, 15(4), 201-212.
- Siyabi, I. A., Mayasi, A. A., Shukaili, A. A., & Khanna, S. (2021). Effect of soiling on solar photovoltaic performance under desert climatic conditions. *Energies*, 14(3), 1-18. doi:<https://doi.org/10.3390/en14030659>
- Spea, S. R., & Khattab, H. A. (2019). Design sizing and performance analysis of stand-alone PV system using PVSyst software for a location in Egypt. Paper presented at the 2019 21st International Middle East Power Systems Conference (MEPCON).
- Varun, M., & Manikandan, S. (2020). Performance evaluation of bifacial and monofacial modules in vertical and latitude mounting at South India using PVsyst. Paper presented at the IOP Conference Series: Materials Science and Engineering.
- Verma, S., Yadav, D., & Sengar, N. (2021). Performance evaluation of solar photovoltaic power plants of semi-arid region and suggestions for efficiency improvement. *International Journal of Renewable Energy Research*, 11(2), 762-775. doi:<https://doi.org/10.20508/ijrer.v11i2.11957.g8210>
- Wu, Z., Yan, S., Wang, Z., Ming, T., Zhao, X., Ma, R., & Wu, Y. (2020). The effect of dust accumulation on the cleanliness factor of a parabolic trough solar concentrator. *Renewable Energy*, 152, 529-539. doi:<https://doi.org/10.1016/j.renene.2020.01.091>
- Yadav, S., & Bajpai, U. (2017). Variation in the performance of solar photovoltaic power plant due to climatic parameters in composite climatic zone. *International Journal of Emerging Technologies in Engineering Research*, 5, 67-72.
- Yaghoobirad, M., Azizi, N., Ahmadi, A., Zarei, Z., & Moosavian, S. F. (2022). Performance assessment of a solar PV module for different climate classifications based on energy, exergy, economic and environmental parameters. *Energy Reports*, 8, 68-84. doi:<https://doi.org/10.1016/j.egyr.2022.05.100>
- Zahedi, R., Seraji, M. A. N., Borzuei, D., Moosavian, S. F., & Ahmadi, A. (2022). Feasibility study for designing and building a zero-energy house in new cities. *Solar Energy*, 240, 168-175. doi:<https://doi.org/10.1016/j.solener.2022.05.036>

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