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Research Paper / *Araştırma Makalesi*

Optimizing the Tilt Angle of Solar Panels to Reduce Carbon Footprint: Case for the West Mediterranean Region of Turkey

Karbon Ayak izini Azaltmak için Güneş Panellerinin Eğim Açısının Optimizasyonu: Türkiye'nin Batı Akdeniz Bölgesi Örneği

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ABSTRACT
Carbon footprint is a term used to express the lasting effect of human consumption activities on nature. A carbon footprint is often defined as CO_2 or equivalent greenhouse gas emitted as a result of an activity or process associated with a product, service or region. The carbon footprint account is one of the most interesting researches in recent years. In this study, the optimal choice of the tilt angle for the solar panels in order to collect the maximum solar irradiation is investigated in order to reduce the carbon footprint in West Mediterranean Region of Turkey.

Keywords: *Solar energy, Tilt angle, Carbon footprint, Turkey*

ÖZ
Karbon ayak izi, insan tüketimi faaliyetlerinin doğaya kalıcı etkisini ifade etmek için kullanılan bir terimdir. Bir karbon ayak izi genellikle bir ürün, hizmet veya bölge ile bağlantılı bir faaliyet veya işlem sonucunda yayılan CO_2 veya eşdeğer sera gazı olarak tanımlanır. Karbon ayak izi hesabı, son yıllarda en ilginç araştırmalardan biridir. Bu çalışmada, Türkiye'nin Batı Akdeniz Bölge-si'ndeki karbon ayak izini azaltmak amacıyla, maksimum güneş ışığını toplamak için güneş panelleri için eğim açısının en uygun seçimi incelenmiştir.

Anahtar Kelimeler: *Güneş enerjisi, Eğim Açısı, Karbon ayak izi, Türkiye*

INTRODUCTION

Due to the depletion of fossil fuel reserves and the corresponding climate change, development of sustainable and renewable energy resources has attracted enormous attention all around the world (Xu etal., 2017). Solar energy is one of the most important renewable energy resources that has huge potential and wide range of applications due to its clean and abundant nature (Sampaio and Gonzalez, 2017). Solar energy can be directly converted into electric power via PV panels, and the tilt angel of the PV panel has significant influence on the electric power output.

The optimal tilt angle depends on several conditions such as climate, utilization time, geographic latitude, atmospheric factors, etc. Various studies have been investigated the optimization of tilt angle to maximize the efficiency in PV generation (Kumar and Chandel, 2013; Bakirci, 2009; Bakirci, 2012; Garni et al., 2019). Tiris et al. (1996) calculated the correlations of the monthly average daily global, diffuse and beam radiations with hours of bright sunshine in Gebze, Turkey. Bakirci (2012) developed the correlations for estimation of daily global solar radiation with hours of bright sunshine in Turkey. Zuhairy and Sayigh (1995) carried out simulation and modeling of solar radiation in Saudi Arabia. Ulgen and Hepbasli (2003) investigated the diffuse fraction of daily and monthly global radiation for Izmir, Turkey. A simple mathematical procedure for the estimation of the optimal tilt angle of a collector is presented based on the monthly horizontal radiation (Tang and Tong, 2004).

Gunerhan and Hepbasli (2007) calculated the optimum tilt angles by searching for the values for which the total radiation on the collector surface is at a maximum for a particular day or a specific period. Mehleri et al. (2010) carried out a study on the determination of the optimum tilt angle and orientation for solar photovoltaic arrays in order to maximize the incident of solar irradiance exposed on the array, for a specific period of time. Despotovic and Nedic (2015) investigated the optimum tilt angle by searching for the values for which the solar radiation on the collector surface is maximum for a particular day or a specific period. In that manner the yearly, biannual, seasonal, monthly, fortnightly, and daily optimum tilt angles are determined. the Moghadam et al. (2011) performed optimization of solar flat collector inclination. Monthly, seasonal, semi-annual and annual optimum tilt angles were determined. Ghosh et al. (2010) determined the seasonal optimum tilt angles, solar radiations on variously oriented, single and double axis tracking surfaces at Dhaka. Three mathematical models for the point source with parameters optimized for a variety of climatic conditions were employed to determine hourly and seasonal optimum tilt angles.

Maatallah et al. (2011) presented an overview on research works on solar radiation basics and photovoltaic generation. The effects of azimuth and tilt angles on the output power of a photovoltaic module were investigated. Kaldellis and Zafirakis (2012) carried out an experimental study in the area of Athens in order to evaluate the performance of different PV panel tilt angles during the summer period. The angle of 15o (±2.5o) was designated as optimum for almost the entire summer period. Benghanem (2011) performed a study on the optimum slope and orientation of a surface receiving a maximum solar radiation. The annual optimum tilt angle was found to be approximately equal to the latitude of the location. Siraki and Pillay (2012) proposed a simple method on a modified sky model to calculate the optimum angle of installation for urban applications. It was expressed that the results demonstrated the dependency of the optimum angle of installation on the latitude, weather conditions and surroundings.

Lave and Kleissl (2011) calculated the optimum tilt and azimuth angles of solar panels for a grid of 0.1o by 0.1o National Solar Radiation Database cells covering the continental United States. The yearly global irradiation incident on a panel at this optimum orientation was compared to the solar radiation received by a flat horizontal panel and a 2-axis tracking panel. Lubitz (2011) investigated the effect of manual tilt adjustments on incident irradiance on fixed and tracking solar panels. The optimum tilt angle for an azimuth tracking panel was found to be on average 19o closer to the vertical than the optimum tilt angle for a fixed, south-facing panel at the same site.

Anthropogenic activities produce permanent impact on the environment. Carbon footprint is a way of expressing the magnitude of this effect. The carbon footprint has defined in various ways in literature. Carbon footprint is the total amount of human activity resulting directly or indirectly accumulated carbon dioxide emissions generated during the life cycle of a product (Wiedman and Minx, 2008).

Carbon footprint which is the largest component of the ecological footprint measures the impact human activities have on the environment in terms of the amount of greenhouse gases produced, measured in units of carbon dioxide, and therefore can determine the unique global warming impact of a person, product or service (World Wildlife Fund, 2018).

Table 1 presents the carbon footprint from different components. Primary footprint, domestic energy consumption and transportation, including fossil fuel combustion directly produce CO_2 emissions and the whole lifecycle of products we use the trail secondary feet (manufacturing of products, and ultimately distortion) are a measure of the relevant indirect CO_2 emissions.

Table 1. Carbon Footprint Classification (Kitzes, et al., 2007; 2008; Jones and Kammen, 2011)

Parameters	Primary Carbon Footprint	Secondary Carbon Footprint
Transportation	- Fuel	- Public transport - Air transport - Car
Housing	- Natural gas	- Electric - Water and waste - Warming
Food		- Grain - Vegetables - Fruit - Meat
Product		- Clothing - Household products - Personal care
Service		- Health - Entertainment - Education

The carbon footprint is divided into specific categories to facilitate the tracking of individuals and sustainability of resource use. However, these categories are building awareness about the need to take more responsibility for what component of individuals. In addition, individuals in this category are evaluated under the framework of CO_2 emission standards with the personal and social status of the Kyoto protocol, the chances of finding comparisons with other countries and they have the opportunity to create local solutions (Mattila et al., 2011).

2. THEORETICAL ANALYSIS

The monthly average values of solar radiation incident on surfaces of various orientations are required for solar energy applications. The monthly averages of the daily solar radiation incident upon a horizontal surface are available for many locations. However, radiation data on tilted surfaces are generally not available. A simple method to estimate the average daily radiation for each calendar month on surfaces facing directly towards the equator has been developed by Liu and Jordan (Beckman Duffie, 1980).

The earth's axis is tilted approximately 23.45° with respect to the earth's orbit around the sun. As the earth moves around the sun, the axis is fixed if viewed from space. The declination of the sun is the angle between a plane perpendicular to a line between the earth and the sun and the earth's axis. An approximate formula for the declination of the sun is given as follows (Liu and Jordan, 1962):

$$\delta = 23.45 \sin\left[(284+n)\frac{360}{365}\right] \tag{1}$$

where n is the number of the day of year starting from the first of January (n=1 on January 1st and n=365 on December 31st, February 29th is ignored).

Sunrise and sunset occur when the sun is at the horizon and hence the cosine of the zenith angle is zero. Setting the cosine of the zenith angle to zero in the relation, we get the following equation,

$$\omega = \cos^{-1}(-\tan\phi \tan\delta) \tag{2}$$

The monthly average daily radiation on a horizontal surface (H), the fraction of the mean daily extraterrestrial radiation (H0), the monthly average daily diffuse radiation (HD),

$$H_0 = \frac{24}{\pi} G_{sc} (1 + 0.033 \cos(\frac{360n}{365}))(\cos\phi \cos\delta \sin\omega + \frac{\pi\omega}{180} \sin\phi \sin\delta) \tag{3}$$

where G_{sc} is the solar constant (1367 W/m^2), is the latitude of the Antalya.

Solar radiation incident outside the earth's atmosphere is called extraterrestrial radiation. On average the extraterrestrial irradiance is 1367 W/m^2. The monthly average daily solar radiation on tilted surface (HT), may be expressed as follow (Liu and Jordan, 1962),

$$H_T = (H - H_D) R_b + \frac{H_D}{2}(1 + \cos\beta) + \frac{H\rho}{2}(1 - \cos\beta) \tag{4}$$

where ρ is ground reflectance (≈0.2).

3. METHODOLOGY

The equations which calculate total solar radiation falling on tilted surface for optimum tilt angle the monthly and the annually are solved with a computer code which is written in Visual Studio 2012 and should be modular to allow users to update component modules easily as new findings become available. The calculations begin with measured hourly global and diffuse radiation received on a horizontal surface. These quantities are then transposed onto an inclined plane by a mathematical procedure. The optimum tilt angle was computed by searching for the values for which the total radiation on the collector surface is a maximum for a particular day or a specific period. In this regard, the calculations were made for a south facing solar collector for 365 days. The tilt angle is changed from 0° to 90°. The solar reflectivity (ρ) was assumed to be 0.2.

4. RESULTS AND DISCUSSION

In this study, determination of the optimal tilt angle for the Western Mediterranean regions, and assessment of the carbon footprint were examined. For 3 different provinces, monthly, seasonal, semi-annually and annually changes of tilt angles and generated solar radiation values are calculated. If you look at the variation of the monthly tilt angle and the amount of solar energy obtained: the tilt angle varies between 1-66 degrees and the obtained solar radiation varies between 503-721 MJ.

When Table 2 is examined in detail: The lowest tilt angle value for Antalya is in June and July, and at the same time the highest solar radiation is this time interval in values. This situation is the same for the other two provinces. This situation is the same in the Isparta and Burdur but it has more solar radiation than the Antalya.

Table 2. Solar radiation and tilt angle for monthly

Months	Antalya		Burdur		Isparta	
	Radiation	Tilt Angle	Radiation	Tilt Angle	Radiation	Tilt Angle
January	529,11	63	540,15	64	540,24	64
February	503,55	54	515,16	55	515,36	55
March	589,77	39	604,33	40	604,66	40
April	614,37	21	630,32	22	630,76	22
May	687,87	5	706,64	5	707,21	6
June	694,99	1	714,93	1	715,59	1
July	701,05	1	720,52	1	721,12	1
August	647,92	15	665,1	15	665,58	15
September	577,99	33	592,52	33	592,87	33
October	562,17	50	575,49	50	575,75	50
November	516,12	61	527,22	62	527,34	62
December	517,75	65	528,1	66	528,15	66

Table 3 and 4 shows that the lowest tilt angle for all three provinces is in summer and spring + summer. The highest solar radiation production is also in the summer and spring + summer. In terms of solar radiation and tilt angle, all three provinces have very close values. The reason for this is the high solar radiation values in summer and the western Mediterranean region is closer to the equator.

Table 3. Solar radiation and tilt angle for seasonally

Seasons	Antalya		Burdur		Isparta	
	Radiation	Tilt Angle	Radiation	Tilt Angle	Radiation	Tilt Angle
Spring	1850,26	22	1898,32	23	1899,62	23
Summer	2032,59	4	2088,23	5	2089,94	5
Autumn	1628,34	48	1666,67	48	1667,37	48
Winter	1545,88	61	1578,79	62	1579,13	62

Solar panels can be kept constant in summer, but there is a high change in tilt angle in winter and autumn compared to summer months. Therefore, in order to reduce carbon footprint by keeping energy production at maximum level, solar panels should be changed according to tilt angle.

Table 4. Solar radiation and tilt angle for semi-annually

Semi-annually	Antalya		Burdur		Isparta	
	Radiation	Tilt Angle	Radiation	Tilt Angle	Radiation	Tilt Angle
Spring + Summer	3850,34	13	3953,14	14	3956,11	14
Autumn + Winter	3156,27	54	3227,19	55	3228,24	55

6.CONLUSION

Energy needs are increasing and renewable energy sources are being used to reduce this need without harming the environment. From this point, in this study, the optimum tilt angle was calculated for three provinces in the western Mediterranean region. The maximum amount of energy that can be produced depends on the variation of tilt angles. The average tilt angle in all three provinces ranges from 33 to 34 degrees. According to Table 5, the solar radiation of Isparta and Burdur is very close to each other, whereas Antalya is slightly less than other ones.

Table 5. Solar radiation and tilt angle for annually

Annually	Antalya		Burdur		Isparta	
	Radiation	Tilt Angle	Radiation	Tilt Angle	Radiation	Tilt Angle
Year	6662,16	33	6827,48	34	6831,27	34

The production of solar energy is very important in terms of reducing carbon footprint. The solar radiation values in the western Mediterranean region are very close to each other. the use of solar energy in this area will provide new and clean energy by reducing the amount of energy obtained from fossil fuels. To leave a clean and sustainable world for future generations, we must focus on renewable energy sources by reducing our carbon footprint.

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