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Fixed and adjusted optimal tilt angle of solar panels in three cities in Albania

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Abstract: In this paper, we are concerned about optimal tilt angle choice of solar panels installation in three cities in Albania. The optimal tilt angle of solar panels is a crucial parameter for a high performance of solar energy systems. Solar energy systems can be tracking systems or fixed systems, fixed tilt angle determination and adjustable tilt angle evaluation of solar panels is an important issue to solve. In this study, Bernard-Menguy-Schwartz (BMS) model is used to determine the yearly and seasonally optimum tilt angle of the solar panels in three cities in Albania. The determination of the optimum tilt angle is made considering the fact that the solar energy reaching the solar panels has maximum value for optimum tilt angle. The yearly optimum tilt angle of the solar panels for the cities: Tirana (41.3275° N, 19.8187° E), Kuksi (42.0807° N, 20.4143° E) and Vlora (40.4661° N, 19.4914° E) are respectively 38o, 39o and 37o. It should be noted that, the yearly optimal tilt angle of solar panels based on the above mathematical model is almost equal to the latitude of the location. A suggestion of seasonably adjustable tilt angle is made. In addition, seasonally or adjusted tilt angles of solar panels were compared with yearly optimal tilt angle.

Keywords: *Adjusted tilt angle, Bernard-Menguy-Schwartz model, BMS model, Optimum tilt angle, Solar energy, Solar panel, Solar water heating*

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Nomenclature	
β	Tilt Angle (º)
δ	Solar Declination (º)
α_s	The Height of the sun at true midday (º)
ω	Hour Angle (º)
θ	The angle between the normal of the collector and the solar rays at midday (º)
I_d	The direct radiation under clear sky condition [Wh/m^2]
D_h	The sky diffused radiation received on the horizontal plane in clear sky condition [Wh/m^2]
G_h	The total radiation received by the horizontal plane [Wh/m^2]
D_i	Diffuse radiation receipts by the inclined collector plane [Wh/m^2]
G_i	Total radiation receipts by the inclined collector plane [Wh/m^2]
φ	Latitude of location (º)
α	Albedo

1. INTRODUCTION

The development of any society relies on one key element, “energy”. It is used in every sector such as household consumption, industry, transport, agriculture etc. Globally, most of the energy consumed (72.7 %) [1] is still supported by fossil fuel. The evidence shows that the uses of energy from non-renewable sources have sharp environmental consequences. [2]

That the fact that economic growth and living standards of a country is strongly related with energy consumption has imposed the rise of energy generated from different sources. Renewable energy sources such as: Solar energy, wind energy, hydropower, wave power, geothermal energy etc, are the only way to avoid the catastrophic consequences of energy from the fossil fuels (because they are finite), as well as to enable a soft transition from fossil fuels to renewable energy. [3]

Solar energy is a primary energy source, from which most renewable sources are derived. First way to harness solar energy is to produce thermal energy through solar collectors, and second one is to produce electricity from photovoltaic panels PV [4]. Since solar energy is abundant and clean, utilization in both systems (solar water heating, solar PV) has attracted more attention in recent years [5].

Albania, with a favorable geographical position in the Mediterranean basin, has very favorable climatic conditions for the use of solar energy, based on this fact Albania is considered to have a high potential of solar energy. Two indicators are commonly used to evaluate the potential of solar energy. The first is the average daily radiation [kWh/m^2] per year, and the second is the distribution of the number of hours of sunshine during the year. In some areas of our territory, the average daily solar radiation varies from 1185 - 1700 [kWh/ m^2] per year. While the number of hours of sunshine during a year varies from 2400-2700 h [6].

The tilt angle of solar panels is an important factor for each location. The energy generated from solar energy systems (solar PV system, solar water heating) depends strongly on the tilt angle of solar panels and produces the maximum energy from solar energy systems, when the tilt angles of solar panels are optimized. Many factors influence the optimum tilt angle such as latitude of location, air pollution, clearness index that has local character, and sunny days of the year, which represent the climatic condition of the location [4,7].

The use of solar energy by solar systems depends on several geometrical parameters. To increase the solar radiation reaching the solar panels, the panels of solar energy systems must install in such a way that the solar radiation falls perpendicular to the surface of the solar panels at any time [8,9]. The angle of incidence is defined as the angle between solar rays and the perpendicular line on the surface, and the amount of the solar radiation incident on a surface is inversely proportional to the value of incidence angle. The angle of incidence is always perpendicular to the surface of solar panels in solar tracking systems, but these systems tend to have higher costs due to mechanism that makes this function possible. To increase the performance of solar energy systems the angle of incidence or the tilt angle of solar panels must be determined [7,10]. For this reason, a series of optimization methods have been developed to determine the optimal tilt angle of solar panels [11,12]. In this study, we have determined the optimal tilt angle of the solar panels based on the BMS model for three cities in Albania.

1.1 Optimal tilt angle, literature review

Many studies have been conducted regarding the determination of the optimal tilt angle of solar panels, for instance Ali [8] determined the optimal slope angle of photovoltaic panels in some cities of Iraq, using the BMS model. In addition, he used some statistical methods to validate the BMS model. He found that the linear and quadratic equations as a function of the solar declination had a maximum R-square value. Slama [13] analyzed the incidental solar radiation according to the solar collector slope, in Tunis. He emphasized that the tilt angle of collector is not equal to the latitude, but it depends on the season. Indeed, if one wants to privilege use solar energy in winter the optimal tilt angle is higher the latitude of the place or if one wants to privilege use solar energy in summer the optimal tilt angle is smaller than latitude of the place. Moltames and Mohammad [14] estimated the optimal tilt angle of solar panels in Iran, used the maximum energy based model. The calculations are made for 4 scenarios. Clearness index is used as input data. According to his study, the optimal tilt angle is 4-8 degree lower than latitude of the city and the monthly tilt angle is the best scenario. Karafil et al [15] calculated the optimum tilt angle in Bilecik, Turkey, based on a mathematical model using some basic equations based on geometry of sun path on the sky and solar panels. According to the study, there is a difference in calculated optimum tilt angle of PV panels and experimental value, this difference is caused by some environmental factors such as temperature, dust and dirt. Abood [16] determined the optimal tilt angle in Bagdad (L=30^o) city, using a MATLAB simulation code. In his study, he showed that the optimal tilt angle for Bagdad city is 33^o. Zang et al [12] determined the optimal tilt angle of solar collectors for different climates in China. According to the study, the yearly average optimal tilt angle is equal to the latitude of the site. In addition, to confirm the models the used some statistical indicators (MABE, RMSE, R). The result of statistical analysis indicates linear and quadratic equations that depend on solar declination.

The literature survey presented above reveals that BMS model is used mainly to determine the yearly optimal tilt angle of solar panels. The main contribution of this study, in addition to determining of yearly optimal tilt angle, is also determined the seasonally tilt angle of solar panels for our cities of study, and the comparison between the yearly optimal tilt angle and seasonally tilt angle of solar panels in terms of energy received on panel surface.

The main objective of the present study is to determine the optimal tilt angle of solar panels in three cities in Albania based on maximizing of global solar radiation reaching the solar panel surface on yearly and seasonally basis. In this context, a comparison was made between the fixed and adjustable tilt angle of solar panels in terms of solar energy received on the surface panels.

The structure of the article is as follows: The introduction is outlined in Section 1 describing also the importance of determination of optimal tilt angle of solar panels. Methodology and computational model is handled in Section 2. It describes the mathematical model used to determine the fixed optimal tilt angle and seasonally tilt angle of solar panels in detail. The results and discussion is given in Section 3. There, the main findings and a comparison between mathematical model used and data measured are clarified. Last section gives Conclusions and summarizes the main findings and gives recommendation for the best way to choose the solar panels installation.

2. METHODOLOGY AND COMPUTATIONAL MODEL

To assess the solar energy received on a tilted surface, we have used the BMS model, the mathematics of the model is given in Eqs. 1–11.

Applying the BMS model is as follows:

First, choose the city (latitude of the place φ), calculate the height of the sun at true midday with Eq. 2, calculate the angle of incidence at solar noon with Eq. 3, calculate all the components of solar radiation with Eqs. 4-8, calculate the duration of the day with Eqs. 9-10, and finally calculate the energy received on an inclined surface with Eq. 11. The procedure is applied for three locations in our study. While the tilt angle of solar panels β varies from -90^o to 90^o, the tilt angle varies from 0 (horizontal) to 90^o [17, 16]. The hour angle ω is zero at solar noon, negative in the morning, positive afternoon, the angle ω changes 15^o per hour [18] [19].

The solar declination angle is given by:

$$\delta = \frac{23.45\,\pi}{180} sin\left(\frac{2\pi(284 + n)}{365}\right) \tag{1}$$

Here, *n* stands for the days of the year, *n* =1 for 1st January [5].

The height of the sun at true midday is given by,

$$\alpha_s = 90 - \varphi + \delta(t) \tag{2}$$

Characteristic declinations is used in our calculations. Here, the declinations on which the extraterrestrial irradiation is identical to its monthly average value. The characteristic declination is given in Table 1. In Eq. 12, the characteristic declination is used to determine the optimal tilt angle of the solar collector for each month of the year.

Table 1 Characteristic declination [18].

Month	Date	δ (degrees)	Day number
January	17	-20.84	17
February	14	-13.32	45
March	15	-2.40	74
April	15	+9.46	105
May	15	+18.78	135
June	10	+23.04	161
July	18	+21.11	199
August	18	+13.28	230
September	18	+1.97	261
October	19	-9.84	292
November	18	-19.02	322
December	13	-23.12	347

The angle θ at solar noon is given by,

$$\theta = 90 - (\beta + \alpha_s) \tag{3}$$

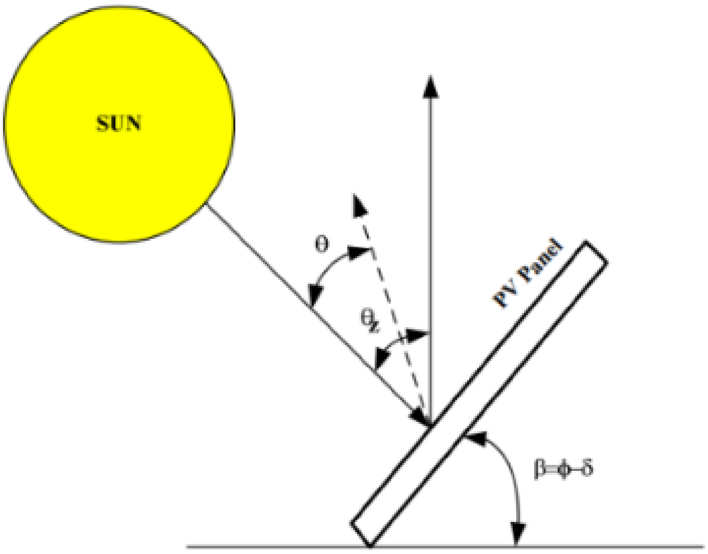

Figure 1. The incidence and tilt angels.

In solar energy applications, it is necessary to evaluate all components direct radiation, diffuse radiation, and ground reflected of solar radiation surviving the atmosphere and reaching the earth's surface [20] [21] [22]. In this study, the components are determined according to BMS Model given by Eqs. (4 – 8).

The direct solar radiation under of clear sky condition is given as,

$$I_D = 1230e^{\left(\frac{-1}{3.8sin(\alpha_s+1.6)}\right)} \tag{4}$$

The sky-diffused radiation received on the horizontal plane in clear sky condition is,

$$D_H = 125(sin(\alpha_s))^{0.4} \tag{5}$$

The overall radiation falling in a horizontal plane is stated as,

$$G_H = D_H + I_D\, sin(\alpha_s) \tag{6}$$

The diffuse and overall radiations in the tilted solar collector plane are,

$$D_i = \frac{1+cos(\beta)}{2}D_H + \frac{1-cos(\beta)}{2}G_H\alpha \tag{7}$$

$$G_i = I_D\, cos(\theta) + D_i \tag{8}$$

α is the albedo coefficient of the surface usually takes 0.2. The duration of the day,

$$\Delta T = \frac{2}{15}arccosh(-tan(\varphi)\, tan(\delta)) \tag{9}$$

Here, φ is latitude of the location. For period between March, 21st and September 23rd, the duration of the day is given by,

$$\Delta T' = 12 + \frac{\Delta T - 12}{7} \tag{10}$$

The energy received is given by Ref. [13],

$$E = \frac{2}{\pi}\, G_i \Delta T \tag{11}$$

3. RESULTS AND DISCUSION

3.1 The Evaluation of the Ideal Tilt Angle of the Solar Panels

For most systems in solar energy, knowing the variations of optimal tilt angle of the solar panels is of a particular importance. The optimal tilt angle varies daily, monthly, seasonally, so it is very important to take into account monthly or seasonally panel tilt adjustment. Another angle to consider is the surface azimuth angle, or the angle of the solar panels facing the equator, in our case this angle is set to be 180^o.

As a rule of thumb, the angle of inclination of the solar panels is the difference between the latitude of the location and the characteristics solar declination, in absolute value.

$$\beta = |\varphi - \delta| \tag{12}$$

Fig. 2 shows monthly variations of optimal tilt angle of solar panels for our cities of studies. For Tirana, monthly optimal tilt angle varies between 18° to 64°. In addition, the calculations demonstrate that in Kukes and Vlora cities, the monthly optimal tilt angle of solar panels varies between 19° to 65° and 17° to 63° respectively. Based on BMS model, the optimal tilt angles of the solar panels for three different cities are calculated. The determination of the optimum tilt angle is made by considering the fact that the solar energy reaching the solar panels has its maximum value. From the BMS model the yearly optimal tilt angle of the solar panels for the cities of Tirana, Kukes and Vlora are respectively 38°, 39° and 37°. It should be noted that, the yearly optimum tilt angle of solar panels based on the above mathematical model is almost equal to the latitude of the location. The adjusted tilt angle of solar panels is calculated according to the zones in Fig. 2. Zone 1 ranges from 48° to 64° , which corresponds the months of October, November, December, January, February. Zone 2 ranges from 30° to 48° which corresponds the months March, April and September, and Zone 3 from 18° to 30° which corresponds the months May, June, July, August. We suggest changing the tilt angle of the solar panels according to zones in Fig. 2.

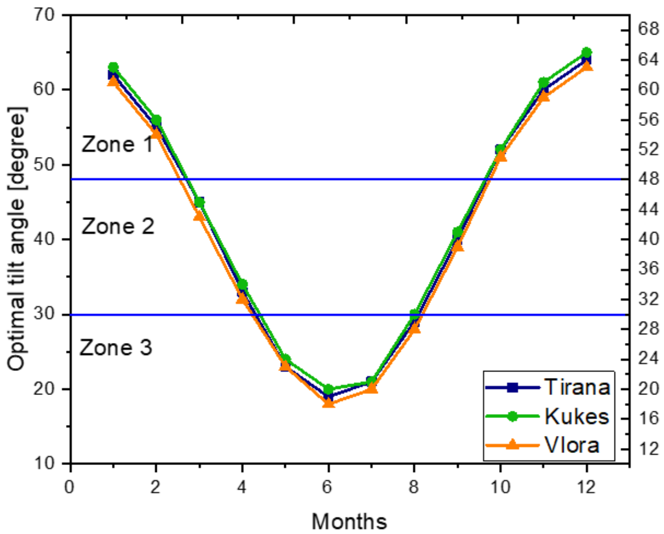

Figure 2. Monthly variations of tilt angle of the solar collector, for three cities

3.2 Energy Received on the Tilted Solar Panels

The seasonally or adjusted optimum tilt angles for cities are calculated by using the zones in Fig. 2. Fig. 3 shows the variations of the energy received on solar panels for different tilt angle for months in zones 1. It seems that the optimal tilt angle for these months is in average 55°. Fig. 4 shows the variations of the energy received on solar panels for different tilt angle for months in zones 2. It seems that the optimal tilt angle for these months is in average 36°. Fig. 5 shows the variations of the energy received on solar panels for different tilt angle for months in zones 3. It seems that the optimal tilt angle for these months is in average 23°. Fig. 6 shows the energy received on solar panels for different tilt angels for 12 months of the year for Kukes. It is seen that the optimal tilt angle for months in zones 1 is in average 56° in zones 2 is in average 34° and in zones 3 is 25°. Fig. 7 shows the energy received on solar panels for different tilt angels for 12 months of the year for Vlora. It is obvious that the optimal tilt angle for months in zones 1 is in average 54° in zones 2 is in average 32° and in zones 3 is 22°.

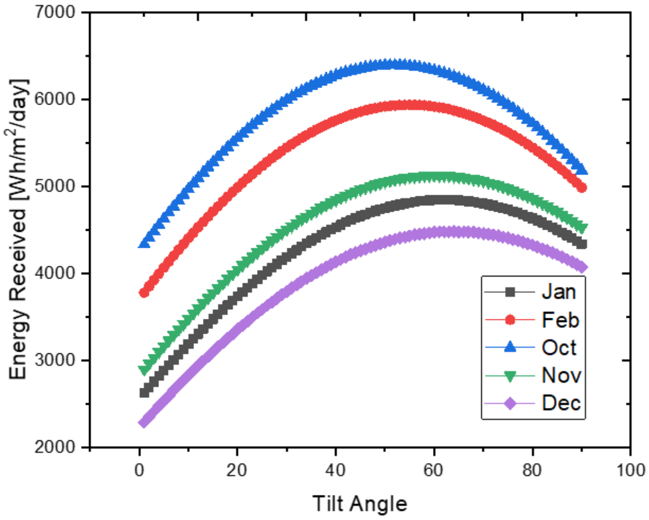

Figure 3. Optimal tilt angle zone 1 for Tirana.

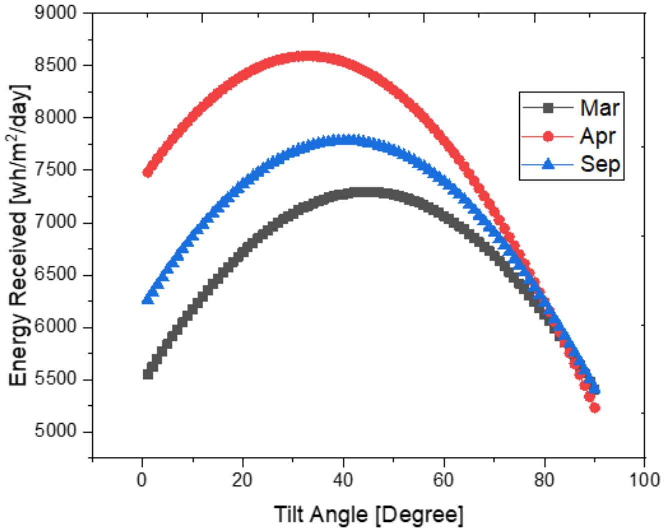

Figure 4. Optimal tilt angle zone 2 for Tirana.

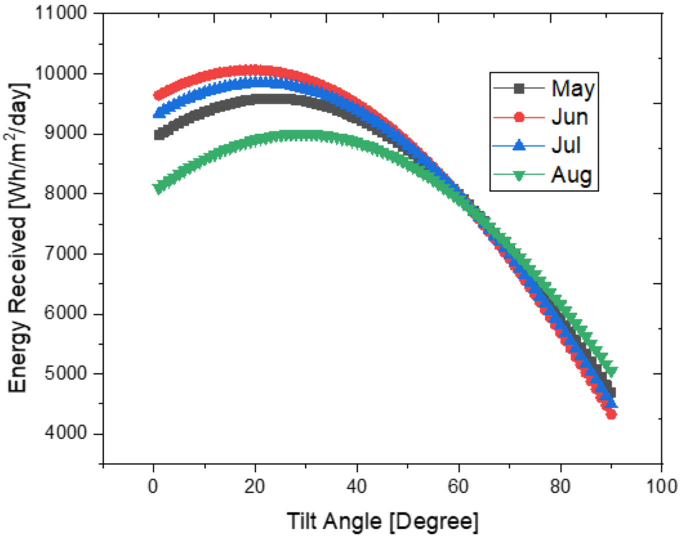

Figure 5. Optimal tilt angle zone 3 for Tirana.

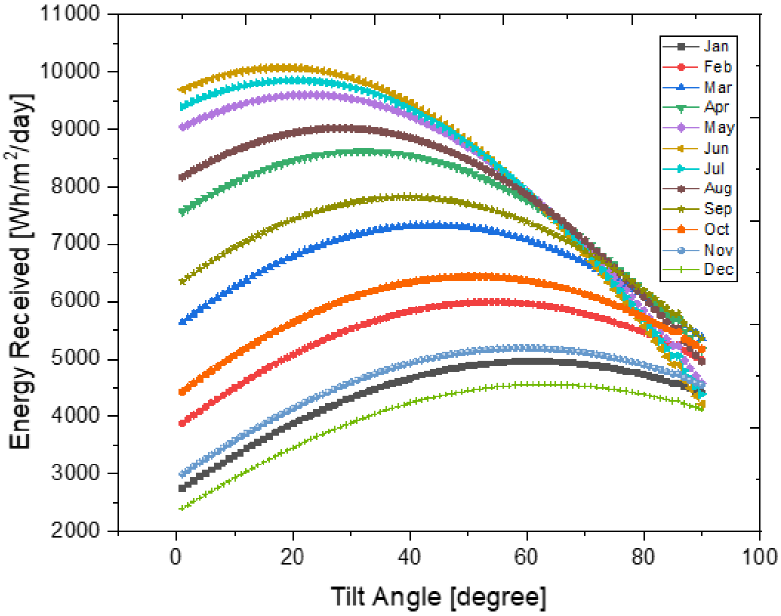

Figure 6. The variations of tilt angle solar panels over the year in Kukes.

We have calculated the energy received on the solar collector for the yearly optimal tilt angle, in addition, it is calculated the energy received on solar panel in adjusted tilt angle according to the equations given in Table 2. The calculations are made for three cities of study. Figs. 8, 9 and 10 show the energy received per square meter per day for fixed optimum tilt angle and seasonally adjusted tilt angle of the solar panels in Kukes, Vlora and Tirana, respectively. From Figs. 8, 9 and 10, it is clear that for almost all months, the energy received per square meter for seasonally adjusted tilt angle of solar panels is higher than the energy received per square meter for optimal tilt angle of solar panels. Table 2 shows the adjusted tilt angle equations according to the zones in Fig. 2. These equations are used to calculate the energy received in solar panels in our study cities. Table 3 shows the regression coefficient for linear equations between the optimal tilt angle of solar panels and the latitude of the site. To validate the BMS model, used in calculation of optimal tilt angle yearly and seasonally, a regression analysis between the optimal tilt angle and the latitude of the site is made. The high value of the *R*-square coefficient, shows a good correlation between the optimal tilt angle of the solar panels and the latitude of the site.

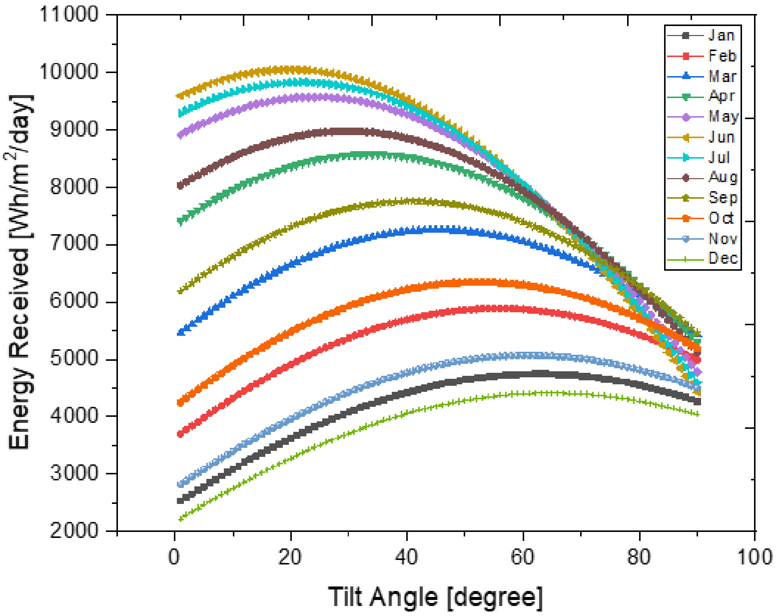

Figure 7. The variations of tilt angle of solar panels over the year in Vlora.

Table 2. Adjusted optimal tilt angle equations.

City	Zone 1	Zone 2	Zone 3
Tirana	$\beta_{opt} = \varphi + 17$	$\beta_{opt} = \varphi - 2$	$\beta_{opt} = \varphi - 19$
Kukes	$\beta_{opt} = \varphi + 17$	$\beta_{opt} = \varphi + 2$	$\beta_{opt} = \varphi - 18$
Vlora	$\beta_{opt} = \varphi + 17$	$\beta_{opt} = \varphi - 2$	$\beta_{opt} = \varphi - 18$

Table 3. Regression coefficient for linear equations.

City	a	b	R -Square	Regression equation
Tirana	41.843	-0.977	0.999	$\beta_{opt} = 41.843 - 0.977 \times \delta$
Kukes	42.593	-0.980	0.999	$\beta_{opt} = 42.593 - 0.980 \times \delta$
Vlora	40.852	-0.971	0.999	$\beta_{opt} = 40.852 - 0.971 \times \delta$

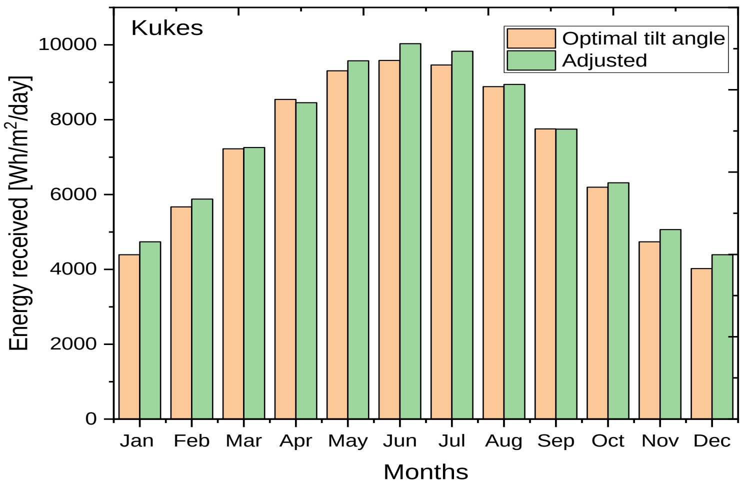

Figure 8. The energy received in Kukes city for optimum tilt angles and adjusted tilt angle

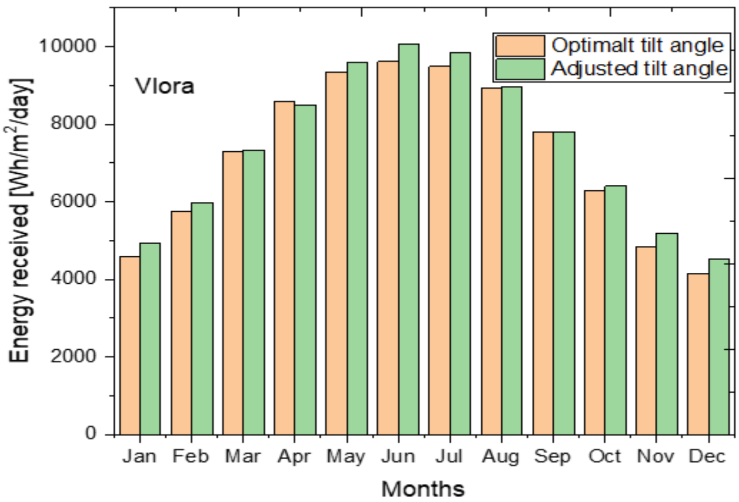

Figure 9. The energy received in Vlora for optimum tilt angles and adjusted tilt angle.

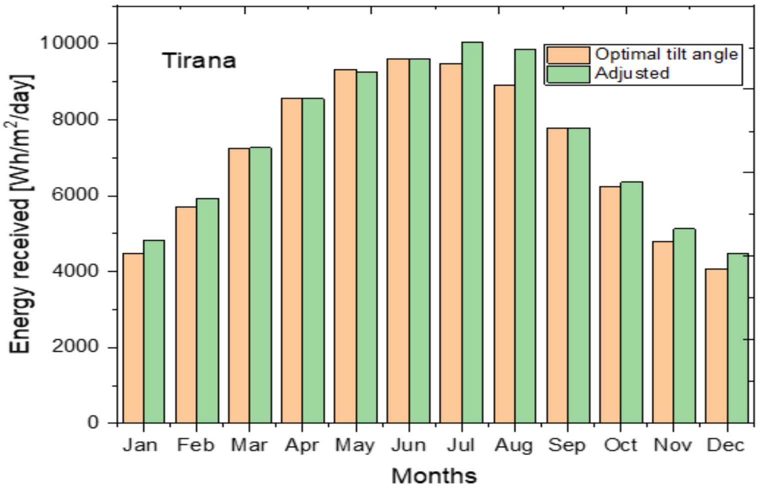

Figure 10. The energy received in Tirana for optimum tilt angles and adjusted tilt angle.

From the calculations, the energy received yearly per square meter on a horizontal surface for cities is 70501.73 [kWh/ day m^2] year for Tirana, 69604.7 [kWh/day m^2] for Kukes, and 71501.6 [kWh/m^2] for Vlora. The energy received per square meter in fixed optimum tilt angle is 22.3 % more than energy received on a horizontal surface and 4.0 % less than energy received per square meter for seasonally adjusted tilt angle of the solar panels for Tirana. The energy received per square meter in fixed optimum tilt angle is 23.2 % more than energy received on a horizontal surface and 3.6 % less than energy received per square meter yearly for seasonally adjusted tilt angle of the solar panels for Kukes. The energy received per square meter in fixed optimum tilt angle is 21.2% more than energy received on a horizontal surface and 3.5 % less than energy received per square meter yearly for seasonally adjusted tilt angle of the collector for Vlora.

3.3 Comparison Data Measured and BMS Model

The solar energy per unit area per day was measured in Tirana by using the meteorological station Davis instrument, situated at high 20 m above the ground on the upper building near to the FEM&EP (Faculty of Engineering Mathematics and Engineering Physics). The data was analyzed for a one-year period. The Davis instrument measure the solar radiation reaching in a horizontal surface. From the measured data, the solar energy for yearly optimal tilt angle of solar panels was calculated for Tirana by following the BMS model. Fig. 11 shows the comparison between data measured from the meteorological station and the BMS model. From Fig. 11, the biggest relative difference between measured data and the BMS model is obtained during months from May-August 16.6 % to 21.5 %, while in other months the difference lies between 9-13% [13].

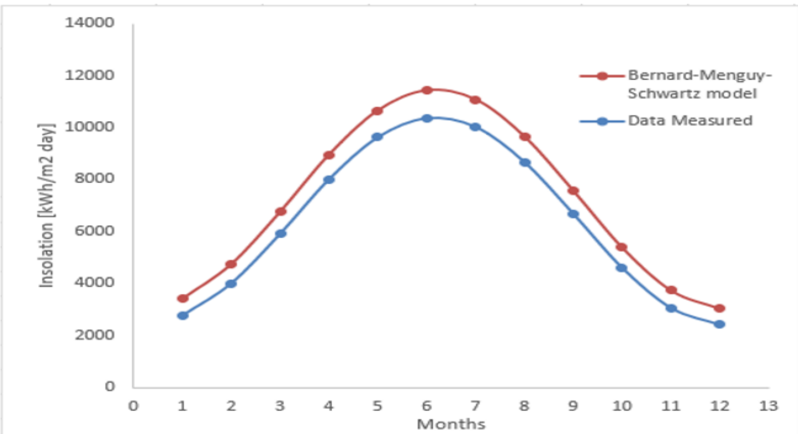

Figure 11. The comparison between data measured and Bernard-Menguy-Schwartz model.

The energy received yearly per square meter for three configurations of solar panels, (horizontal, yearly optimal tilt angle and adjusted tilt angle) are shown in Table 3.

Table 3. Comparison of energy received in solar panels for horizontal surface, optimal tilt angle and adjusted tilt angle.

City	Energy [kWh/m^2] (received yearly per square meter on a horizontal surface)	Energy [kWh/m^2] (received yearly per square meter yearly optimal tilt angle)	Energy [kWh/m^2] (received yearly per square meter adjusted tilt angle)
Tirana	70501.73	86223.61	89043.68
Kukes	69604.7	85752.99	88258.75
Vlora	71501.6	86659.93	89162.49

4. CONCLUSION

The yearly and adjusted optimal tilt angles for three cities in Albania is determined by using BMS model. The tilt optimum angle of the solar panels for the cities Tirana, Kukes and Vlora are 38^o, 39^o and 37^o, respectively. The calculations of optimal tilt angle are made for two scenarios: The annual fixed tilt angle of the solar panels and seasonally adjustable tilt angle according to Fig. 2.

For summer months (zone 3), the optimum tilt angle is found to be $\beta_{opt} = \varphi - 19$; $\beta_{opt} = \varphi - 18$ and $\beta_{opt} = \varphi - 18$, respectively in Tirana, Kukes and Vlora; for winter months (zone 1) the optimum tilt angle is found to be $\beta_{opt} = \varphi + 17$ in three cities; and for spring and autumn months (zone 2) is $\beta_{opt} = \varphi - 2$, $\beta_{opt} = \varphi + 2$, $\beta_{opt} = \varphi - 2$ in Tirana, Kukes and Vlora, respectively. To increase the harness of solar radiation, the optimum tilt angle of solar panels should be adjusted seasonally, but that has additional cost to operate. The regression analysis shows a very high value of *R*-square coefficient, which indicates a good relationship between evaluated optimal tilt angle and the latitude of the site.

The comparison between data measured and the BMS model show that the biggest relative difference of measured data with the model is during months from May-August 16.6 % to 21.5 %, while in other months this deviation lies between 9-13 %.

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