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Influence of Climatic Factors Affecting Photovoltaic System

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Abstract— In Mongolia, in recent years, the installation and use of solar photovoltaic systems by enterprises and households has increased. The attractiveness of a PV system depends deeply of the module and it is primarily determined by its performance. The amount of electricity and energy produced by a PV system depends more on external and environmental factors than on internal factors specific to the PV system. Ulaanbaatar is one of the coldest cities in the world and ranks first in air pollution. Therefore, this research aims to determine how external factors and environmental factors affect the operation results of the solar system installed in Ulaanbaatar city. In this research, results were developed using data from January 2022 to December 2022 for a grid-connected 15 kW solar power system installed on the roof of the 8th building of the University of Science and Technology. The data on the energy produced by the solar electric system were analyzed in terms of the influence of factors such as ambient air temperature, relative humidity, wind speed, and solar radiation. The data of ambient temperature, relative humidity, wind speed and solar radiation of Ulaanbaatar city in 2022 were obtained from the NACA Power Data Access Viewer site and analyzed by correlation and regression. According to the research results, the correlation coefficient R is positive for wind speed, air temperature, and solar radiation, and negative for humidity, which are 0.319, 0.708, 0.791, and -0.941, respectively. The coefficient of determination R2 is 0.102, 0.502, and 0.626 for wind speed, air temperature, solar radiation, and 0.887 for humidity. However, it was determined that the effect of solar radiation and ambient temperature on energy production is between strong and weak correlation.

Keywords—Solar power system, energy production, influencing factors.

I. INTRODUCTION

Solar PV systems are widely used in both developed and developing countries due to the environmental and economic benefits of converting solar energy into electricity. According to the International Renewable Energy Agency (IRENA), global renewable energy installations are expected to increase by 50% between 2019 and 2024, to approximately 1220 GW (IRENA, 2019) [1]. Due to the over-concentration of the population of Ulaanbaatar, the city's electricity and heat consumption is increasing dramatically. Recently, due to the rising cost of energy production and climate change, interest in using solar electric systems has increased.

Solar energy has many advantages, such as no negative impact on the environment, no fuel consumption, easy to install, simple to use, long-lasting, no noise during use, and expandable to obtain the desired capacity [2,3]. The main obstacles to the widespread use of solar electric systems in the community are the high initial investment, the large installation space required, and the cost per unit of energy produced is still higher than the cost of conventional electricity. For a PV system installed in extreme weather conditions, ensuring normal operation has a direct impact on system life, maintenance, operating costs, and energy production. Also, many environmental factors such as dust, humidity, temperature, and wind speed affect the operation of the solar power system and its energy production efficiency [4, 5]. PV voltages and currents vary with changes in temperature and irradiance levels [6]. Air humidity has been studied to have a negative effect on the efficiency of solar power generators [7]. It has been studied that humidity diffuses the reflection of direct solar radiation and reduces the intensity of radiation reaching the solar cell [8]. This will directly affect the PV open circuit voltage and short circuit current. It can be seen from many research articles that many factors such as humidity, dust, and wind speed affect PV system energy production [9]. PV power output is very sensitive to partial shade. If partially covered by tree leaves or other shading sources, the energy output is significantly reduced. For series-connected PVs, total shading reduces the output power to zero [10].

The energy production efficiency of a solar photovoltaic system is influenced more by external factors than internal factors such as the characteristics of inverters, transmission cables, and power electronics. Ulaanbaatar is home to more than half of Mongolia's population and has a high concentration of population. Mongolia's energy system is underpowered and the installed equipment is working at full capacity, which is very risky. Therefore, companies and households are installing solar

photovoltaic systems to meet a certain percentage of their electricity consumption. On the other hand, the city of Ulaanbaatar is one of the coldest cities in the world, and it also ranks first in terms of pollution. Therefore, this research aims to study the factors to consider when installing solar photovoltaic systems in a city with high pollution and seasonal temperature differences. In this research, we have studied the effect of ambient temperature, air humidity, wind speed, and solar radiation on the production of solar power systems located in Ulaanbaatar.

II. CLIMATIC FACTORS

A. *Basic parameters of PV*

The main parameters used to determine the efficiency of solar generators are maximum power generation (P_{max}), short circuit current density (I_{sc}), open circuit voltage (V_{oc}) and fill factor (FF).

Short Circuit Current (I_{sc}) is the current that passes through the external circuit when the electrodes of the solar cell are short-circuited. It is determined depending on the spectrum of light reflected on the solar generator and its photon flow. The value of the current when the voltage is equal to zero, or the point where it intersects the y-axis, is called the short-circuit current. The short-circuit current depends on the area of the solar cell being measured. Short-circuit current density is often used to determine the maximum current that a solar cell can deliver. The maximum current that a solar cell can transmit depends largely on the optical properties of the absorber layer, such as absorption and reflection.

Open circuit voltage (V_{oc}) is the voltage when no current is flowing through the external circuit. The value of the voltage when the current is equal to zero, or the point where it intersects the x-axis, is called the open-circuit voltage. This is the maximum voltage that a solar cell can deliver.

The fill factor is expressed as the ratio between the maximum power produced by the solar cell ($P_{max} = I_{mpp} * V_{mpp}$) and the open circuit voltage and short circuit current. The fill factor is the ratio between the maximum power of the solar generator ($P_{max} = I_{mpp} * V_{mpp}$) and the product of the open-circuit voltage and the short-circuit current.

$$FF = \frac{I_{mpp} * V_{mpp}}{I_{sc} * V_{oc}} \quad (1)$$

Figure 1 shows the current-voltage relationship of a solar generator.

The efficiency (η) of a solar PV is calculated as the ratio of the maximum power of the solar generator to the incident solar radiation (P_{in}).

$$\eta = \frac{P_{mpp}}{P_{in}} = \frac{V_{mpp} * I_{mpp}}{P_{in}} = FF \frac{V_{oc} * I_{sc}}{P_{in}} \quad (2)$$

The maximum output power of the PV is important for the system. Efficiency can be increased by increasing the output power.

B. *Factors Affecting the Production of Solar Power Systems*

PV power stations convert solar energy into electrical energy and feeds it into the power grid through three coupling processes, including solar energy collection, photoelectric conversion, and electrical energy transmission. There are many factors that affect the operation and efficiency of the PV plants, which are mainly divided into physical factors, external environmental factors, and human related factors, such as scheduling constraints and operation maintenance. The detail is given in Figure 1.

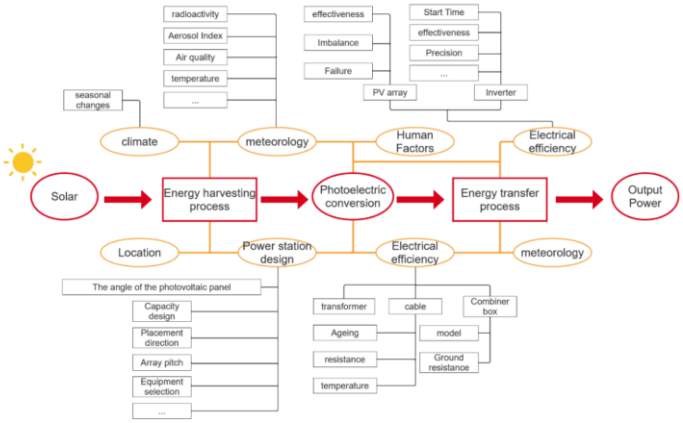

Figure 1. Influencing factors of PV generation.

Environmental factors refer to meteorology, climate, and geographical factors, and affect PV generation differently in different environments.

PV energy production is affected by many external factors, such as temperature (T), solar radiation (G), tilt angle, shading, and dust (PM10, PM2.5). In addition, factors such as humidity (H), wind speed (V), and location have a major effect. Figure 2 shows the main factors affecting PV energy production.

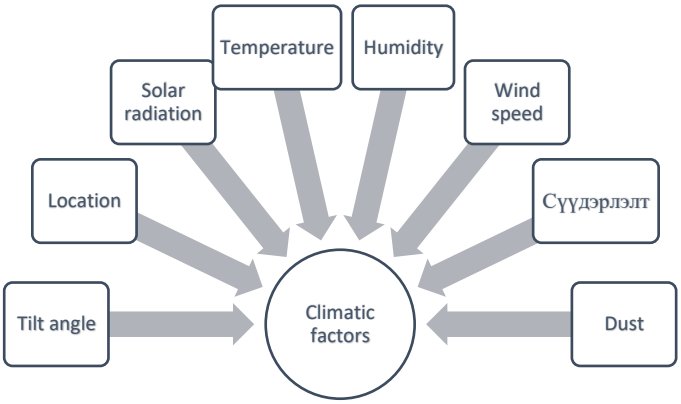

Figure 2. Climatic factors influencing PV energy production

The surface temperature parameter of the PV is directly related to the PV energy production.

$$T_{PV} = T_{amb} + \frac{G}{800} * (T_{stc} - 20) \quad (3)$$

Here, T_{amb} – external ambient temperature, (^{0}C), G – solar radiation (W/m^2), T_{stc} - normal working temperature of PV, (^{0}C).

The maximum PV output power is calculated by the following expression, taking into account climatic conditions such as surface temperature and solar radiation.

$$P_{PV} = P_{mpp} * \frac{G}{1000} * [1 - \gamma * (T_{PV} - 25)] \quad (4)$$

Here, γ is the temperature parameter of the PV, which is the specification of the installed PV.

Temperature and solar radiation are the main factors that affect the power output of a solar generator. The operating conditions for PV rated power generation are temperature 25◦C, solar radiation 1000 W/m^2 and air mass 1.5 AM.

The temperature change greatly affects the output voltage, while the short-circuit current remains almost unchanged. The change of solar radiation has little effect on the open circuit voltage and has a strong effect on the short circuit current.

The effect of pollution and shading on the output power of the solar generator is calculated by the following expression.

$$P_{out} = \left(1 - \frac{df}{100}\right) * \left(1 - \frac{Sp}{100}\right) * P_{mpp} \quad (5)$$

Here, df – indicator of pollution accumulated on the surface of PV, %. Pollution will reduce the output power of the PV. S_p is the loss due to shading effects, %.

After calculating the PV peak power and the actual output power, the power loss is calculated.

$$P_{loss} = P_{PV} - \mathrm{P}_{out} \quad (6)$$

The PV output power decreases directly as the relative humidity increases.

Wind speed affects PV output power. Wind speed is lower at low altitudes and increases with elevation. As the wind speed increases, the air temperature decreases. The effect of wind speed on the PV surface temperature when the ambient temperature is 25 °C and the solar radiation is 1000 W/m^2.

III. CALCULATION AND RESEARCH

A. Object of study

The United Nations Development Program, in cooperation with the Ministry of Construction and Urban Development, developed the calculation using the measurement data values of the 15 kW solar electric system installed on the roof of the MUST of "G-Power" LLC within the framework of the NAMA project.

The system has been in operation since May 2020, and the produced electricity is supplied to the central power system and works in parallel with the grid.

15 kW SG15KTL (380-800 B) inverter from China Sungrow company, HTM330PA-72 brand manufactured by HT Solar company, 330 W capacity, size 1957 x 992 x 40 mm, total 50 pieces, polysilicon (Si-poly, V_{mpp} =37.52 V, I_{mpp}=8.8 A, AUC-17%) module is installed.

Figure 3 shows a view of the 15kW solar power system installed on the roof of MUST.

Figure 3. 15 kW solar power system installed on the roof of the MUST

The connection of the solar electric system consists of a total of 4 parallel groups. Figure 3 shows the general connection diagram of a 15 kW solar power system.
Each of the first 2 parallel groups consists of 12 series modules, the power of the family is 7.92 kW, the current is 17.6 A, the voltage is 450.24 V, and there are 24 modules in total. The next 2 parallel groups consist of 13 series modules each, the power of the family is 8.58 kW, the current is 17.6 A, the voltage is 487.56 V, and there are 26 modules in total.
The system was installed at a 45^0 angle, facing steeply south, and anchored to a concrete base using custom stainless steel.

B. Measurement results

The solar radiation data of Ulaanbaatar city was obtained from the NACA Power Data Access Viewer site, and the solar radiation is shown by month.

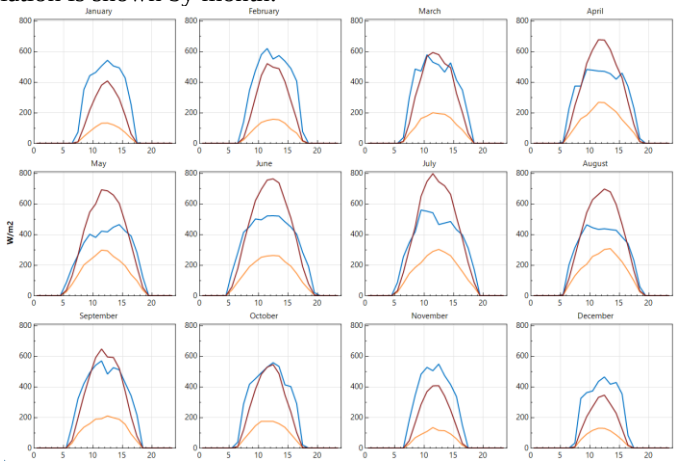

Figure 4. Annual global irradiance, diffuse irradiance, and beam irradiance.

According to the annual mode of solar radiation, brown is global irradiance, orange is diffuse irradiance, and blue is beam irradiance.
Calculations were made using the energy consumption of the solar electric system and the building's electricity consumption data for the period from January 2022 to December 2022.

Figure 5 shows the energy production of the solar power system.

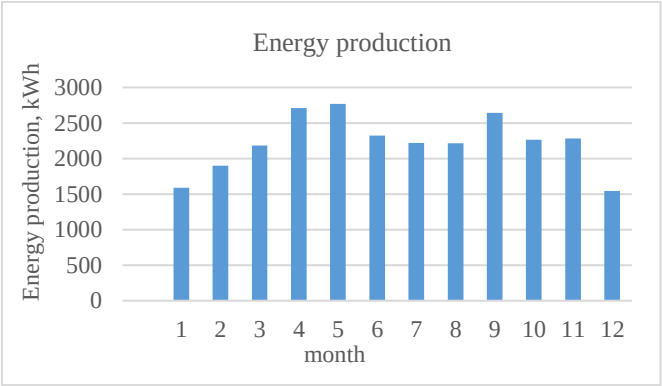

Figure 5. Energy production of solar electric system

According to the measured values, energy production decreases in winter and is the lowest in December, 1545.28 kWh. Energy production increases in the spring season, in April and May, and the peak value is 2767.55 kWh in May, due to the long duration of solar heating and the number of sunny days.

We have installed a total of 8 solar power stations. Currently, there are “Altai sum” SPS, "Nar" SPS, "Monnaran" SPS, "Gegeen" SPS, "Bukhug" SPS, "Sumber" SPS, and "Gobi" SPS, which are working in parallel with the power system.

For solar power plants, energy production is highest in March and April, and for rooftop solar power systems, energy production is highest in April and May.

This is due to the increase in wind speed and decrease in air temperature. Increased wind speed increases dust and reduces

the efficiency of solar generators. Also, when the wind speed increases, the relative humidity of the atmosphere decreases and the efficiency of the solar PV increases.

C. Study of energy production and influencing factors

The model was evaluated using Matlab. The current I is then evaluated using these parameters, and the variables Voltage, Irradiation, and Temperature. If one of the input variables is a vector, the output variable (current) is also a vector.

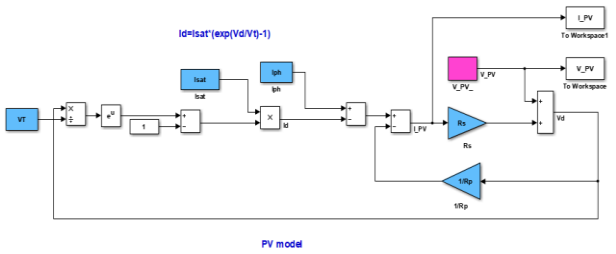

Figure 6. Matlab Modeling of Solar Photovoltaic Systems.

The output of the Matlab function is shown first for various irradiation levels, and then for various temperatures.

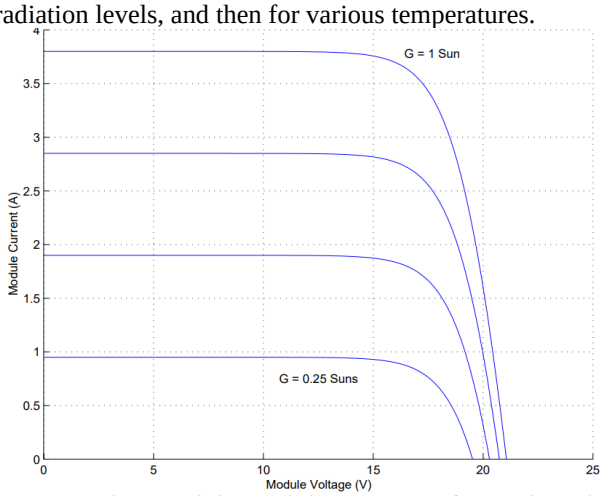

Figure 7. The Matlab model VI curves for various irradiation levels.

The discrete data points shown are taken from the manufacturer's curves, and show excellent correspondence with the model.

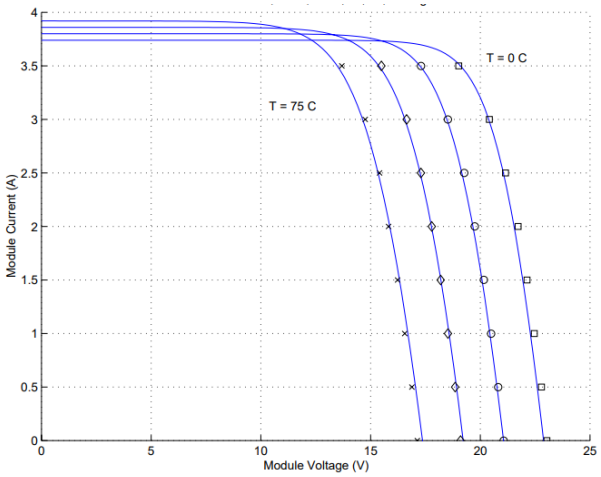

Figure 8. The Matlab model VI curves for various temperatures.

This may not occur for simultaneous low insolation levels and high panel temperatures. Inspection of figure 8 shows the maximum power point falls logarithmically with falling insolation, reaching 13.8V at around 150Wm^2 (0.15 Suns) and 50 ^{o}C.

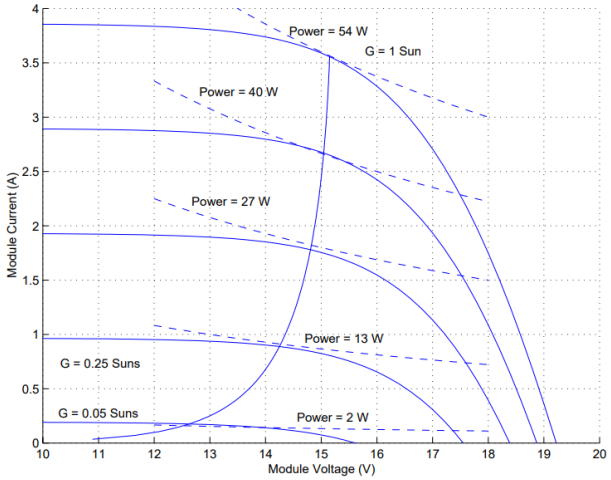

Figure 9. The Matlab model curves for various irradiance levels (G = 50; 250; 500; 750; 1000W/m^2) at the panel's nominal operating temperature of 50^{0}C.

The constant power curves which are tangential to each of the VI curves are shown, as well as the locus of the maximum power point voltage.

D. Study of energy production and influencing factors

The influence of ambient temperature, relative humidity, wind speed and solar radiation on the energy production of the solar electric system on the roof of MUST building 8 was studied. Ambient temperature, relative humidity, wind speed, and solar radiation data of Ulaanbaatar city from NACA Power Data Access Viewer (https://power.larc.nasa.gov/data-access-viewer) website (Ulaanbaatar - latitude: 47° 55' 12" longitude: 106° 55' 12") The data from January to December 2022 are processed and shown in Table I.

TABLE I. FACTORS AFFECTING ENERGY PRODUCTION

№	*E, [kWh]*	*Factors affecting energy production*				
		T, [^{0}C]	*H, [%]*	*V, [m/s]*	*G, [kWh/m^2]*	*Dust (PM10, PM2.5)*
1	1590.97	-17.95	84.18	5.06	1.91	229.9
2	1901.12	-16.98	79.22	5.87	3.23	207.9
3	2183.13	-6.56	58.19	6.26	4.39	131.9
4	2708.10	3.14	48.07	7.03	6.04	112.1
5	2767.55	11.22	44.18	6.32	7.11	80.3
6	2324.20	17.57	56.23	4.79	6.41	73.4
7	2217.10	18.67	58.82	4.65	5.60	61.9
8	2214.39	15.67	62.95	4.94	5.60	62.1
9	2641.39	10.81	54.37	5.90	5.02	88.5
10	2266.56	-1.37	58.56	5.31	3.20	124.0
11	2284.20	-10.19	71.01	5.85	2.15	128.1
12	1545.28	-22.29	92.92	6.15	1.28	195.5

Energy production, relative humidity and solar radiation curves. As the relative humidity of the air increases, the energy production of the solar electric system decreases. Energy production is high in the months of April, May and September when humidity is the lowest.

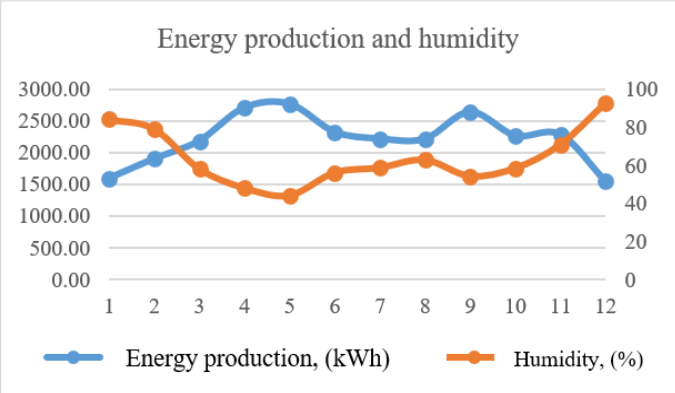

Figure 10. Energy production and air humidity curve

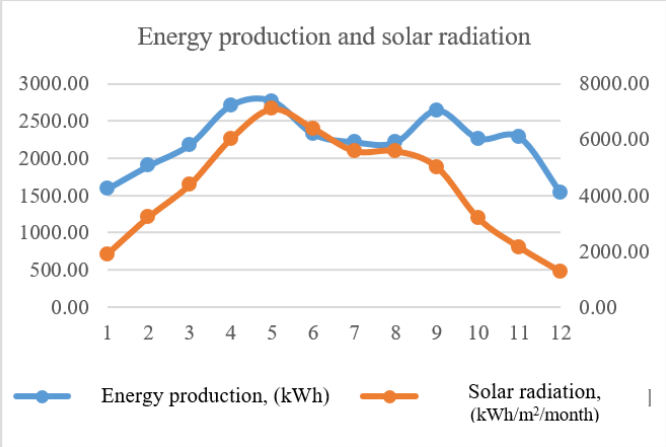

Figure 11. Energy production solar radiation curve.

Figure 12 shows that the relative humidity decreases when the wind speed increases. Thus, it can be seen from Table I that PV has a positive effect on energy production.

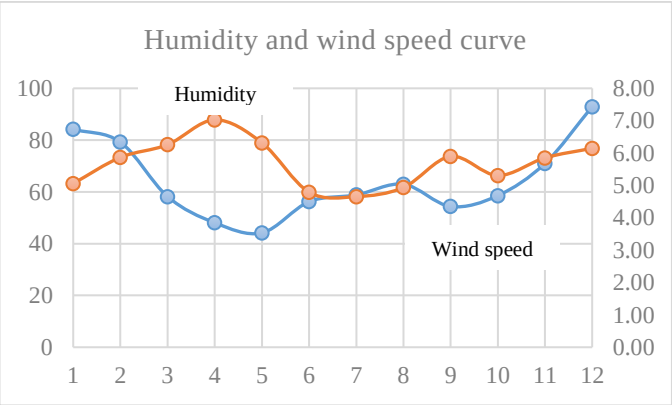

Figure 12. Wind speed and relative humidity

The correlation coefficient and regression methods were used to calculate the relationship between ambient temperature, relative humidity, wind speed, and solar radiation in the production of solar electric systems, and the results are presented in Table II.

TABLE II. RELATIONSHIP OF FACTORS AFFECTING ENERGY PRODUCTION

Energy production, [kWh]	***Factors affecting energy production***				
	T, [^{0}C]	***H, [%]***	***V, [m/s]***	***G, [kWh/m^2]***	***PM10, PM2.5***
Correlation coefficient, R	0.708	0.941	0.319	0.791	0.431
R^2	0.502	0.887	0.102	0.626	0.180

The correlation coefficient R is 0.319, 0.708, 0.791, 0.941, and 0.431 for wind speed, air temperature, solar radiation, humidity, and particulate matter, respectively.

The coefficient of determination R2 is 0.102, 0.502, 0.626, and 0.180 for wind speed, air temperature, solar radiation, and particulate matter, and 0.887 for humidity.

IV. CONCLUTION

PV energy production is affected by many factors, including the type of PV cell, the location of the system, the angle of the sun, the surface temperature, the mode of grid connection, the amount of solar radiation, pollution and shading.

In this research, the effects of ambient temperature, relative humidity, wind speed, solar radiation, and dust on the 2022 energy production of a 15kW solar electric system installed on the roof of the 8th building of the University of Science and Technology were investigated.

The following conclusions are reached by comparing the environmental temperature, relative humidity, wind speed, and solar radiation data of Ulaanbaatar city from the NACA Power Data Access Viewer site and how they affect the system's energy production. Air pollution data were obtained from the Air Quality Historical Data Platform.

- Atmospheric water vapor content scatters solar radiation and reduces solar intensity reaching the PV. Increased relative humidity reduces the energy production of solar power systems.
- The ambient temperature affects the surface temperature of the PV and can vary by about 10-20^{0}C. The PV can operate at its rated capacity when the surface temperature is around 25^{0}C. According to the measurement results, the maximum energy consumption is 2708.10 kWh and 2767.55 kWh in April and May, when the ambient temperature is 3.14 ^{0}C and 11.22 ^{0}C.
- The average wind speed of Ulaanbaatar city at a height of 35 m (MUST building 8) is approximately 4.65 m/s to 7.03 m/s. In April and May, the spring season with high wind speed, the relative humidity is low and dryness is high, so energy consumption is high.
- In summer, despite the longer day length and more solar radiation, the increase in PV surface temperature due to the increase in ambient temperature causes a relative decrease in energy production.
- Correlation coefficient R is 0.319, 0.708, 0.791, 0.941, and 0.431 for wind speed, air temperature, solar radiation, humidity, and particles, respectively. The coefficient of determination R2 is 0.102, 0.502, 0.626, and 0.180 for wind speed, air temperature, solar radiation, and particulate matter, and 0.887 for humidity.
- From this, the coefficient R2, which determines the humidity factor, has a strong effect on energy production. Wind speed and dust have a weak effect. However, the effects of solar radiation and ambient temperature on energy production are between strong and weak correlations.
- The pollution of Ulaanbaatar affects the intensity of solar radiation and scatters direct radiation.

REFERENCE

[1] IRENA, “International Renewable Energy Agency (IRENA),” Irena.org, 2019. https://www.irena.org/

[2] Koehl M, Heck M and Wiesmeier S, Modeling of conditions for accelerated life time testing of Humidity impact on PV-modules based on monitoring of climatic data, Solar Energy Materials & Solar Cells 99 (2012) 282-291

[3] Elminir H K, Benda V and Tousek J, Effects of solar irradiation conditions and other factors on the outdoor performance of photovoltaic modules, Journal of Electrical Engineering, vol. 52, No. 5-6, pp: 125-133, 2001.

[4] Kempe M D, Modeling of rates of moisture ingress into photovoltaic modules, Solar Energy Materials and Solar Cells, vol. 90, No. 16, pp: 2720-2738, 2006.

[5] Koehl M, Heck M and Wiesmeier S, Modeling of conditions for accelerated life time testing of Humidity impact on PV-modules based on monitoring of climatic data, Solar Energy Materials & Solar Cells 99 (2012) 282-291

[6] Haider Ibrahim, Nader Anani,Variations of PV module parameters with irradiance and temperature, Energy Procedia,Vol.134, 2017, pp: 276-285, ISSN 1876-6102, doi.org/10.1016/j.egypro.2017.09.617.

[7] Mekhilef S, Saidur R, Kamalisarvestani M, Effect of dust, humidity and air velocity on efficiency of photovoltaic cells, Renewable and Sustainable Energy Reviews, vol. 16, pp: 2920-2925, 2012.

[8] Gwandu B A L, Creasey D J, Humidity: a factor in the appropriate positioning of a photovoltaic power station, Renewable Energy, vol. 6, No. 3, pp: 313- 316, 1995.

[9] S. M. Salih, "Analysis of Shading Impact Factor for Photovoltaic Modules," IRAQI JOURNAL OF DESERT STUDIES, vol. 5, no. 1, pp. 1-9, 2013.

[10] Ruchpaul, Rikesh & Shamachurn, Heman. (2020). Performance Comparison of Three PV Technologies under the Effect of Partial Shading and Varying Tilt Angles. 9-18.

[11] [11] Kh. Sarangerel, E. Munkhtuya, "Possibilities of using BAPV and BIPV technology in Mongolia," Energy & Engineering, 2021-2(204), pp. 33-38.

[12] H. Belmili, S. M. A. Cheikh, M. Haddadi and C. Larbes, "Design and development of a data acquisition system for photovoltaic modules characterization," Renewable Energy, vol. 35, no. 7, pp. 1484-1492, 2010.

[13] Y. Kuai and S. Yuvarajan, "An electronic load for testing photovoltaic panels," Journal of Power Sources, vol. 154, no. 1, pp. 308-313, 2006.

[14] H. Rezk, I. Tyukhov, M. Al-Dhaifallah and A. Tikhonov, "Performance of data acquisition system for monitoring PV system parameters," Measurement, vol. 104, pp. 204-211, 2017.