Exergy Analysis of Solar Radiation Based on Long Term for Van City

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ABSTRACT

The present study has analyzed the solar radiation exergy for the period of 1993 to 2007 in Van (38.28ºN, 43.20ºE). In this regard, various models have been applied for determination of solar radiation exergy. The exergy efficiency of solar radiation taken from meteorological data is evaluated based on these models for Van. According to results, the highest long term monthly average solar radiation exergy values is observed in June with 26.85 MJ/m^2 for Petela Model and same result also is observed for Spanner model but Jeter's approach is different from these models approximately %1.7. The ratio of solar radiation exergy to the long term monthly average solar radiation energy values varies from 0.934 to 0.939 both Spanner and Petela approach, and from 0.950 to 0.954 for Jeter's approach. The highest annual value exergy of the solar radiation is observed for the year of 2000 with 19.68 MJ/m^2 and the lowest annual value exergy of the solar radiation is found for the year of 1993 with 16.50 MJ/m^2.

Keywords: Solar radiation, solar exergy, renewable energy, energy utilization.

Van İli için Uzun Dönemli Güneş Radyasyonunun Exerji Analizi

ÖZ

Bu çalışma 1993 ve 2007 yılları arasındaki Van ilinin ((38.28ºN, 43.20ºE) güneş radyasyonun exerjisini analiz etmektedir. Bu bağlamda çeşitli modeller güneş radyasyonun exerjisini belirlemede kullanıldı. Van için güneş radyasyonunun exerji verimi, çeşitli modellerin meteorolojiden alınan verilere uygulanmasıyla değerlendirildi. Sonuçlara göre; en yüksek uzun dönem aylık ortalama güneş radyasyonu exerji değeri Haziran ayında 26.85 MJ/m^2 ile Petela modelinde gözlendi ve aynı sonuç Spanner modeli içinde gözlendi fakat Jeter'in yaklaşımı bu modellerden yaklaşık olarak %1.7 kadar farklıdır. Güneş radyasyon exerjisinin uzun dönem aylık ortalama güneş radyasyon enerjisine oranı 0.934'ten 0.939'a kadar hem Petela hem de Spanner modellerinde değişmektedir. Jeter modelinde ise bu değer 0.950'den 0.954'e kadar değişmektedir. En yüksek yıllık güneş radyasyon exerjisi 2000 yılında 19.68 MJ/m^2 olarak hesaplandı ve en düşük yıllık güneş radyasyon değeri ise 1993 yılında 16.50 MJ/m^2 olarak hesaplandı.

Anahtar Kelimeler: Güneş radyasyonu, güneş ekserjisi, yenilenebilir enerji, enerji kullanımı.

1. INTRODUCTION

Biomass, wind power, tidal power, hydro-electric power and solar energy are important renewable sources that are intended to replace of fossil fuels. Due to restricted energy sources, environmental concerns make that renewable energy technology can be good alternatives to fossil fuels [1]. Many administration have researched to enhance the portion of renewable energy in total energy sources, so many governments in Europe ensured an outline for improve such sources in this region[2]. The irreversibility does not consider in the first law of thermodynamics that is mainly deal with energy efficiency and represent the quantity of energy. The second law of thermodynamics deals with losses in the system so the quality of energy is important for this law [3]. The first law of thermodynamics is more suitable for energy equilibrium. Because energy equilibrium equations are mostly used for systems designs. But the second law of thermodynamics is more suitable if the performance of a system or its every component is to be investigated with regard to qualitative. Different solar energy systems are investigated based on exergy concept of solar energy implementation [4]. One of main conclusion of their study is that thermal efficiency is not adequate in order to select the requested system. So, the concept of exergy is essential for specific designs to succeed better performance of a system.

The exergy analysis broadly used for different applications that are performance assessment and design of systems has been strong apparatus. So, it is very important for analyses of energy systems. To reveal faults in the system or to investigate quantitatively of an energy system, the exergy analysis has to be evaluated [5].

Based on these literature reviews it can be say that calculation of exergy is very important for analyzing of solar assisted energy system.

The notion of exergy has emerged during the development of ordinary thermodynamics in the 19th

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century study that are taken by Thomson and Gibbs, Clapeyron, Carnot and Rankine. But this term was first used in 1953 by Rant [6]. The general rule of thermodynamic gives the upper limit of the any reversible thermodynamic system. This upper limit is generally called as the Carnot efficiency. Besides this, the law indicates that how always realizes the irreversibility in the real system.

This situation of system gives a reference for determining of a case function named exergy [7]. Exergy can be defined as the maximum amount of useful work that can be obtained theoretically if the system provides balance with environment [8]. Exergy is also described by [9] as the maximum work obtained when a system come thermodynamic equilibrium states from beginning state after various reversible process.

In literature, it is observed that there is very limited paper on exergy analysis of solar radiation in a given location. Whereas, a lot of work has been done on the potential of solar radiation, and the exergy analysis was also performed in most of works on solar energy systems.

So, the solar radiation exergy has a significant effect on renewable energy system such as solar energy system when it is analyzed for the performance. Due to this importance of exergy, different researchers give more efforts to prediction the solar radiation exergy on the world [10-14]. In literature, generally three methods are considered for calculating the exergy of solar radiation. These methods are called with researchers names that are Petela [15], Jeter [16] and Spanner [17]. Petela model is widely used model by many researchers [18-21]. Definition of solar radiation exergy is evaluated by Petela [22]. The solar radiation exergy also has been evaluated by Jeter and Spanner. Their models can be useful for evaluate the solar radiation exergy. The installation place of solar energy system has very important effect on efficiency of solar exergy due to decreasing of solar radiation by the environment. This effect should be considered when evaluating the capacity of different region, or when assessing various renewable energies in offered area [23]. It is observed from literature that the territorial solar radiation exergy values have been studied very limited. Recently, different methods are used to determine the solar radiation exergy.

Alta et al. [24] has mapped the spread of the monthly average solar radiation exergy from the satellite and they found amount of solar radiation exergy reaching to the Earth's surface depending on latitude, longitude and season.

The map of solar radiation exergy term is improved by Joshi et al. [25] and they accomplished a wide case work to illustrate how it would be useful for solar energy systems. However, to understand the accuracy of these methods, the researchers again compare the results of their studies with previous models such as Petela model. It observed that although several novel studies have been undertaken in the literature, most of studies are usually based on the three models that are Petela, Jeter and Spanner. One of the other regional studies is estimated by Öztürk et al. [26]. They examined the solar radiation exergy of the Southeast Anatolia region of Turkey. They found that the average value of solar radiation exergy and annual mean ratio of solar radiation exergy to solar radiation energy is 446.2 W/m^2 and 0.93 respectively. Hepbasli and Alsuhaibani [1] investigated the solar exergetic values based on different approach. This is one of the researches conducted recently on regional study of solar radiation exergy. They investigated difference between two regions that are northeastern of Saudi Arabia and İzmir, Turkey. Based on investigated models, they found that the ratio of solar radiation exergy to to solar radiation energy is 0.933 for Petela and Spanner approach. But, they found 0.950 in Jeter's approach. They also calculated these ratios for Izmir, Turkey, and they found that it is 0.935 and 0.951 for the same approaches, respectively.

Based on literature it is observed that solar radiation exergy should be known for application of solar energy systems that is depend of regional location. Therefore, a case work about solar radiation exergy is carried out based on meteorological data for Van, Turkey location. Van is located between the Latitude of 38.28^o N, Longitude 43.20^o E. Van province has one of locations with the longest yearly daily sunshine duration and is one of optimal location for improve of solar energy applications in Turkey. Van has high annual average solar radiation potential with 18.75MJ/m^2 and highest monthly mean value of solar radiation was measured in the month of June with 28.72MJ/m^2. Based on this data, it is decided that Van is an appropriate place for the improving of solar energy applications. According to literature this paper investigates three different approaches proposed by Patela, Spanner and Jeter for comparison of solar radiation data of Van, Turkey.

2. THE EXERGY OF SOLAR RADIATION

Heat transfer by radiation plays an important role for high temperature engineering applications. The main goal of any solar energy conversion model is to create an upper limit for converting the efficiency of solar energy to work. In literature survey, it is observed that most accepted models based on solar radiation exergy are the Petela, Spanner and Jeter models. Jeter's approach is relevant to the analysis of heat engine and the researcher described exergy of heat radiation with Carnot efficiency. The solar radiation exergy is also evaluated by Petela [15] who considered that it has accepted as thermal radiation at temperature of sun. According to the proposal of Spanner's, exergy of direct solar radiation is concerned with exact work instead of beneficial work. The exergy of black body radiation emission flux $Ex_{rad,b}$ using the laws of thermodynamics based on conservation equations is modeled by Petela [15]. This model is developed on a surface at the environment temperature To.

$$Ex_{rad,b} = \frac{ac}{12}(3T^4 + T_o^4 - 4T_oT^3) \quad (1)$$

The equation for gray surface with emissivity ε is also derived by Petela.

$$Ex_{rad,g} = \varepsilon \frac{ac}{12}(3T^4 + T_o^4 - 4T_oT^3) \quad (2)$$

where a is the universal constant (7.561x10^{-19} kJ/m^3 K^4), c is the light speed in vacuum, and T is the absolute temperature.

According to Petela, exergy efficiency of radiation can be defined as follow,

The energy emission for a surface of emissivity ε E_{rad} (kW/m^2) is:

$$E_{rad} = \varepsilon.\frac{ac}{4}.T^4 \quad (3)$$

where ε=1 for black surface.

The energy conversion efficiency η_e can be evaluated as the ratio of the work W to the energy E_{rad}:

$$\eta_e = \frac{W}{E_{rad}} \quad (4)$$

According to Petela, solar radiation exergy ψ is equal to maximal solar radiation efficiency. Researcher evaluated as ratio of the maximum solar radiation exergy to solar radiation energy:

$$\psi = \eta_{e\ max} = \frac{Ex_{rad}}{E_{rad}} \quad (5)$$

as result, Petela efficiency can written as follow;

$$\psi = 1 + \frac{1}{3}\left(\frac{T_0}{T_1}\right)^4 - \frac{4}{3}\left(\frac{T_0}{T_1}\right) \quad (6)$$

The same formula is also derived by Candau [27]. According to this researcher, the formula of efficiency is positive every time. İf T=T_0, efficiency goes to 0, if T < T_0 ,the efficiency can be bigger than 1.

A different equation is recommended also by Spanner for the maximum conversion efficiency. He introduced a maximum economic efficiency η_s and assumed that if the source is black-body radiation, the specific exergy fluxes are represented as:

$$\psi_s = 1 - \frac{4}{3}\frac{T_0}{T_s} \quad (7)$$

Jeter's work is the heat engine cycle work, the heat q is supplied to the engine at temperature T, and this heat is converted to the work W at the Carnot efficiency η, which is equal to the Jeter's conversion efficiency η_j:

$$\psi_j = \eta_{Cs} = \frac{T_s - T_0}{T_s} = 1 - \frac{T_0}{T_s} = \frac{W_j}{q_j} \quad (8)$$

3. RESULT AND DISCUSSION

The data used in the exergy analysis of solar radiation for Van province are based on the measured values obtained from in the Turkish State Meteorological Service (TSMS) which is the meteorological authority of Turkey and the data are taken for a fifteen year period from 1993 to 2007. For the definition of exergy, the yearly average values of the outdoor temperature are taken as reference temperature T_0. In this study, solar radiation exergy of VAN province is investigated based on three different approaches proposed by Petela, Spanner, and Jeter. These approaches are also used for comparison purposes.

Table 1 illustrates the variation of monthly average long term global solar radiation exergy efficiency and exergy values for a period of 15 year for Van. As can be seen in this table, the monthly highest and lowest temperatures are observed on July with 296.06(K) and January with 271.05 (K), respectively. Using Petela and Spanner

Table 1. The Long Term Monthly Average Solar Radiation Exergy values for Van

		Exergy-to-Energy Ratios			*Solar Radiation Exergy Values, MJ/m^2*		
Months	*Temperature, T_o(K)*	Ψ_{petela}	$\Psi_{spanner}$	Ψ_{jeter}	$\boldsymbol{Ex_{petela}}$	$\boldsymbol{Ex_{spanner}}$	$\boldsymbol{Ex_{jeter}}$
Jan.	271.05	0.939768	0.939767	0.954825	9.51	9.51	9.67
Feb.	271.57	0.939653	0.939651	0.954738	13.08	13.08	13.29
Mar.	275.40	0.938801	0.938799	0.954099	16.43	16.43	16.70
Apr	281.25	0.937502	0.937500	0.953125	19.24	19.24	19.56
May	286.92	0.936242	0.936241	0.952181	23.40	23.40	23.80
June	292.20	0.935069	0.935067	0.951301	26.86	26.86	27.32
July	296.06	0.934212	0.934210	0.950657	25.86	25.86	26.32
Aug.	295.98	0.934229	0.934227	0.950671	23.60	23.60	24.02
Sept.	290.93	0.935351	0.935349	0.951512	20.12	20.12	20.47
Oct.	284.85	0.936702	0.936700	0.952525	14.29	14.29	14.53
Nov.	277.85	0.938257	0.938256	0.953692	10.10	10.10	10.27
Dec.	272.95	0.939346	0.939344	0.954508	8.15	8.15	8.29

Table 2. The Long Term Annual Average Solar Radiation Exergy Values for Van

Months	*Temperature, T_o (K)*	*Exergy-to-Energy Ratios*			*Solar Radiation Exergy Values, MJ/m²*		
		Ψ_{petela}	$\Psi_{spanner}$	Ψ_{jeter}	Ex_{petela}	$Ex_{spanner}$	Ex_{jeter}
1993	281.88	0.937363	0.937361	0.953021	16.50	16.50	16.77
1994	283.28	0.937050	0.937048	0.952786	16.84	16.84	17.12
1995	282.84	0.937148	0.937146	0.952860	17.54	17.54	17.83
1996	283.53	0.936996	0.936994	0.952746	17.36	17.36	17.65
1997	282.37	0.937253	0.937252	0.952939	17.65	17.65	17.94
1998	283.59	0.936981	0.936980	0.952735	17.69	17.69	17.99
1999	283.82	0.936931	0.936930	0.952697	17.50	17.50	17.79
2000	283.46	0.937011	0.937009	0.952757	18.44	18.44	18.75
2001	283.98	0.936894	0.936893	0.952669	18.03	18.03	18.33
2002	282.72	0.937176	0.937174	0.952881	18.00	18.00	18.30
2003	283.08	0.937096	0.937094	0.952821	17.21	17.21	17.50
2004	282.69	0.937181	0.937180	0.952885	17.85	17.85	18.15
2005	283.08	0.937094	0.937093	0.952819	17.64	17.64	17.94
2006	283.15	0.937079	0.937078	0.952808	17.89	17.89	18.19
2007	282.79	0.937159	0.937157	0.952868	17.36	17.36	17.65

approach for Van, exergy of solar radiation various between 8.15 and 26.86 MJ/m^2 while Jeter approach values vary from 8.29 to 27.32 MJ/m^2. It is observed that Calculation of solar radiation exergy efficiency depend of Spanner and Petela models gives very near result to each other. However, tAASSDShere are very few different between Jeter's model and the other models outcomes. This difference of solar radiation exergy values for three approaches is less than %1.7. Table 2 shows multiple years variations of annual average solar radiation exergy values that are exergy efficiency and solar radiation exergy for a fifteen year period from 1993 to 2007. It is observed that solar radiation exergy values vary from 16.50 to 18.44 MJ/m2 using Petela and Spanner approach for long term period. According to Jeter's approach solar radiation exergy values vary between 16.77 - 18.75 MJ/m2. It is seen that the long term exergy to energy ratios according to Petela and Spanner approach is very close to each other and exergy to energy ratios vary from 0.934 to 0.954 according to three approaches.

It is also observed that the difference of annual average temperature is very small for multiple year variations and these temperature difference vary from 281.88 (K) to 283.98 (K) between the years of 1993-2007.

So, it can be say that there is not more difference between exergy-to-energy ratios for multiple years variations. Figure 1 shows variation of the annual average values of the global solar energy and solar radiation exergy in order to detect year-to-year variation. It is observed from this figure that there is not a large difference between the years of 1993-2007. The highest annual value of the solar radiation energy and exergy is observed for the year of 2000 with 19.68 MJ/m^2 and 18.44 MJ/m^2, respectively. The lowest annual value of the solar radiation energy and exergy is observed for the year of 1993 with 17.60 MJ/m^2 and 16.50 MJ/m^2, respectively., The annual average values of solar radiation exergy that is evaluated based on Petela and Spanner approach varies between 16.50-18.44 MJ/m^2 while Jeter approach values changes between 16.77-18.75 MJ/m^2. It is seen that annual average of solar radiation exergy is close to each other for three approaches. Variation of the monthly average values of the global solar radiation energy and solar radiation exergy for the long term period is shown in Figure 2. As can been seen in this figure, the highest monthly long term energy and exergy of average global solar radiation is observed in the month of June with 28.72MJ/m^2 and 26.86 MJ/m^2 that is according to Petela, respectively. The lowest solar radiation energy and exergy for the fifteen year period is calculated in the month of December with 8.68 MJ/m^2 and 8.15 MJ/m^2 that is according to Petela, respectively.

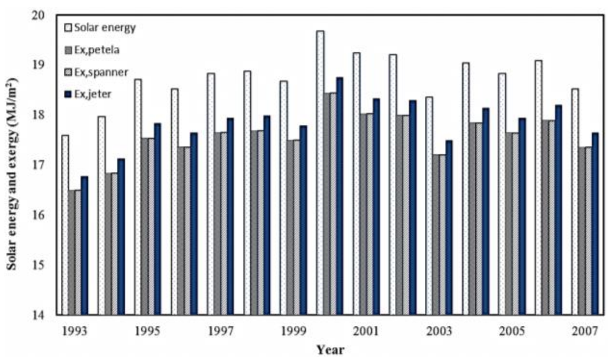

Figure 1. Variation of the annual average values of the global solar radiation energy and exergy for fifteen years

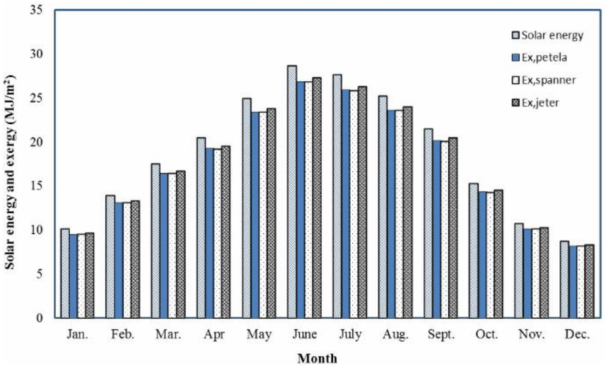

Figure 2. Variation of the monthly average values of the solar radiation energy and exergy for long term period

Figure 3 illustrates variation of average values of the global solar radiation energy and solar radiation exergy for winter, spring, summer and autumn season for long term period. In this figure, seasonal global solar radiation energy and solar radiation exegy for the long term period is calculated. The effects of climate and seasons on solar radiation exergy are investigated by considering data for the fifteen years period. It seen that the solar radiation energy reaches to highest value in the summer season with 27.22 MJ/m^2. It can be also seen from this figure that the maximum value of long term solar radiation exergy is observed during the summer season with 25.44 MJ/m^2 but the minimum value of long term solar radiation exergy is seen in winter with 10.25 MJ/m^2.

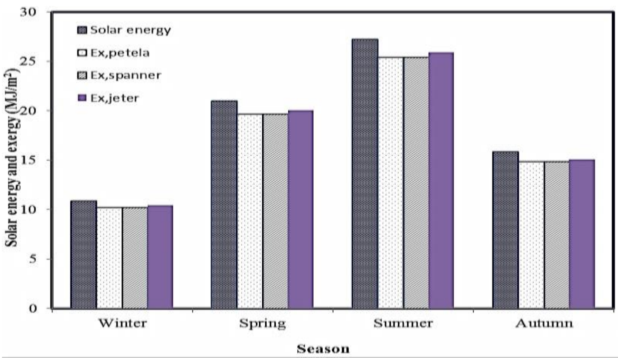

Figure 3. Variation of the seasonal average of the solar radiation energy and exergy for long term period

The finding of this study based on the long term period has been reflected by the correlation. Figure4. shows variation of solar radiation exergy with long term global solar radiation energy for Van. The correlation shown in this figure presented that the correlations between global solar radiation energy and solar radiation exergy show a positive slope and a good linear fit. As a result, solar radiation exergy values can be calculated based on these correlation equations for three approaches. The prediction of solar radiation exergy by Petela and Spanner superimposes because the difference between the two approaches is very close. So, a single exergetic value can be accepted for Spanner and Patella approach for Van and it can be presented by;

$$Ex_{petela\ and\ spanner} = 0.9371E_{rad}$$

Based on the long term period, the following equation can be used for Jeter's approach;

$$Ex_{jeter} = 0.9528E_{rad}$$

In this way, it is possible to easy calculate solar radiation exergy multiplying this coefficient with the total solar radiation measured in Van, Turkey location.

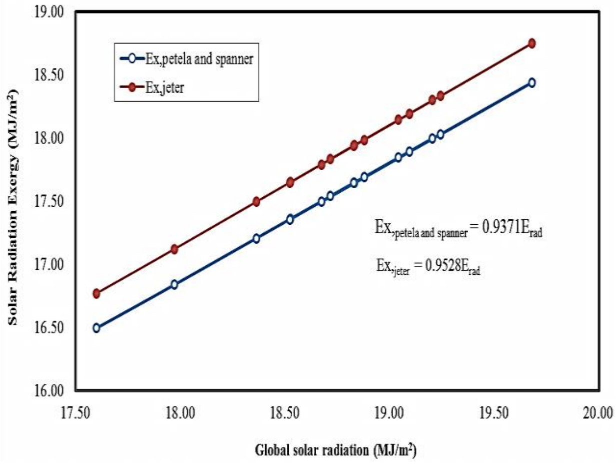

Figure 4. Variation of the solar radiation exergy with annual average of solar radiation energy for long term period

4. CONCLUSIONS

In this work, long term solar radiation data measured from 1993 to 2007 were analyzed for VAN city located in the eastern region of Turkey. This study aimed to demonstrate the solar exergy potential in a region and also to evaluate the performance of solar energy systems using the exergy analysis method. In this study three approaches suggested by various researchers have been used to determine the exergy of solar radiation.

Based on measured data, firstly, the long term monthly average solar radiation exergy values and the long term annual average solar radiation exergy values are processed based on Petela, Spanner and Jeter approach. After that correlations are made between exergy and energy of solar radiation. The main findings taken from the current work can be summarized as follows:

a) The long term monthly average solar radiation exergy values for Van, Turkey change between 8.15 MJ/m^2 and 26.85 MJ/m^2 from December to June for both approaches of Petela and Spanner, and from 8.29 to 27.32 for Jeter's approach. The difference of solar radiation exergy values for three aproach is less than %1.7.

b) The ratio of the long term monthly average solar radiation exergy to solar radiation energy values varies from 0.934 to 0.939 both Spanner and Petela approach, and from 0.950 to 0.954 for Jeter's approach.

c) It is observed that there is a difference in the solar radiation exergy between the four seasons; winter, spring, summer and autumn. The maximum and minimum value of long term solar radiation exergy is observed during the summer and winter season with 25.8 MJ/m^2 and 10.2 MJ/m^2 based on three approaches, respectively.

d) A linear regression has been fitted to easily determine variations of the solar radiation exergy with solar radiation energy for helping designers and engineers interested in solar energy field in Van, Turkey. Similar studies also are possible for other places.

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