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Evaluating of Renewable Energy Potential in Turkey

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Abstract-Like the whole world, Turkey's demand for energy has been growing up annually and is expected to continue to grow. Fossil fuel reserves are limited and these fuels have high level of ash, sulfur and moisture. Accretions of the energy consumption and enviromental pollution have turned out to be a serious problem. Thus, the sustainable energy development of the renewable energy sources such as solar, wind and solar-hydrogen are accepted as one of the most fruitful and effective solution to prevent enviromental pollution. A model house is designed for this study. Seven cities are selected from among the seven regions of Turkey and need for energy of this model house is provided with wind turbines and photovoltaic systems. Wind potential and hourly radiation data gotten from Turkish State Meteorological Service are used to calculate the energy demand. Cost analysis of these two systems is conducted and energy costs of both systems are compared with the national electrical energy costs.

Keywords-Wind energy; solar energy; electric energy; photovoltaic panel; wind turbine.

1. Introduction

When the limited usage duration of fossil fuels that meet a significant portion of the world energy demand, the destruction upon the environment and energy needs of future generations are taken into account, the importance of renewable energy sources is understood better. It is also seen that energy demand has increased significantly due to Turkey's growing population and economy in progress. For this reason, to reduce the dependence on the outside in terms of diversifying energy production and meeting energy needs has become a fundamental aim. To this end, more attention should be paid on renewable energy sources such as wind, solar, wave and geothermal.

Wind energy is the world's most important and fastest-growing renewable energy source. Also, wind energy is the most promising energy source for Turkey. To take advantage of wind energy, it is first needed to identify the regions's wind energy potential and characteristics of the wind. It plays an important role to establish the meteorological basis in this respect. To coordinate the studies to date and speed up the studies that will be performed on a larger area are going to have a positive effect on the utilization of wind energy. Various studies have been performed about wind energy in our country until now. EIE (The Electrical Power Resources Survey and Development Administration) carried on various studies in relation to this matter and at the end of these studies, EIE charted the atlas of Turkey's wind in accordance with the data gotten from DMI (Turkish State Meteorological Service). Based on this atlas, it was found that Mediterranean, the Black Sea coast, a part of Southeastern Anatolia and especially the Aegean region which has wind speed values shifting between 4.5 and 10 m/s have a high potential. Although Turkey has got this potential, the studies here aren't sufficient and the required support isn't given yet [4-6].

Due to its geographic location, Turkey is very lucky compared to the other countries in terms of solar energy potential. As a result of the study performed by DMI, it was determined that

Turkey's average annual total sunshine duration is 2640 hours and the average intensity of total radiation is 1311 kWh / m²-year.

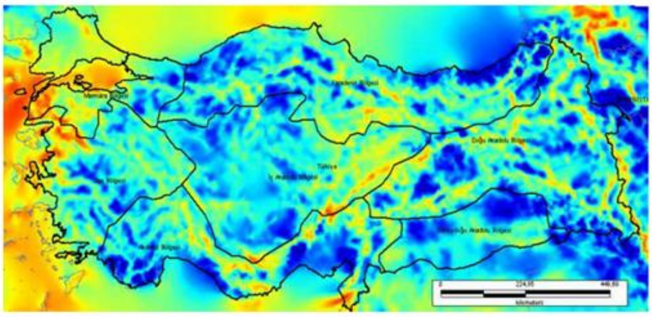

Fig.1. Turkish wind atlas [1]

The annual average solar radiation of Turkey's larger part and the total yearly radiation period have enough potential for solar energy applications. Despite this potential, in today's Turkey, the solar energy is generally used for heating, cooling and to get hot water for buildings. The usage for getting hot water is the most common form of benefiting from solar energy. Turkey is a well- suited market for the usage of photovoltaic energy [3].

Ilkılıc given overall information about wind energy and he explored progress in wind energy power systems in Turkey and in the world. He was reliazed that, the number of application, utilization, power plants and installations in order to take advantage of wind energy is rapidly increasing [10]. Ozgener investigated utilize of wind energy in Turkey and on world [11]. Sahin reviewed wind energy and opened for further discussion. He reviewed wind energy history, wind-power meteorology, the energy–climate relations, wind-turbine technology, wind economy, wind–hybrid applications and the current status of installed wind energy capacity all over the world with further enhancements and new research trend direction suggestions [12]. Ozkaya et al. examined the systems of electricity production from renewable resource of wind energy and taking into consideration the city of Kayseri, the environmental consequences evaluated [13]. Ozdamar et al. studied a combined system which is produced electrical energy from both solar radiation via solar cells and wind energy by using wind turbine [14].

In this study, the model house is designed as the theoretical study. Operating time of electrical devices in model house have been estimated. The same model house used in the calculations for all provinces. The model house's energy demand are provided with wind turbine and photovoltaic system. The solar radiation and wind speed data belonging to seven cities which are selected from seven regions of Turkey are used for this purpose. The energy costs of the wind turbine and photovoltaic system are compared with the national electrical energy costs.

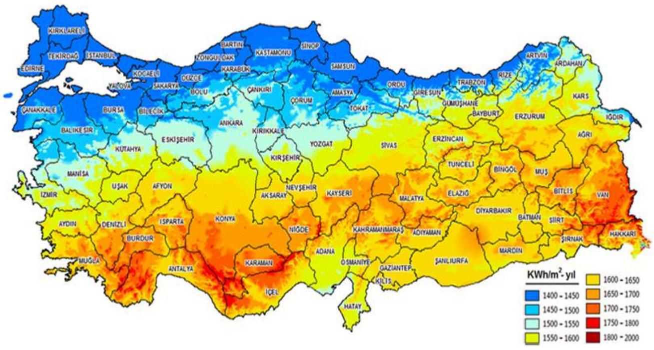

Fig.2. Turkish solar atlas [1]

2. Thermodynamic Analysis

Wind energy E is the kinetic energy of a flow, air of mass m at a speed V. The mass m is difficult to measure and can be expressed in terms of volume V through its density $\rho = \frac{m}{v}$. The volume can be expressed as V= A.L where A is the cross-sectional area perpendicular to the flow and L is the horizontal distance. Physically, L = V.t and wind energy can be expressed as [8]:

$$E = \frac{1}{2}\rho.A.t.V^3 \tag{1}$$

Betz applied simple momentum theory to the windmill established by Froude for a ship propeller. In that work, the retardation of wind passing through a windmill occurs in two stages: before and after its passage through the windmill rotor. Provided that a mass m is air passing through the rotor per unit time, the rate of momentum change is m(V1-V2) which is equal to the resulting thrust. Here, V1 and V2 represent upwind and downwind speeds at a considerable distance from the rotor. The power absorbed P can be expressed as [8]:

$$P = m.(V_1 - V_2).\bar{V} \tag{2}$$

On the other hand, the rate of kinetic energy change in wind can be expressed as:

$$E_k = \frac{1}{2} m.(V_1^2 - V_2^2) \tag{3}$$

The expressions in Equations (2) and (3) should be equal, so the retardation of the wind, $V_1 - \bar{V}$; before the rotor is equal to the retardation $\bar{V} - V_2$, behind it, assuming that the direction of wind velocity through the rotor is axial and that the velocity is uniform over the area A. Finally, the power extracted by the rotor is:

$$P = \rho.A\bar{V}(V_1 - V_2)\bar{V} \tag{4}$$

Furthermore,

$$P = \rho.A\bar{V}^2(V_1 - V_2) = \rho.A\left(\frac{V_1 + V_2}{2}\right)^2.(V_1 - V_2) \tag{5}$$

And

$$P = \rho.\frac{AV_1^3}{4}[(1+\alpha)(1-\alpha^2)] \tag{6}$$

Where $\alpha = \frac{V_2}{V_1}$

Differentiation shows that the power P is maximum when $\alpha = \frac{1}{3}$, i.e. when the final wind velocity V_2 is equal to one third of the upwind velocity V_1.

Net energy produced by photovoltaic modules can be found as follows:

$$E_{PV} = \eta_{PV}.\eta_C.A.G \tag{7}$$

In this formula, $\eta_{PV}$is photovoltaic modules efficiency, $\eta_C$is the total efficiency of other power conversion and electronic devices, A module area and G is solar radiation.

3. Photovoltaic System Design for Turkey

Energy consumption of electrical devices for model house was calculated and given in Table 1. Photovoltaic system and wind turbine design according to this energy consumption were carried out. Operating time of electrical devices in model house have been estimated. Operating time of electrical devices may variable.Firstly, energy demand of model house with photovoltaic modules was provided. Solar radiation values presented in Table 2 for energy calculations produced by photovoltaic modules were used.

Table 1. Energy requirement of model house [2]

	Of the devices used at home		**Spent power (kW)**	**Daily working hours (min)**			**Repeat**	**Total working time per month**	
	Type	**Mark**		**Day**	**Night**	**Total**		**(h)**	**(kWh)**
1	Dishwasher	Arçelik	1,8	120	-	120	4	8	14,4
2	Washer	Arçelik	1,8	120	-	120	4	8	14,4
3	Brooms	Arçelik	1,2	60	-	60	6	6	7,2
4	Oven	Arçelik	2,9	60	-	60	4	4	11,6
5	Iron	Arçelik	1,2	60	-	60	6	6	7,2
6	Television	Arçelik	0,065	120	300	420	20	140	9,1
7	Refrigerator	Arçelik	1,462	300	300	600	31	310	45,3
8	Lamp(3 pieces)	40 W	0,1	-	240	240	25	100	10
Average electrical energy consumption of electrical device at model house									**119,2**

Table 2. Total solar radiation values

Regions	Cities	Total Solar Radiation Amounts(kWh/m^2-year)
South Eastern Anatolia	Mardin	1610
Mediterranean	Antalya	1715
Aegean	Afyonkarahisar	1594
Central Anatolia	Kayseri	1451
Eastern Anatolia	Malatya	1519
Marmara	Çanakkale	1427
Black Sea	Sinop	1214

Technical specifications of photovoltaic modules used in this study were given in Table 3

Table 3. Technical specifications of photovoltaic modules [2]

Peak power	64 W
Area	1,03 m2
Efficiency	0,10
Weight	9,17 kg
Operating temperature	-40°C ÷ +90°C
Voltage	16,5 V
Current	3,88 A
Cost ($)	445
η_{PV}	0,10
η_C	0,80

The number of required photovoltaic modules for each month were calculated and given in Table 4.

Table 4. The number of photovoltaic modules required for each cities [2]

Regions	Cities	Solar Radiation Amounts(kWh/m^2-year)	Energy production per module (kWh/year)	Total load (kWh)	The required number of modules (units)	Module
South Eastern Anatolia	Mardin	1610	11,05	119,2	10,78	11
Mediterranean	Antalya	1715	11,77	119,2	10,12	11
Aegean	Afyonkarahisar	1594	10,94	119,2	10,89	11
Central Anatolia	Kayseri	1451	9,96	119,2	11,96	12
Eastern Anatolia	Malatya	1519	10,43	119,2	11,42	12
Marmara	Çanakkale	1427	9,79	119,2	12,16	13
Black Sea	Sinop	1214	8,33	119,2	14,29	15

The amount of energy per every photovoltaic module is calculated and given in Fig. 3. It is seen that the most energy production per module is in Antalya and the least one is in Sinop.

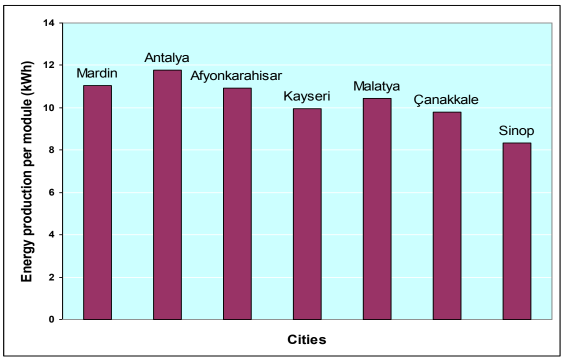

Fig. 3. Energy production per module in cities

4. Wind Turbine Design for Turkey

Secondly, energy demand of the same model house with wind turbine was provided. Wind speed values presented in Table 5 for energy calculations produced by wind turbine were used. Wind speed data for Turkey were obtained from Turkey Meteorological Institute.

In this study, ALTEMA 7500 model wind turbine were used. Rotor diameter of this turbine is 4 m. In Table 6, technical specifications of wind turbine are shown.

Table 5. Average wind speed data (10 m)

Regions	Cities	Average wind speeds (m/sec)
South Eastern Anatolia	Mardin	4,3
Mediterranean	Antalya	2,7
Aegean	Afyonkarahisar	2,7
Central Anatolia	Kayseri	1,8
Eastern Anatolia	Malatya	2,7
Marmara	Çanakkale	3,9
Black Sea	Sinop	3,6

Table 6. Technical specifications of wind turbine

Model	Altema 7500
Type	Three winged
Optimum output power (W)	7.500
Wing Semi-Diameter (m)	2
Voltage (Volt)	48–96
Speed (m/sn)	3 – 25
Optimum Speed (m/s)	13
Operating temperature oC	-40 / 60 oC
Aşırı rüzgar koruması	Mikroişlemci kontrollü
Inclusive ($)	19665
Column Price ($)	3330
Column-free price ($)	17800

In Table 7, electrical energy produced by wind turbines for Turkey according to cities are given.

Table 7. Electrical energy produced by wind turbines

Regions	Cities	Average Wind Speeds (m/sec)	Produced Electric Power (kW/month)
South Eastern Anatolia	Mardin	4,3	362,39
Mediterranean	Antalya	2,7	89,71
Aegean	Afyon karahisar	2,7	89,71
Central Anatolia	Kayseri	1,8	26,58
Eastern Anatolia	Malatya	2,7	89,71
Marmara	Çanakkale	3,9	270,37
Black Sea	Sinop	3,6	212,65

The amount of energy produced by wind turbines is calculated according to the provinces and represented in Fig. 4. The most energy production is in Mardin and the least one is in Kayseri.

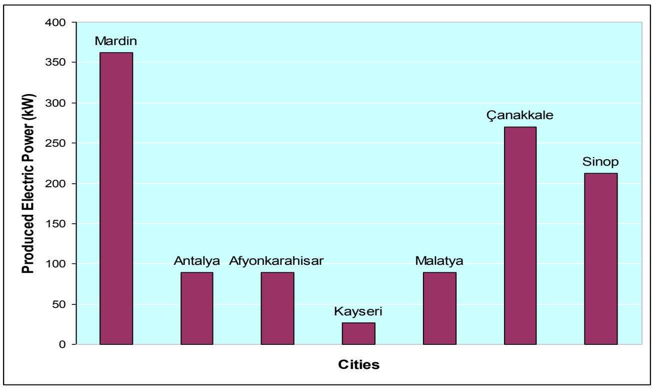

Fig. 4. Production electric power by wind turbine in cities

5. Cost Analysis

Energy costs of designed model house in all cities were compared with the national energy costs. Obtained results are given in Fig. 5. Cost analysis and amortization periods are set out of 25 years. This period is given by the manufacturers of wind turbine and photovoltaic module.

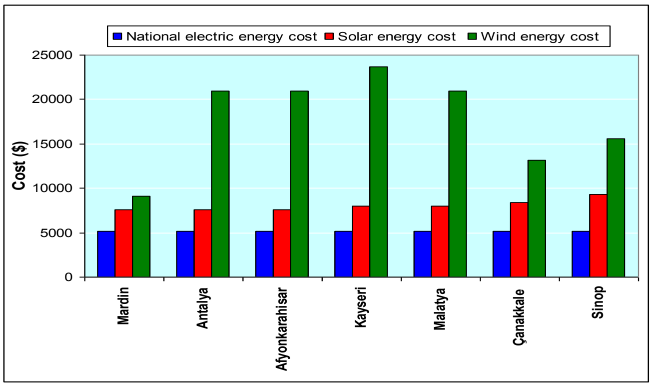

Fig. 5. Energy costs of model house (for all cities)

6. Conclusion

As a result of the analysis, among the selected provinces, Mardin reveals itself as the most suitable one in terms of electricity production with wind turbine and photovoltaic panels. The amortization period of the panel and wind turbine systems is too long due to the fact that their initial investment costs are very high and the supports are inadequate about this issue. The amortization periods of wind turbine and photovoltaic panels for Mardin are designated respectively, the 44 and 36 years. Similarly, it is 101 and 36 years for

Antalya, 101 and 36 years for Afyon, 114 and 38 years for Kayseri, 101 and 38 years for Malatya, 63 and 40 years for Çanakkale, and finally 75 and 45 years for Sinop.

This study was made for suitability of investments in order to determine of existing solar and wind energy potential in Turkey. Even if the solar and wind energy systems have high investment costs today, they will provide significant contributions in terms of meeting future energy needs by the help of studies and supports. Solar and wind energy potential in Turkey provides an important alternative for the future.

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