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TE-RE-RD 2014

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CONFERENCE PROFRAMME

Thursday, June 12	Friday, June 13	Saturday, June 14
	Breakfast	Breakfast
14.00-15.00 Registration of participants	08.30-09.30 Registration of participants	09.00-13.00 Visit to Ancient City of Histria
15.00-15.30 Opening ceremony	09.30-11.00 Oral presentations "Sections 1 and 2"	13.00- Participants departure
15.30-18.00 Plenary session	11.00-11.30 Coffee break	
18.00-20.00 Welcome cocktail	11.30-13.00 Oral presentations Section 1 and 2"	
	13.00-14.30 Lunch	
	14.30-16.00 Oral presentations "Sections 1 and 2	
	16.00-16.30 Coffee break	
	16.30-17.30 Workshop Efficiecy increase of the solid biomas combustion under hydrogen flow	
	19.30-22.00 Conference dinner	

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SECTION 2 : BYOTECHNICAL SYSTEMS, RENEWABLE ENERGY AND RURAL DEVELOPMENT

SECTION 3 :HYDRAULICS, PNEUMATICS, ELECTRONICS, MISCELLANEOUS

STUDY OF THE PV MODULES INCLINATION ANGLE ON THE ENERGY PRODUCTION

Angel Terziev[1], Veselka Kamburova[2], Iliya Iliev[3], Kiril Mavrov[4], Deyan Deltchev[5]

ABSTRACT

The energy produced by the PV panels depends generally on several parameters – local weather data (solar intensity, amount of impurities in the air (Linke Turbidity Factor), temperature, wind speed and etc.), type and orientation of the PV panel.

The impact of local data and type of the PV panels on the production of electricity was discussed and presented in the previous works [1], [2].

The aim of the current study is to show the impact of the inclination angle of the PV panels on the electricity production. Generally, depending on the type of mounting, the PV systems are divided into free-standing and building integrated. Concerning the tracking options the systems are classified into: fixed, tracking in vertical and inclined axes and 2 axis tracking. Here is presented a study on the electricity production for different systems and angle orientations. Mainly focuses on the fixed systems, fixed systems with a single change of the angle during different seasons, and 2 axis tracking systems. Simplified financial analysis based on the energy generated by the PV modules, investments for the implementation of the reviewed systems in respect with the angle change is presented.

1. INTRODUCTION

The photovoltaic modules use energy from the sun to produce electricity. At present the highest possible sunlight conversion rate is about 20% [3] which is typically lower than the efficiencies of the separate cells in isolation. The optimal absorption of the solar irradiation flux is guarantee for maximal energy production and higher profit.

In current paper is discussed the impact of the inclination angle of the PV panels on the energy production. In addition it is also presented the impact on the local atmospheric data (geographical location) on the energy production. The analysis includes 6 different sites evenly distributed on the territory of Bulgaria. For a couple of the sites the PV farms are in operation for more than one year providing additional information for the analysis. The simplified financial analysis was made based on the system investment costs and revenues generated.

2. LONG-TERM DATA ANALYSIS

Site specifics and long term data interpretation

The current study is focused on the energy production of the photovoltaic modules installed at different locations on the territory of Bulgaria (Figure 1) [4]. The selected six locations are close to the following populated areas: Ihtiman, Varna, Vidin, Dobritch, Dolna

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Lipnitza and Elhovo. Concerning the geographical location the spots are characterized with specific solar irradiation, air temperature, humidity, amount of impurities in the air (Linke turbidity factor) and etc.

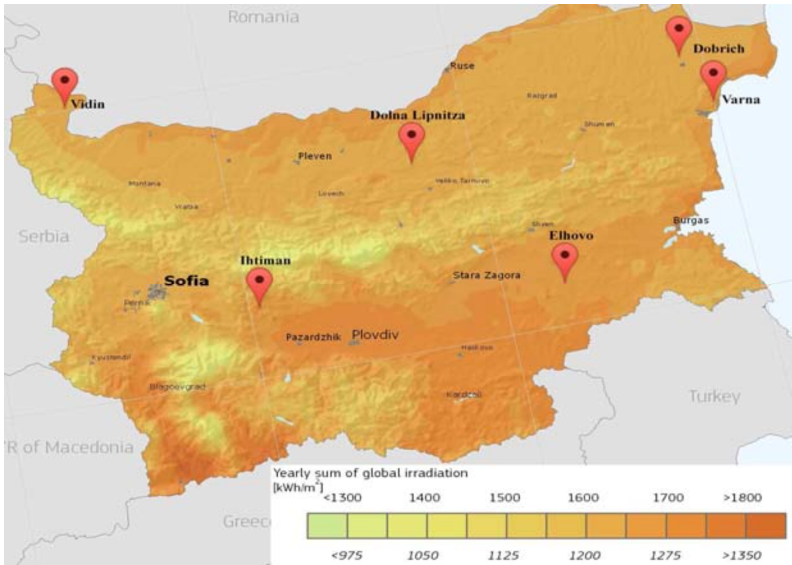

Figure 1: Location of the selected sites on the territory of Bulgaria

Figure 2 presents the yearly energy yield for the concerned six places at optimal inclination angle fixed for the entire year. The presented energy yield concerns the crystalline silicon PV panels. It is obvious that annually the specific solar energy yield varies between 60 and 145kWh/kWp. On monthly bases the highest difference in electricity production among the selected six place is observed during the winter period, and it is in the amount between 17 and 20%. During the rest of the year the discussed difference is between 6 and 8% among the places. Here it should be pointed that in about 80% of the annual energy production is between March and October. The places were selected because the PV farms are already installed. PV farm located close to the Dolna Lipnitsa village is in operation since December 2012. Hence the specific analysis made further in the paper refer to this location.

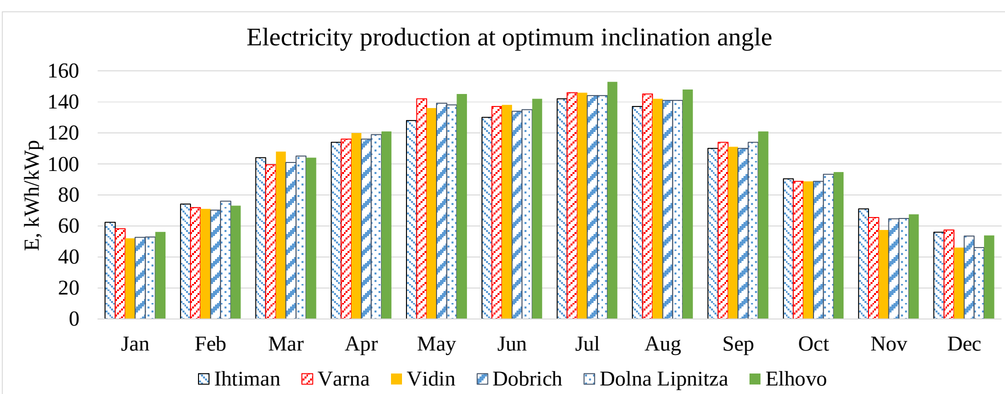

Figure 2: Specific energy yield for the selected locations

As discussed in [1] and [2] the energy yield of the specific location is mainly affected by the parameters of the atmospheric air – temperature, relative humidity and amount of impurities in the air (Linke turbidity factor). The yearly distribution of the air parameters are presented in the figures below.

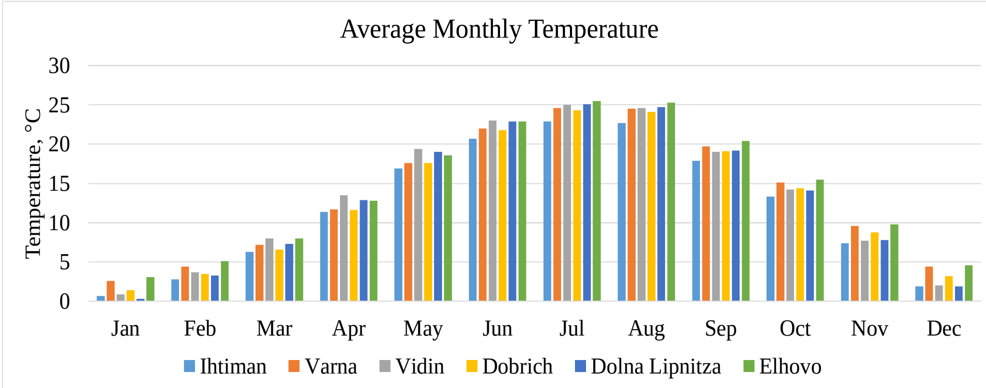

Figure 3: Annual temperature distribution for the selected locations

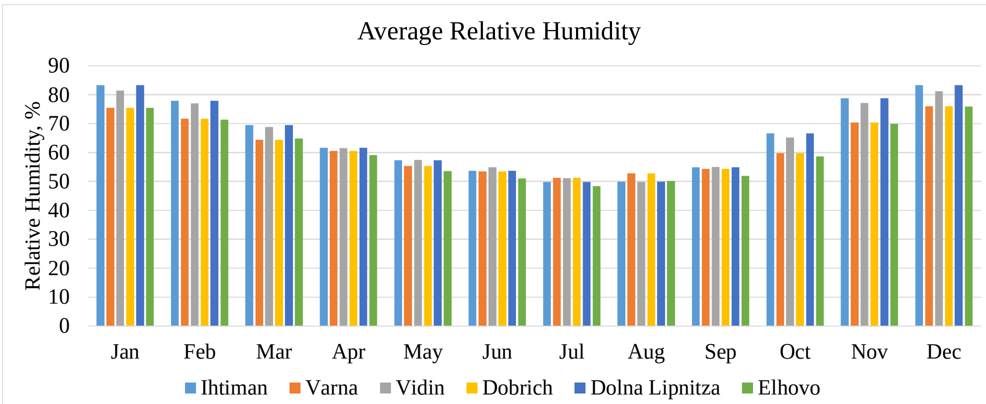

Figure 4: Annual relative distribution for the selected locations

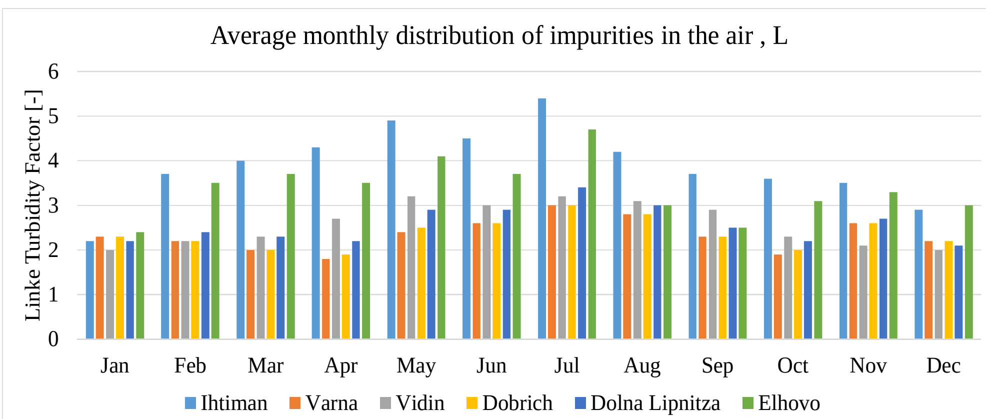

Figure 5: Annual Linke turbidity factor distribution for the selected places

As discussed in [1] and [2] the energy yield of the specific location is mainly affected by atmospheric air parameters.

Figure 3 shows that the average temperature distribution for the sites changes annually insignificantly. Greater difference in temperatures are visible during only the winter season. However, these differences are not significant and they will not have significant impact on energy production. Humidity distribution for the places is presented on figure 4. In relation with temperature the higher values of this parameter are observed during the winter period. Higher values of the relative humidity are observed for the sites close to Ihtiman, Vidin and Dolna Lipnitza.

On figure 5 is presented the degree of pollution of the air. Sites located close to Ihtiman and Elhovo are characterized with higher values of Linke turbidity factor all year long. The higher values affect the energy production from the PV panels [1], [2].

Analysis of the impact of the inclination angle on energy production

The proper selection of the panels' inclination angle is crucial for the energy production. On figure 6 is presented the specific energy production for the selected sites gained by the change of the angle of the panels.

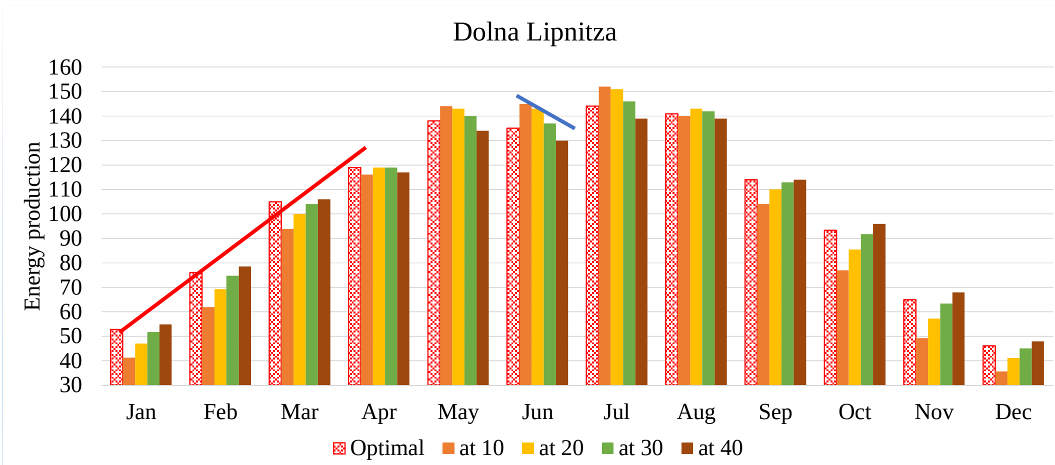

Figure 6: Average monthly energy production for the selected locations at different inclination angles

Figure 6 shows the energy output from the PV panel for a site located close to the Dolna Lipnitza village at different inclination angles. It is obvious that for the first 4 months of the year the energy output is maximum at optimal inclination angle recommended for the site. During next three months (May – July) the maximum energy output can be reached at small inclination angles (up to 20^{o}). For the August the output at different inclination angles remains the same. This is determined by the geographical location of the site (respectively horizon angle). For the rest of the year the maximum utilization of solar radiation can be expected at large inclination angles (optimal or larger).

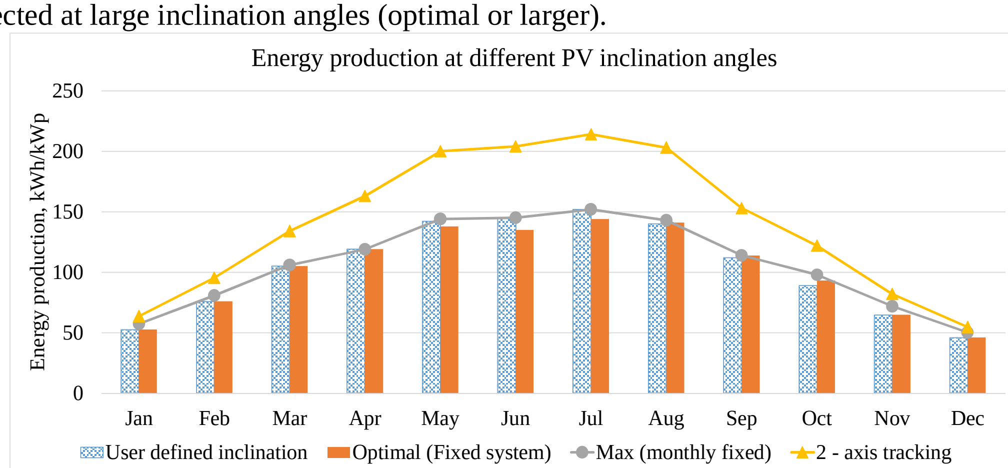

Figure 7: Estimated energy production at various systems (fixed and tracking)

Based on this on figure 7 is presented the energy yield for the location Dolna Lipnitza for different types of systems. The study shows that when a system is fixed over the year at optimal inclination angle the energy production is in the amount of 1228 kWh/kWp. Currently the inclination angle of modules of the PV farm changes four times per year (at 10, 25 and 35 degrees). The study shows that the energy production is in about 1243kWh/kWp or in about 2% higher than optimal angle. The third option is to adjust the optimal angle monthly. In this case the energy production is in the amount of 1281kWh/kWp (or 4.3% higher than the yearly fixed optimal inclination angle). When the system is equipped with 2 axis tracking system then the energy production is estimated to 1689kWh/kWp (or 37.5% higher than the fixed system at optimal inclination).

Regression analysis

The data for the selected sites were analyzed and the regression statistic were presented. The initial parameters for the regression model are the impurities in the surrounding air (Linke turbidity factor, X_1), air temperature (X_2), relative humidity of the air (X_3) and inclination angle (X_4). The resulting function Y is energy production presenting in accordance with the site specifics. Through the non-linear regression the following expression was obtained:

$$Y = a.X_1 + b.X_2 + c.X_3 + d.X_4, \quad (1)$$

where a, b, c and d are regression results (relevant for 99% Confidence interval) presented in the table below.

Table 1: Components of the generated biogas

Variable	Value	99% (+/-)	Lower Limit	Upper Limit
a	17.36393298	33.70409126	-16.34015827	51.06802424
b	-3.10877712	4.842039289	-7.950816409	1.733262169
c	-4.414273335	2.993990372	-7.408263707	-1.420282963
d	11.76658603	7.025533324	4.741052704	18.79211935

The regression shows maximum Error (%) in the amount of -10% for the data related with highest air relative humidity. The proportion of variance explained is 95.85%. The adjusted coefficient of multiple determination (Ra^2) is 0.945.

3. FINANCIAL ANALYSIS

Here is presented a simplified financial analysis for the abovementioned systems as a function of inclination angle. To assess the economic impact of different types of systems it is necessary to estimate the amount of the increased electricity production as a function of the increased investment and operational costs. The selected photovoltaic system in Dolna Lipnitza is with installed capacity of 1,184.4 kW and total investment costs of EUR 2,467,872. Annually the PV inclination angle of the system changes 4 times per year resulting in annual energy production in the amount of 1,457,252 kWh/per year. Accepting the current fixed purchase price of the electricity of 0.24828 EUR/kWh [5] and annual O&M costs of EUR 36,425 the resulting yearly income is about 325,386 EUR/yr. Taking into account that change of the inclination angle for the presented PV system is manually accomplished the investment and operational costs for the fixed systems and with manual inclination angle selection can be considered to be the same.

The two-axis tracking system requires significantly higher investment, as well as operational costs. Concerning [6] the average investment costs for the implementation of a two-axis tracking system is 40.54% more expensive than the fixed one. Also the operational costs are 41.09% higher. In table 2 is given summary of the economic indexes of the different types of systems, considering the different investments and operational costs.

Table 2: Financial analysis for different type of inclination angle management

	Fixed system at optimal inclination	User defined inclines	Maximal inclination	Two-axis tracking
Energy yield, kWh	1,441,306	1,457,253	1,502,044	1,980,330
Investment	2,467,872	2,467,872	2,467,872	3,468,236
Yearly incomes	357,852	361,812	372,933	491,683
O&M costs	36,425	36,425	36,425	51,391
Net yearly income	321,427	325,387	336,508	440,292
Simple payback	7.68	7.58	7.33	7.88
NPV (in 20 years)	€2,121,829	€2,178,364	€2,337,163	€2,818,747

After 20 years of operation under specific local conditions, despite of the higher initial investment and the highest simple payback period, a system with two-axis tracking has the higher NPV factor (at discount rate 3.45%), thus the two-axis tracking system is the most economically viable.

4. CONCLUSIONS

An analysis about the energy production of different types of PV systems (fixed and with changed of PV modules inclination angle) here is presented. For this purpose six different locations on the territory of Bulgaria were selected and analyzed. In order to be assessed the impact of the inclination angle the site specifics were carefully analyzed and considered in the regression model. Relation between inclination angle, site specifics and energy production were presented. Simplified financial analysis was provided about the profitability of the introduced PV systems.

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