Design and Performance Analysis of Rooftop Solar Photovoltaic (PV) System with Net Metering Mechanism for PSTU Academic Building

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Abstract: In this paper a 1-kilowatt peak (kWp) grid tied rooftop solar Photovoltaic (PV)system is designed with a net meter and measured the solar energy output for an Academic Building of PSTU. The properties of solar output power for synchronizing with the grid is analyzed. This methodology included gathering geolocation data, available rooftop area, solar energy resource information, PV module specifications, and PV array sizing. The report also showed how much CO_2 is reduced while generating the same amount of electrical energy from traditional fossil fuel-based power plants. The reduction of CO_2 reduces the greenhouse effect and global warm and keep the environment green. The results of this analysis are shown that rooftop solar PV systems are economically feasible and contribute to green energy.

Keywords: Renewable energy, Net Meter, Solar Photovoltaic, CO_2, Greenhouse gases.

Introduction

Bangladesh is a highly densely populated country and have large number of commercial industries, ready-made garments (RMG) factories which demands enormous amount of energy to continue their productions. In the year 2023, total electricity demand in Bangladesh will be approximately 20,000 MW. Bangladesh will need an estimated 34,000 MW of power by 2030 to sustain its economic growth of over 7 %. Currently, the country can produce 13,646 MW (maximum power generation in August 2022) according to Bangladesh power development board, which is still too small to cover all needs. We rely primarily on fossil fuels for energy production, but the scarcity of fossil fuels and their expensive processes make it difficult to increase the energy production needed in this current situation. Carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions result from burning fossil fuels such as natural gas, crude oil, and coal. Conventional power plants burn large amounts of fossil fuels to generate electricity. As a result, non-conventional renewable energy sources are becoming more and more popular every day around the world. Bangladesh plans to generate 10% of its total electricity generation from renewable energy sources such as solar, wind, biomass, tidal power and ocean waves by 2023. The country plans to increase the share of renewable energy to 17% by 2041 under its intended Nationally Determined Contribution (INDC) commitment to reduce greenhouse gas emissions by 5% by 2030 (Siddique et al., 2021). To achieve this goal, the Bangladesh government is looking for various options. Preferably looking for renewable energy sources such as solar, wind, biomass and ocean waves. In Bangladesh's existing power generation scenario, renewable energy accounts for a very small proportion of total power generation under current conditions.

Renewable energy sources such as solar, biomass, wind, tidal, hydroelectric and ocean waves are long-lasting and boundless sources of energy and solutions to many ecological difficulties. In the long run, renewable energy will only replace conventional energy on a global scale. They are clean and ecologically approachable sources of energy. The Government of the People's Republic of Bangladesh established the Sustainable and Renewable Energy Development Authority (SREDA) to research renewable energy sources and reduce pollution. SREDA has Building Energy Performance and Environmental Rating (BEEER) guidance and goes beyond renewable energy inclusion. Buildings that use 100% renewable energy (Net Zero Buildings) score 10 points (Mertens et al., 2014). Solar energy is clean and non-polluting and available everywhere in the world, so it could be an excellent source of energy to face the power crisis.

Bangladesh is located in a tropical region and is a country with great potential for solar energy. Bangladesh has an average solar radiation and temperature is 4.59 kWh/m² and 26.93ºC respectively (Kumar et al., 2018). A great advantage of solar energy is that it is inexhaustible and can produce a wide range of power from microwatts to megawatts. Currently in Bangladesh, total renewable power generation is 766.45 MW, but only solar power is 532.46 MW, accounting for 69.50% of total renewable power generation. Solar energy is harnessed today by photovoltaic (PV) equipment. Solar radiation is converted into electrical power based on the PV effect. This PV method can be used in two methods:

Standalone and grid-connected configurations. Self-sufficient PV systems are very attractive as an essential energy source in remote areas where grid infrastructure is lacking (Bedi et al., 2016). A drawback of this technology is, on the one hand, its inability to provide a continuous energy supply due to seasonal and periodic fluctuations. Grid-tied PV systems are currently being implemented to hybridize PV systems with conventional energy sources to meet load demands. When solar output exceeds load requirements, surplus power is automatically supplied to the grid. This arrangement requires a step-up transformer and switchgear to inject power into the grid. In this method, net metering is a novel method that enables charging mechanisms that provide additional energy for the grid to solar array owners (Koganti et al., 2017, Maharaja et al., 2016).

The fuel cost for generating power per unit is very high, but zero for solar power systems. Conventional power plants have high operating and maintenance costs, while solar power has almost no operating and maintenance costs. Because conventional power plants are far from consumers, there are technical losses in power transmission and distribution. Photovoltaic electrical energy can be distributed with minimal technical losses due to the negligible distance between photovoltaic and consumer loads. On the other hand, the function of photovoltaic systems is to act as alternative power sources for each other. And with a rooftop solar power system, the sun's rays hit the solar panels and the roof doesn't heat up like traditional buildings. There are some studies on the impact of cool roof colors on building roofs and photovoltaic panels, but there is a lag in investigating heat reduction from the photovoltaic panels themselves (Altan et al., 2019). Solar panels absorb the heat and cover the roof. As a result, less energy is used for cooling, making the building more energy efficient. The main focus of this work was to show how photovoltaic systems can contribute to substantially sustaining clean and green electricity consumption. On the other hand, there is also research that theoretically calculates the reduction of CO_2 emissions, but lags behind the actual data (Rajput et al., 2017). According to theGlobalEconomy.com, Bangladesh's carbon emissions reached thousands of tons between 1960 and 2018. Bangladesh averaged 24702 kt during this period, with a minimum of 3509 kt in 1972 and a maximum of 82760 kt in 2018. The latest value for 2018 was 82760 kt. Actionable data on reducing CO2 emissions is very important as it is an indicator of clean power generation. In the past, some studies have been done to analyze the payback period, but the architectural and structural design of the building have not been considered (Zeraatpisheh et al., 2018). Architectural floor plane is required to measure rooftop area of the building and structural design is required to ensure the lifetime of the building.

The main objective of the research work was to design and performance analysis of a novel net-metering rooftop solar power technology for the south-central region of Bangladesh, which was installed at PSTU's CSE building. A grid-connected 1 kWp rooftop solar power system with a net meter was designed and the solar output of the 1 kWp rooftop solar power system was measured. It also analyzes the characteristics of solar energy output for synchronization with the grid. We evaluated the reduction of CO2 emissions.

The cost-effective design of the photovoltaic system, taking into account the shading effect of the frame and the architectural and structural planning, shortens the payback period. Figure 1 shows a grid-connected photovoltaic system.

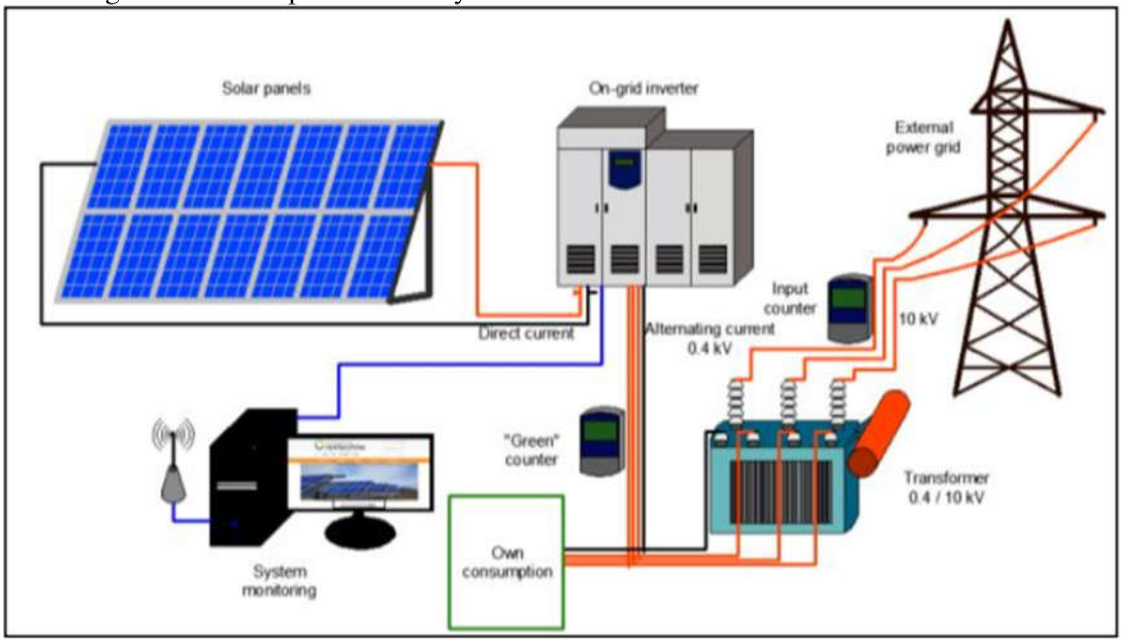

Figure 1. A grid-tied PV systems include photovoltaic panels, grid-tied, grid-tied inverters, step-up transformers, and connected domestic loads (Arshad et al., 2021).

Materials and Methods

During our research work, the rooftop of the university building was considered. Site selection is very important and takes place in the early stages of the project. Architectural plans for the roof of the building are required. Information about building construction is important because building life is an important issue. The service life of a solar module is about 25 years. Therefore, we need to ensure that the university building we choose has a useful life of at least 25 years. Otherwise it would not economical. This architectural and structural information will be collected during the second phase of the project. Geographic information such as latitude and longitude coordinates is important and data is collected. Monthly and seasonal average solar radiation data are collected as an essential part of this work. Collecting this geographic data is the third phase of this work. Considering shading effects and other factors, the usable area of the roof of the building is completed and constitutes the fourth phase of the work (Tahera et al., 2018).

The solar power system is designed based on the grid-tied method, also known as the grid-tied solar power system. Net metering is a design parameter of a solar photovoltaic system. The design of a small scale solar power system is completed after collecting all the necessary data for the above design purposes and this is the fifth phase of the work as well as the very important one. important. Solar photovoltaic generators are sized according to desired capacity, roof surface and available budget (Mansur et al., 2018). The designed small-scale rooftop solar power method has been built-in. The panels of the solar photovoltaic system depend on the available area, length and width, east-west coordinates of the building roof. The installation of the solar power system according to the design will be carried out in the sixth phase of the work. The complete workflow diagram is shown in Figure-2.

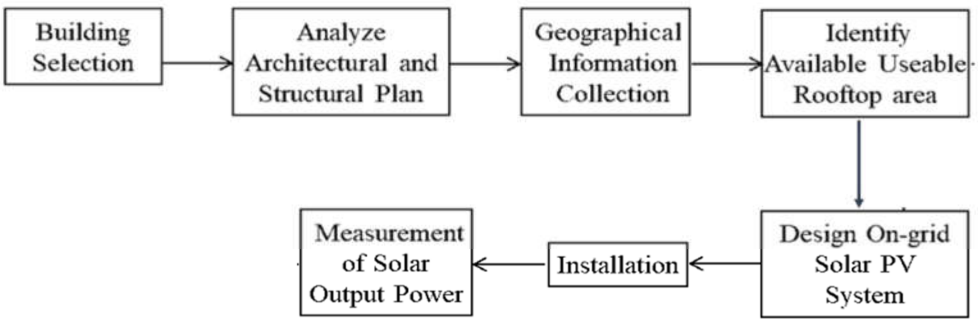

Figure 2. Work Flow Diagram.

Installed solar PV systems are useful to find actual data on solar power generation and this data is aided in designing large scale solar power systems. The PV solar panel is connected in series with the On-Grid solar inverter. The solar energy production of the system is recorded. Hourly, daily, weekly, monthly and annual information is collected to examine the energy production of the solar power system and its contribution to load efficiency. Network metering scheme to save excess output energy. The energy meter registers power coming from the network and power coming from the consumer system. Electricity in and out is adjusted in the payment system at the end of the year. The measurement of solar production is carried out in the seventh phase of the work.

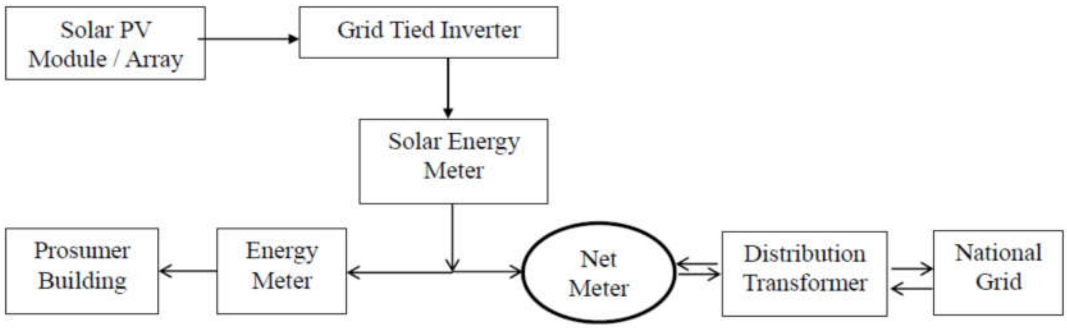

Figure 3. Net metering Solar PV system.

Concept of Net Meter: Net metering is an available utility payment mechanism that provides credit to residential and commercial customers that generate excess electricity with their solar panel system and return it to the grid. By using a rooftop solar photovoltaic system, we can get more electricity than we consume during the day. The net measurement diagram is shown in Figure 3.

In a metered solar power system, if the output of the solar panels exceeds the unit power consumption, the excess energy will be supplied to the grid and the excess energy must be recorded. Energy meters' record power coming from the network and power coming from the consumer system (Maharaja et al., 2016). Electricity in and out is adjusted in the payment system at the end of the year.

With net metering, consumers are billed only for the "actual" energy consumed by a given building each month, i.e. the difference between the energy produced by the solar power system and the energy consumed by the house over the monthly billing period [13]. From the Figure 3, we can write the net energy consumption as:

Net energy consumption = Energy from the grid - Solar energy generation

Carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions into the environment are caused by burning fossil fuels such as natural gas, oil and coal. Conventional power plants burn large amounts of fossil fuels to generate electricity. Bangladesh's Green Emission Factor (GEF) is 0.67 tons CO_2/MWh (Arshad et al., 2021).

The reduction in carbon dioxide (CO_2) emissions for the same output of conventional fossil fuel power plants can be calculated from the relationship:

CO_2 (Emission Reduction) = Solar power generation × GEF

Result and Discussion

Site information

The rooftop of the four-storied building of PSTU's CSE faculty was chosen for this work. The geographic coordinates (longitude and latitude) of selected buildings were collected from the website of NASA. The geographic coordinates (latitude and longitude) of the selected buildings are shown in the Table-1. Geographic coordinates are required to determine solar radiation. To estimate the performance of a photovoltaic system, solar irradiance information is required.

Table 1. Geographic coordinates of the selected building.

Serial No.	Description	Information
I	Latitude	22°25'59.99" N
II	Longitude	90°22'0.01" E
III	Sea level	3 meter

Architectural and Structural Plan

The rooftop area of the building is measured from the architectural plan. Information about building construction is important because building life is an important issue. The service life of a solar module is about twenty-five years. Therefore, it is important to confirm that the academic building that we choose has a useful life of at least twenty-five years. Otherwise, it will not be economically viable. Our selected building is new and has a useful life of about fifty years.

Measurement of Shaded Area

By holding the PV solar panel at the same angle as its latitude, the incident beam will be perpendicular to the PV solar panel for maximum output (Arshad et al., 2021). In this experiment the tilt angle is θz = 23°. There is a water tank on the rooftop of the building. The tank is 5.6 meters long, 3.60 meters wide and 5.00 meters high. Sphere length (l) = tanθz × ruler height (h) = tan23° × 5 = 2.1223 meters. Shade unusable area = pool length ×shade length × 2 = 5.6×2.1223× 2 = 23.7697 m^2. A typical 1 KWP photovoltaic needs a roof area of 10 m^2. There was enough space on the roof for this experiment.

Figure 4. Rooftop view of the academic building for CSE

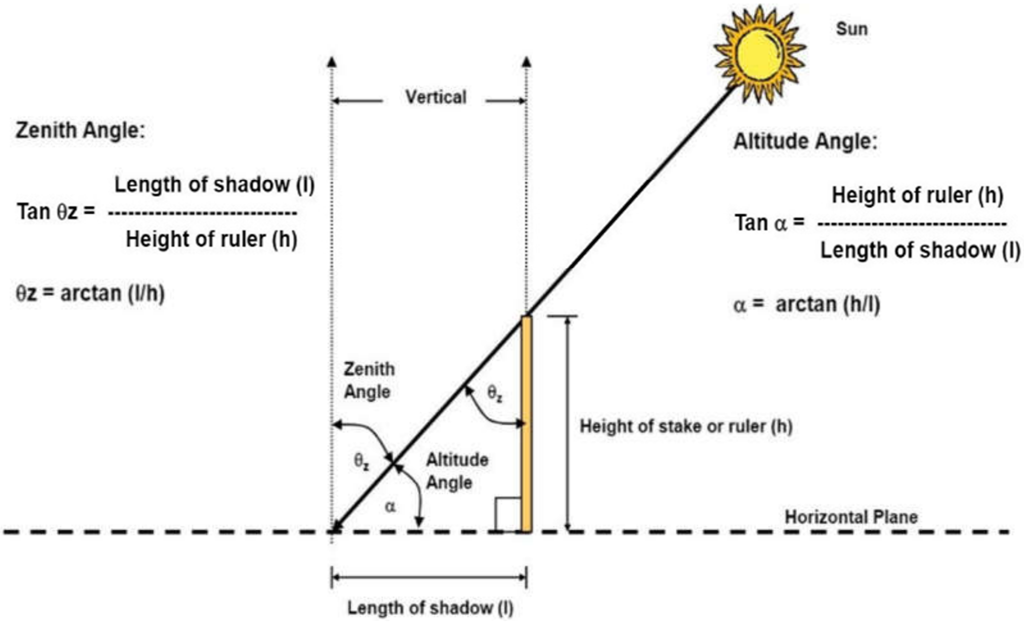

Figure 5. Shading effect of a ruler

Monthly average data for solar irradiance, monthly mean temperature, mean sunshine, and mean sunshine.

Average monthly solar irradiance, average monthly temperature, average daylight and average sunshine are important for solar photovoltaic system sizing and design to get maximum output. Tables 2, 3 and 4 present data for monthly mean solar irradiance, monthly mean solar temperature, mean daylight and mean sunshine, respectively. In this experiment, we observed that the monthly average solar irradiance is 5.499 kwh/M^2/day, the monthly average data of solar temperature is 27.73°C, and the monthly average data of daylight and sunshine are 12:05 Hours and 9:00 Hours respectively.

Table 2. Monthly average data of solar irradiance.

Serial No.	Duration	Monthly average Solar Irradiance (kwh/M^2/day)
i	01.01.2022 to 31.01.2022	4.49
ii	01.02.2022 to 28.02.2022	5.86
iii	01.03.2022 to 31.03.2022	5.80
iv	01.04.2022 to 30.04.2022	5.71
v	01.05.2022 to 31.05.2022	5.37
vi	01.06.2022 to 30.06.2022	5.51
vii	01.07.2022 to 31.07.2022	5.50
viii	01.08.2022 to 31.08.2022	5.53
ix	01.09.2022 to 30.09.2022	5.83
x	01.10.2022 to 31.10.2022	5.66
xi	01.11.2022 to 30.11.2022	5.41
xii	01.12.2022 to 31.12.2022	5.32
	Total	**65.99**
	Average	**5.499**

Table 3. Monthly average data of solar temperature

Serial No.	Duration	Monthly Average Temperature(°C)
i	01.01.2022 to 31.01.2022	21.51
ii	01.02.2022 to 28.02.2022	24.30
iii	01.03.2022 to 31.03.2022	29.10
iv	01.04.2022 to 30.04.2022	31.20
v	01.05.2022 to 31.05.2022	31.60
vi	01.06.2022 to 30.06.2022	31.15
vii	01.07.2022 to 31.07.2022	29.80
viii	01.08.2022 to 31.08.2022	29.70
ix	01.09.2022 to 30.09.2022	29.50
x	01.10.2022 to 31.10.2022	27.90
xi	01.11.2022 to 30.11.2022	24.50
xii	01.12.2022 to 31.12.2022	22.53
	Total	**65.99**
	Average	**5.499**

Table 4. Monthly average data of daylight and sunshine.

Serial No.	Duration	Average Daylight(Hour)	Average Sunshine(Hour)
i	01.01.2022 to 31.01.2022	10:57	7:50
ii	01.02.2022 to 28.02.2022	11:42	7:48
iii	01.03.2022 to 31.03.2022	12:10	10:10
iv	01.04.2022 to 30.04.2022	12:42	10:50
v	01.05.2022 to 31.05.2022	13:25	10:00
vi	01.06.2022 to 30.06.2022	13:12	9:00
vii	01.07.2022 to 31.07.2022	13:24	7:30
viii	01.08.2022 to 31.08.2022	12:27	8:20
ix	01.09.2022 to 30.09.2022	12:30	8:30
x	01.10.2022 to 31.10.2022	11:36	7:50
xi	01.11.2022 to 30.11.2022	11:10	7:40
xii	01.12.2022 to 31.12.2022	10:42	7:50
	Average	**12:05**	**9:00**

Power generation from this method

A 1 kWp solar photovoltaic system was installed on the roof of the academic building for CSE. The monthly solar power generation of the system was measured. Table 5 shows the monthly solar energy output of a 1 kWp PV system. By this system, it is observed that the total solar power generation per year is 1,236 kWh.

Table 5. Power generation from 1 kWp photovoltaic system.

Serial No.	Duration	Solar Energy (kWh)
i	01.01.2022 to 31.01.2022	79
ii	01.02.2022 to 28.02.2022	83
iii	01.03.2022 to 31.03.2022	115
iv	01.04.2022 to 30.04.2022	118
v	01.05.2022 to 31.05.2022	117
vi	01.06.2022 to 30.06.2022	112
vii	01.07.2022 to 31.07.2022	108
viii	01.08.2022 to 31.08.2022	90
Total Solar Power Generation in 8 months		822
Average		103
Total Solar Power Generation per year		1,236

Electrical Characteristics

For 1 kWp solar PV system, we have measured the following electrical characteristics for several times which are shown in the Table-6. We observed very regular characteristics of the solar power output.

Table 6. Electrical Characteristics.

Characteristics	1	2	3	4	5	6	7	8
DC Voltage(V_{dc}) in Volt	119	116	121	125	124	120	118	122
AC Voltage(V_{ac}) in Volt	226	223	226	208	210	236	214	217
AC Current (I_{ac}) Ampere	1.5	1.7	1.3	0.9	0.8	1.7	1.1	2
AC Power(P_{ac}) Watt	339	379	293	187	168	401	235	434

Reduction of Carbon Dioxide (CO_2) Emissions

The average annual solar output from a solar photovoltaic system is 1,236 kWh. The total solar power output over the life of the solar power system is 1 kWp = 1,236 × 25 = 30,900 kWh = 30.9 MWh. The Green Emission Factor (GEF) of Bangladesh is 0.67 tons CO_2/MWh (Arshad et al., 2021). In this technology, CO_2 (emission reduction) = solar power output × GEF = 30.9 × 0.67 = 20,703 tons.

Conclusion

A cost-effective solar photovoltaic technique was designed and collected architectural and structural plans, geographic information and available roof area. This research has developed a novelty technology to convert solar radiation into solar energy by rooftop solar photovoltaic method, which plays an important role in the field of power development. The average annual solar output from the designed solar photovoltaic system is 1,236 kWh. The total solar energy output over the lifetime (25 years) of a 1 kWp solar photovoltaic system is 30,900 kWh. This solar energy is added directly to the grid. To improve the national economy, electricity or energy plays an important role in all fields. Energy is a key factor in the economic and human development of any country. In Bangladesh, energy consumption is increasing day by day due to rapid population growth and economic expansion. Fossil fuel shortages and these delays take a toll on Bangladesh's economy as the country is heavily dependent on imports. It seems that energy consumption appears in a dual trend with economic growth, one is growth dependent on access to cost-effective and environmentally friendly energy sources, the other is growth rate. Economic growth is considered to be dependent on energy demand. Bangladesh can receive carbon credits known as Certified Emission Reductions (CERs). During 25 years CO_2 emission reduction is 20,703 tons per 1 kWp solar photovoltaic system. Therefore, the research results contribute to the realization of sustainable development technology. Further research is needed to find out more information about this type of grid-metered rooftop solar system.

Author Contributions: In this research, author 1, 2,3 are responsible for conceptualization, resources, methodology, data collection, formal analysis, investigation; author 1, 2, 3,4 are responsible for writing--review and editing, project administration, funding acquisition; author 4, 5, 6 are responsible for validation, writing--original draft preparation, visualization. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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