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Estimation of Optimum Tilt Angles for Solar Panels Across Chattogram Division of Bangladesh with Terrain-Based Comparison

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ABSTRACT

It is important to determine the tilt angle of photovoltaic (PV) panels correctly if we hope to get maximum solar energy. This study mainly focuses on finding the optimal fixed and seasonal tilt angles for solar panels in all districts of Chattogram Division, Bangladesh. Using standard solar geometry formulas, we calculated important parameters such as declination, solar altitude, zenith angle, air mass, irradiance and daily solar radiation for each day of the year. Several fixed tilt angles (ranging from 1° to 40°) were tested to find the one that produced the highest total annual energy, which was identified as the best one. Also two seasonal tilt angles – one for April to September and the other for October to March – were identified to improve energy production and maximize solar energy. Comparison between hilly and flatland districts showed clear differences in the optimal angle and energy production. The results confirm that both latitude and terrain influence the best tilt angle. This work can help to better manage PV panel installations across Chattogram and support solar energy plans across Bangladesh.

Keywords: Latitude, Optimum Tilt Angle, Solar Energy.

1. Introduction

To advance the human race, energy will be the most demanding tool. To meet this huge demand, most countries still rely on fossil fuels such as coal, oil, and natural gas [1]. However, these energies play a big role in environmental pollution. Consequently, renewable energy has become an essential option. Among all the renewable energy sources, solar energy is considered one of the best, since it is clean, free, and widely available all over the world [2]. Solar panels or photovoltaic (PV) systems convert sunlight into electricity. The efficiency of these systems depends on various factors, such as location, solar radiation, panel direction, and, most importantly, the tilt angle of the panel. Tilt angle is the angle between the surface of the panel and the ground. This angle needs to be selected correctly to increase the total energy production; then the panel can capture the maximum amount of sunlight, which increases the total energy production [3]. In many countries, solar panels are often installed at a fixed angle close to the latitude of the location. But due to variations in season, geography, and sunlight intensity, it is possible to improve energy performance by using the correct fixed tilt angle or seasonal angle. In Bangladesh, especially in the Chattogram division, the landscape includes both flat and hilly areas, which affect solar radiation for many reasons. Therefore, it is necessary to find the correct tilt angle for each district separately. This study focused on determining the optimal tilt angle for solar panels across all districts of Chattogram division. Using solar geometry-based formulas, important parameters such as solar declination, altitude, zenith angle, air mass, radiation, and daily radiation were calculated. Both annual fixed angle and seasonal (April-September and October-March) tilt angles were estimated. In addition, a comparison between flat and hilly districts was made to understand how topography affects solar energy production. By the end of this research, we can help engineers and policymakers install solar panels more effectively and increase the use of renewable energy in the region. This will not only improve solar energy in the future, but also support Bangladesh to prosper.

2. Formulation

The optimal tilt angle for a fixed solar photovoltaic (PV) panel can be determined using geometric means. We used the following equations to derive the relevant solar angle, irradiance, irradiance of the tilted surface, and total power generation.

$$\delta = 23.45^0 * \sin(\frac{360}{365} * (d - 81)) \quad (1)$$

Equation (1) [4] where δ is the solar declination angle and d is the day of the year (1 to 365).

$$\alpha = 90° - \text{latitude angle} + \text{declination angle} \quad (2)$$

Here, α is the solar elevation angle.

$$\theta = 90° - \text{elevation angle} \quad (3)$$

The solar zenith angle θ is the angle between the vertical and the line to the sun.

$$AM = \frac{1}{\cos(\theta)} \quad (4)$$

Equation (4) [5] Air Mass (AM) indicates the path length of sunlight through the atmosphere relative to the shortest possible path.

$$I = 1.1 * 1.353 * 0.7^{AM^{0.678}} \quad (5)$$

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This equation (5) [6] estimates the actual irradiance (I) in kW/m² reaching the Earth's surface.

$$\text{Solar Radiation} = I * \text{Sin}(\alpha + \beta) \quad (6)$$

The Equation (6) [7] of the solar radiation on a tilted surface, and β is the tilt angle of the PV panel.

$$\text{Sunrise} = 12 - \frac{1}{15^o} Cos^{-1}\left(\frac{-Sin\varphi Sin\delta}{Cos\varphi Cos\delta}\right) \quad (7)$$

$$\text{Sunset} = 12 + \frac{1}{15^o} Cos^{-1}\left(\frac{-Sin\varphi Sin\delta}{Cos\varphi Cos\delta}\right) \quad (8)$$

These two equations (7) & (8) calculate the time of sunrise and sunset in hours.

$$\text{Sun hour} = \text{Sunset} - \text{Sunrise} \quad (9)$$

Sun hour denotes the daily duration of sunlight availability.

$$\text{Daily Energy} = \text{Solar Radiation} * \text{Sun Hour} \quad (10)$$

This gives the total daily solar energy received per unit area (kWh/m^2-day).

3. Simulation

The simulation and all output plots were done using Excel. Only the results of the simulation for Chattogram district (Latitude-22.37763^o) [8] are shown here:

3.1 One optimum tilt angle for the whole year

The whole year has been chosen as this simulation has been done to find a single optimum tilt angle for the whole year. The graph of the simulation results is shown in Fig. 1. Here, the amount of energy available for 1 to 40 degrees throughout the year has been found out separately. Calculations have been made for each day separately, and then the daily energy for the whole year has been added together. The maximum angle at which the maximum energy is available for the optimum tilt angle. The result of this simulation can be summarized as follows:

Optimum tilt angle = 20.5^o
Total Energy = 4244.548 kWh/m2-year

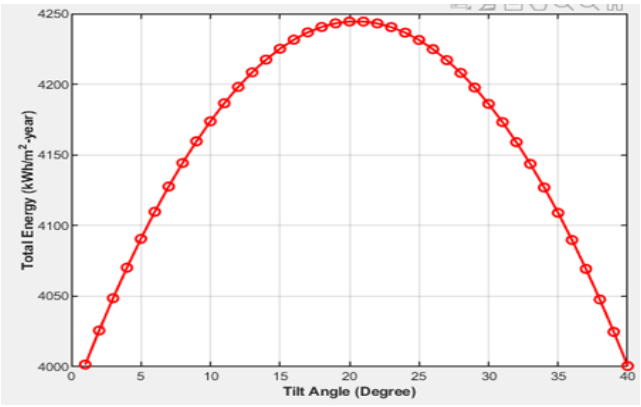

Fig.1: Change in Total Energy with Tilt Angle for Chittagong district.

Apart from Chattogram, this simulation has been done in the same way for all the districts of Chattogram division. The summary of the simulation is shown in Table 1.

Table 1: Optimum tilt angle for 11 districts of Chattogram division with total yearly energy.

Districts	Optimum Tilt Angle	Total Energy (kWh/m^2 year)
Chattogram	20.5^o	4244.548
Cox's Bazar	19.5^o	4251.834
Khagrachari	21^o	4238.628
Bandarban	20.5^o	4245.948
Rangamati	20.5^o	4242.26
Feni	21^o	4239.483
Noakhali	21^o	4240.655
Lakshmipur	21^o	4240.016
Brahmanbaria	22^o	4231.254
Chandpur	22^o	4237.36
Comilla	22^o	4235.67

3.2 Optimum tilt angle for two seasons

Now, this time the simulation is run by dividing the year into two parts. So that two different optimum tilt angles are obtained. Here, the 12 months of a year are divided into 2 periods of 6 months each. One is the April to September period, and the other is the October to March period [9]. The main purpose of doing this is so that we can get more energy.

Period – April to September:

The results of this simulation are shown in Fig. 2. The amount of energy available from 1° to 40° for six months (April to September) has been calculated separately. In this case, it has been calculated separately too for each day, and then the daily energy has been aggregated for the entire six months. Then the angle at which the maximum energy is available has been chosen as the optimal tilt angle for these six months. The result of this simulation can be summarized as follows:

Optimum tilt angle = 7.5^o

Total Energy = 2416.561 kWh/m^2-year

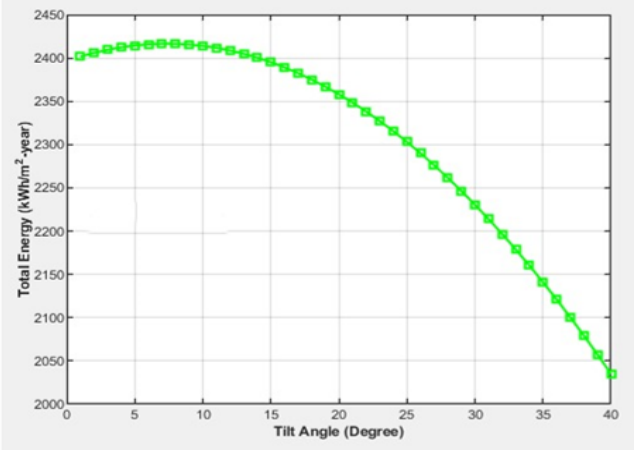

Fig.2: Change of total energy from April to September season with Tilt Angle for Chittagong district

The optimum tilt angle for six months has been derived for all the remaining districts on the same basis. Now, the summary of the simulation is shown in Table 2.

Table 2: Optimum tilt angle and Total Energy for 11 districts of Chattogram division from April to September

Districts	Optimum Tilt Angle	Total Energy (kWh/m^2year)
Chattogram	7.5^o	2416.561
Cox's Bazar	6.5^o	2410.292
Khagrachari	8^o	2421.38
Bandarban	7^o	2415.36
Rangamati	7.5^o	2418.421
Feni	8^o	2420.709
Noakhali	8^o	2419.754
Lakshmipur	8^o	2420.28
Brahmanbaria	9^o	2427.114
Chandpur	8^o	2422.093
Comilla	8.5^o	2423.57

Period – October to March:

Again, the results of this simulation is shown in Fig. 3. Here, this time, the amount of energy available from 1 to 40 degrees has been calculated separately for the remaining six months, i.e., October to March. As before, the calculation has been done separately for each day, and it has been combined. Then the angle at which the maximum energy is available at the end has been chosen as the best tilt angle for these six months. The result of this simulation can be summarized as follows:

Optimum tilt angle = 36.5^o

Total Energy = 1968.772 kWh/m^2-year

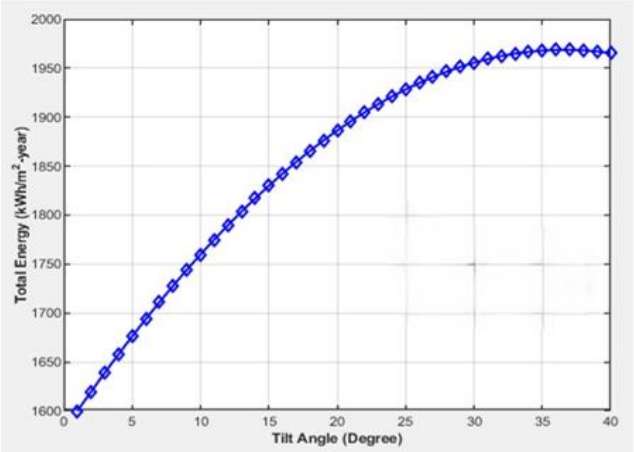

Fig.3: Change of total energy from October to March season with Tilt Angle for Chittagong district

Table 3: Optimum tilt angle and Total Energy for 11 districts of Chattogram division from October to March

Districts	Optimum Tilt Angle	Total Energy (kWh/m^2year)
Chattogram	36.5^o	1968.772
Cox's Bazar	35.5^o	1982.8
Khagrachari	37.5^o	1957.669
Bandarban	36.5^o	1971.484
Rangamati	37^o	1964.517
Feni	37.5^o	1959.228
Noakhali	37^o	1961.439
Lakshmipur	37^o	1960.228
Brahmanbaria	38^o	1944.066
Chandpur	37.5^o	1955.979
Comilla	37.5^o	1952.522

4.Comparison

After completing this simulation, some variations can be observed among the districts of Chattogram division. Some districts of Chattogram division are flat, and some are hilly. Therefore, it can be seen that there is some difference in the optimum tilt angle in flat areas like Chandpur and Lakshmipur compared to hilly areas like Rangamati and Cox's Bazar. This difference is mainly due to the height of the terrain as well as the difference in the path of the sun. Although the annual energy production is almost the same, there is some variation in the angle. The graph of this comparison is shown in Fig. 4.

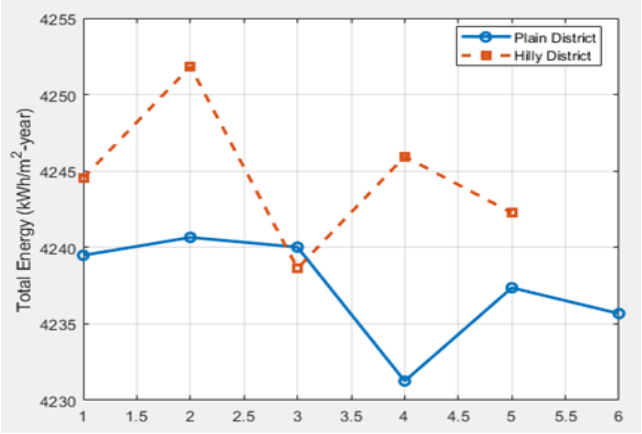

Fig.4: Variation of Total Energy in Hilly and Plain Districts

6. Conclusion

The purpose of this study was to find the exact Optimum tilt angle for all the districts of Chattogram division. In this study, the angle has been found by solving mathematical problems. After getting all the results, it is seen that there is a difference in the angle due to the difference in location and terrain. Hilly areas show a slightly different angle than the flat areas. These angles can help in increasing solar energy through its use. Besides, the results can pave the way for better thinking about solar energy in the future and can enrich Bangladesh with renewable energy.

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Nomenclature

Symbol	*Meaning*	*Unit*
δ	Solar declination angle	Degree(°)
α	Solar elevation angle	Degree(°)
θ	Solar zenith angle	Degree(°)
AM	Air Mass	Dimensionless
I	Solar irradiance	kW/m²
β	PV panel tilt angle	Degree(°)