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Full Research Paper

Techno-Economic Analysis of Solar Water Heating Systems in Turkey

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Abstract: In this study, solar water heater was investigated using meteorological and geographical data of 129 sites over Turkey. Three different collector types were compared in terms of absorber material (copper, galvanized sheet and selective absorber). Energy requirement for water heating, collector performances, and economical indicators were calculated with formulations using observed data. Results showed that selective absorbers were most appropriate in terms of coverage rate of energy requirement for water-heating all over Turkey. The prices of selective, copper and galvanized absorber type's heating systems in Turkey were 740.49, 615.69 and 490.89 USD, respectively. While payback periods (PBPs) of the galvanized absorber were lower, net present values (NPVs) of the selective absorber were higher than the rest. Copper absorber type collectors did not appear to be appropriate based on economical indicators.

Keywords: Solar energy, Solar water heater, Energy conservation.

1. Introduction

Due to the increasing prices of the primary energy resources and their associated serious environmental issues, the use of renewable resources, especially, the solar energy is increasingly on demand in both developing and developed countries. The most common way of using solar energy is through hot water by solar water heaters. Hot water is required for domestic and industrial uses such as houses, hotels, hospitals, and mass-production and service industries. Solar water heaters in various Indian stations were reported to provide 100 L of hot water at an average temperature of 50-70 ^oC, which can be retained to 40-60 ^oC until used next day morning [1]. Although solar collectors have a history extending back to about 120 years ago, the requirements of many diverse applications are still continued to be more effectively satisfied with advantages of new materials and manufacturing processes. The total solar collector area installed worldwide is now estimated to be over 58 km^2 [2]. For example in Lebanon, 70% of residential houses use electricity to heat their water, 25% use diesel, and 5% use gas, wood, solar and other energy sources [3,4]. The share of solar water heaters in 2002 was 1.7% of total energy demand of Jordan [5]. About 100 km^2 of solar collector are expected to be installed in Europe by the year 2010 [6]. The fact that solar water heaters are affordable and a cheap substitute for (non-)commercial fossil fuel-burning renders them increasingly popular.

Turkey receives a high level of solar radiation throughout the year with a mean daily solar energy intensity of 12.96 MJ m^{-2} d^{-1} and sunshine duration of about 7.2 h [7]. The solar potential unconstrained by technical, economic or environmental requirements of Turkey is estimated as 88 million tonnes oil equivalent (toe) per year 40% of which is considered economically usable. Three-fourths (24.4 million toe per year) of the economically usable potential is considered suitable for thermal use, with the reminder (8.8 million toe per year) for electricity production [8]. The household energy consumption of Turkey involves electricity, coal, natural gas, petroleum and renewable energy sources. The biggest share comes from wood, but the share of solar energy was only about 1.1% in 2002 [9]. The share of household sector in consumption was 31% in 2002 [9], lower than 40% of the developed countries [10]. Increasing this proportion could decrease the present total fossil fuel-related CO_2 emissions of 61.7 Mt (mega ton) carbon (C), and the emission rate of 0.87 t C per capita [11]. In Beirut, a 2.5 m^2 flat plate glazed collector with 114 L storage capacity placed at a slope of 33.8^o was reported to result in a greenhouse gas reduction of 1.42 t CO_2 per year [3].

In Turkey, 11 million m^2 of collector surface area (an equivalent of 0.15 m^2 collector surface per capita) were installed with a heat output of 0.4 Mtoe in 2005 [12]. This rate was 0.23 m^2 for Austria in 2002, 0.28 m^2 for Greece in 2002 [13], and 0.82 m^2 for in Cyprus in 2003 [14]. Given the present Turkish manufacturing capacity for solar water heater of 1 million m^2 per year, the growth in this market is expected to continue, thus increasing the quantity and quality of collectors installed [15]. For example, the installation rate by households was about 4.32% in Taiwan in 2005 [16]. Average annual installation rate between 1995 and 2000 was 6.6% for Spain, 5.2% for Germany, 5.0% for France, 4.0% for Italy, 3.4% for Netherlands, 1.8% for UK and 0.2% for Greece [45].

The most commonly used solar water heating system for domestic needs is through natural circulation type that consists of a flat plate solar collector connected to an insulated storage tank. The sun's rays pass through the glass and are trapped in the space between the cover and plate or are absorbed by the black body. The circulating water through a conduit system located between the cover and absorber plate is heated and then carried to the storage tank. Flat plate collectors are most suitable when a temperature below 100 ^oC is required. These are simple to assemble; low cost; simple in design and fabrication; durable; do not require sun-tracking; can work on cloudy days; and require minimum maintenance [17,18]. The average life of typical solar water heating system is generally assumed to be ca. 20 years. Utilization of renewable energy for water heating can increase electrical reserve margins, raise the system load factor, improve load following capabilities and reduce the need for capacity expansion. In addition, using renewable energy sources provides clear opportunities for reductions in CO_2, CO, nitrogen oxide, sulfure oxide, particulate matter and volatile organic compounds during power generation [19,20]. When four alternative water heating technologies (standard electric water heating, heat pump water heater, solar hot water system and heat pump desuperheaters) were compared, the solar hot water systems were found to be the most efficient and to have the greatest reduction in electric peak demand [21,22].

The performance of a solar water heater system is highly dependent on its orientation, optical and geometric properties, macro and microclimatic conditions, geographical position, operational parameters, and the period of use [15,18,23-26]. In this study, a techno-economic assessment of the most common solar water heating systems in Turkey was carried out quantifying the rate of solar energy that is gained, required and used, and payback period (PBP) and net present value (NPV) in terms of liquid petroleum gas (LPG) and electricity savings.

2. Design of Solar Water Heaters

The design of the flat plate collector is shown in Fig. 1. The absorber area of the flat plate collector was 1.82 m^2, and two heaters were used in the subsequent calculations.

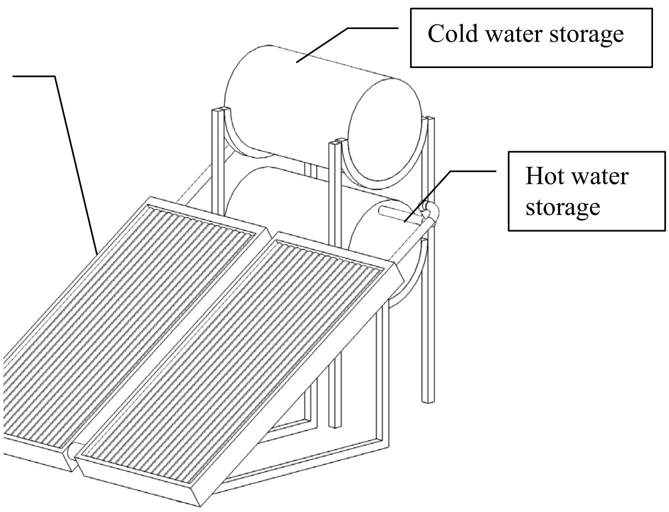

Figure 1. Components of solar water heating system.

3. Determination of Solar Collector Performance

In this study, meteorological and geographical data of 129 sites over Turkey were used in the calculations. First, the monthly average daily solar radiation on a horizontal surface was converted to hourly solar radiation on a tilted surface.

The monthly average clearness index (K_T) is the ratio of monthly average daily solar radiation on a horizontal surface (H) to monthly average daily extraterrestrial radiation on a horizontal surface (H_o). H_o can be calculated using the following equation [27]:

$$H_0 = \left(\frac{24}{\pi}\right) I_{gs}\ f \left[\cos\lambda \cos\delta \sin w_s + \left(\frac{\pi}{180}\right) w_s \sin\lambda \sin\delta\right], \tag{1}$$

where I_{gs} is the solar constant (1367 W m^{-2}); f the eccentricity correction factor; λ latitude; δ the solar declination; and w_s the mean sunset hour angle for a given month. The eccentricity correction factor, solar declination and sunset hour angle can be estimated thus [28]:

$$f = 1 + 0.033\left(\cos\frac{360\,n}{365}\right), \tag{2}$$

$$\delta = 23.45 sin\left[360(284+n)/365\right], \tag{3}$$

$$w_s = cos^{-1}\left(-tg\lambda . tg\delta\right), \tag{4}$$

where n is the number of the day of the year starting from the first of January. In order to determine monthly average daily diffuse solar radiation over Turkey, the following correlation was used [29]:

$$\frac{H_d}{H} = 1.6932 - 8.22262\left(\frac{H}{H_o}\right) + 25.5532\left(\frac{H}{H_o}\right)^2 - 37.807\left(\frac{H}{H_o}\right)^3 + 19.8178\left(\frac{H}{H_o}\right)^4, \tag{5}$$

The ratio of hourly total to daily global radiation was calculated as a function of sunshine duration thus [30 from 28]:

$$r_t = \frac{I}{H}, \tag{6}$$

Based on sunshine duration and daily global radiation, the hourly global radiation can be estimated. In the curves shown by Liu and Jordan (1960), the hours are designated by the time for the midpoint of the hour, and days are assumed to be symmetrical about solar noon. The curves were represented by the following equation [31]:

$$r_t = \frac{\pi}{4.S_o}\left\{Cos\left[90\frac{h}{w_s}\right] + \frac{2}{\sqrt{\pi}}\left(1-\psi\right)\right\}, \tag{7}$$

$$\Psi = \exp\left[-4\left(1-\frac{|h|}{w_s}\right)^2\right], \tag{8}$$

where h is hour angle changing 15° per hour, with morning being negative and afternoon being positive, and S_o is maximum possible sunshine duration calculated as follows [28]:

$$S_o = \frac{2}{15}\omega_S \, , \tag{9}$$

The ratio of hourly diffuse to daily diffuse radiation can be estimated as follows [28]:

$$r_d = \frac{I_d}{H_d} = \frac{I_o}{H_o} \, , \tag{10}$$

The curves based on the assumption of Liu and Jordan (1960) that I_d/H_d is the same as I_o/H_o are shown by the following equation [28]:

$$r_d = \frac{\pi}{24}\frac{Cos\ h - Cos\ w_S}{Sin\ w_S - \frac{\pi}{180} w_S\ Cos\ w_S} \, , \tag{11}$$

The beam radiation can be then calculated as follows [28]:

$$I_b = I - I_d \, , \tag{12}$$

The total solar radiation on the tilted surface was calculated for an hour as the sum of beam, isotropic diffuse and solar radiation diffusely reflected from the ground as follows [28,32]:

$$I_T = I_b R_b + I_d \frac{(1 + Cos\beta)}{2} + I \frac{(1 - Cos\beta)}{2} \rho_g \, , \tag{13}$$

where ρ_g is ground reflectance (equal to 0.2). The geometric factor (R_b) can be calculated as follows [28]:

$$R_b = \frac{Cos(\lambda - \beta) Cos\delta\, Cosh + Sin(\lambda - \beta)\sin\delta}{Cos\lambda\, Cos\delta\, Cosh + Sin\lambda\, Sin\delta} \, , \tag{14}$$

Second, the useful energy output of a collector, the difference between the absorbed solar radiation and the thermal losses, can be calculated as follows [28,33,34]:

$$Q_u = A_c\ F_r\ \left[I_T\ (\tau\alpha) - U_L\ (T_{f,i} - T_a)\right], \tag{15}$$

where A_c is collector area, F_r is heat removal factor, $(\tau\alpha)$ is transmittance-absorptance, U_L is overall heat loss coefficient, $T_{f,i}$ is fluid inlet temperature and T_a is ambient air temperature.

The most common three solar heater types according to their absorber plates were taken into consideration in this study and included (1) galvanized black painted iron sheet, (2) copper painted black sheet and (3) selective black surface. The heat removal factor could be calculated as shown below [28]:

$$F_r = \frac{G\,C_p}{U_L}\left[1 - \exp^{-\left(U_L F^l / G\,C_p\right)}\right], \tag{16}$$

where G is fluid flow rate per unit collector area, C_p is specific heat at constant pressure, F'' is collector efficiency factor, and the latter can be calculated as follows [28]:

$$F^l = \frac{1/U_L}{W\left\{\frac{1}{U_L\left[D + (W-D)F\right]} + \frac{1}{C_b} + \frac{1}{\pi\,D\,h_{f,i}}\right\}}, \tag{17}$$

where W is the distance between the tubes, D is the tube diameter, F is the fin efficiency factor, C_b is the bond conductance, and $h_{f,i}$ is the heat transfer coefficient between the fluid and the tube wall. The term "$1/C_b$" was assumed to be equal to zero in the calculations since minimum value was 0.1 or lower [34].

The fin efficiency factor could be calculated as follows [28]:

$$F = \frac{\tanh\left[m(W-D)/2\right]}{m\,(W-D)/2}, \tag{18}$$

where

$$m = \left(\frac{U_L}{k_p\,\delta_p}\right)^{1/2}, \tag{19}$$

and k_p is the conductivity, and δ_p is the thickness of the absorber plate.

The heat transfer coefficient between the fluid and the tube wall ($h_{f,I}$) can be calculated as follows [34,35]:

$$h_{f,i} = \frac{Nu\,k}{D}, \tag{20}$$

where Nusselt number calculated from $Nu = 1.86\,(\mathrm{Re\,Pr})^{1/3}\,(D/L)^{1/3}$ for $\mathrm{Re} \le 2300$ and $Nu = 0.027\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{1/3}$ for $\mathrm{Re} > 2300$. The Re is Reynolds, and Pr is Prandantl number in the equations.

The transmittance-absorptance was calculated as follows [34,35]:

$$\left(\tau\alpha\right)=\frac{\tau\alpha}{1-\left(1-\alpha\right)\rho_d}, \tag{21}$$

where τ is transmission of the cover, α is the absorptance of the absorber plate, and ρ_d is the reflectance of the glass cover (equal to 0.16).

The overall heat loss coefficient is equal to the sum of top, back and edge heat losses as shown below [33,34]:

$$U_L = U_t + U_b + U_e, \tag{22}$$

These top, back and edge losses can be calculated as follows [35,36 from 37]:

$$U_t = \left\{ \frac{N}{\frac{344}{T_p}\left[\frac{\left(T_p - T_a\right)}{\left(N+f\right)}\right]^{0.31}} + \frac{1}{h_w} \right\}^{-1} + \frac{\sigma\left(T_p + T_a\right)\left(T_p^2 + T_a^2\right)}{\left[\varepsilon_p + 0.0425\ N\ \left(1-\varepsilon_p\right)\right]^{-1} + \left(\frac{2N+f-1}{\varepsilon_g}\right) - N}, \tag{23}$$

$$U_b = \frac{k_b}{L_b}, \tag{24}$$

$$U_e = \frac{k_e\ c\ h}{L_e\ A_c\ 1.8236}, \tag{25}$$

where $T_p = T_{f,i} + 5$, N is number of cover (equal to one in this study), $f = \left(1 - 0.04\ h_w + 5x10^{-4}\ h_w^2\right)\left(1 + 0.058N\right)$, $h_w = 5.7 + 3.8\ V_r$, V_r is wind speed (m/s), σ is Stefan-Boltzmann constant, ε_p is emissivity of absorber plate, ε_g is emissivity of glass cover, k_b is conductivity of back insulation, L_b is thickness of back insulation, k_e is conductivity of edge insulation, L_e is thickness of edge insulation, c is perimeter of the collector, and h is height of the collector.

The daily useful energy output of a solar collector for tilt angles of 0 to 90^o with one degree intervals was calculated for 129 sites in Turkey. The sum of the daily values for each tilt angle was attained as useful energy gained annually by the collector. The optimum tilt angles were then determined by which receives the highest energy over the year for the three types of solar water heaters.

Third, the energy requirement to heat water to 55 ^{o}C for consumption was calculated as follows [38]:

$$Q_{ss} = G_w C_p \Delta T, \tag{26}$$

where G_w is amount of water (L d^{-1}) (equal to 100 L for one family), ΔT is temperature differences between tap water temperature and required water temperature (equal to 55 ^{o}C) [39,40].

Finally, the PBPs were calculated by considering savings equivalent in liquid petroleum gas (LPG) and electricity. The calorific values and thermal efficiencies were taken from [41]. The PBPs were estimated based on the relationship shown below [18]:

$$N = \frac{\log\left[(E-M) \big/ (a-b) \right] - \log\left\{ \left[(E-M) \big/ (a-b) \right] - C \right\}}{\log\left[(1+a) \big/ (1+b) \right]}, \tag{27}$$

where a is interest rate equal to 0.19, M is maintenance equal to 0.035 and b is inflation rate equal to 0.09 for Turkey [42,43].

The net present value (NPV) was calculated as follows [43]:

$$NPV = \sum_{t=0}^{nn} \frac{CF}{(1+i)^t}, \tag{28}$$

where CF is cash flow at a given year t, i is discount rate, t is year and n is end of process.

4. Mapping Spatial Variability in Energy Requirements and Coverage Rates

Maps of national energy requirements for water-heating, and coverage rates according to the selective, copper and galvanized absorber plates were created with a grid resolution of 500 m x 500 m from the 129 meteorological stations using the spatial interpolation method of universal kriging in ArcGIS 9.1 [50]. The implementation of kriging necessitates the calculation of a semi-variogram model that defines variance as function of distance, and direction as follows [51]:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{k=1}^{N(h)} \left[z(x_k) - z(x_k + h) \right]^2, \tag{29}$$

where $\gamma(h)$ is the semi-variance of variable z as a function of both lag distance or separation distance (h); $N(h)$ is the number of observation pairs of points separated by h used in each summation; and $z(x_k)$ is the random variable at location x_k.

The degree of spatial auto-correlation for energy requirements and coverage rates was determined using Moran's Index (I). In the universal kriging, detrending was implemented due to the presence of an overriding drift by the removal of first order trends from all the semi-variogram models and by adding back before predictions were made. In the semi-variogram models, the range (a) corresponds to the distance at which the semi-variogram reaches its asymptote and beyond which there is little or no spatial dependence. The sill defines the asymptotic height of the variogram and consists of nugget (c_0) and partial sill (c). The partial sill and the nugget are the spatially correlated component of the variance as a measure of the strength of the spatial dependence and the spatially uncorrelated component of the variance and also what is spatially correlated below the level of the minimum lag size as a measure of the inherent or non-spatial variation, respectively.

5. Results and Discussion

Moran's high I values for energy requirement (kWh year^{-1}) (0.2), coverage rates (%) by the selective (0.15), copper (0.13) and galvanized (0.12) absorber plates revealed the presence of a strong spatial auto-correlation for a robust geostatistical interpolation ($P < 0.01$). The anisotropic spherical semi-variogram models of universal kriging were implemented to map spatial variability in energy requirement and coverage rates at the national scale. Parameters and cross-validation R^2 values for spatially interpolated surface maps are presented in Table 1.

Table 1. Anisotropic spherical semi-variogram model parameters and cross- validation R^2 values of universal kriging for mapping spatial variability over Turkey.

	Energy requirement for water-heating (kWh year^{-1})	Coverage rate by selective absorber plate (%)	Coverage rate by copper absorber plate (%)	Coverage rate by galvanized absorber plate (%)
Range (*a*)	5.42	6.51	5.09	4.26
Minor range	3.05	2.14	1.26	0.71
Partial sill (*c*)	8477.6	8.52	15.98	21.67
Nugget effect (c_0)	2214.2	21.45	37.15	32.06
Lag size	0.51	0.55	0.43	0.36
Number of lags	12	12	12	12
Neighbors to include (at least)	9(5)	9(5)	9(5)	9(5)
Cross-validation R^2 (%)	67.03	49.86	46.29	45.12

The annual energy requirement of one family of four people for hot water production was calculated using formula [26]. In order to heat 100 L of water to temperature of 55˚C, the energy required varied between 1418.69 and 1975.08 kWh for 129 sites of Turkey (Fig. 2). It is clear that while the south and west locations of Turkey require less energy, the east locations of Turkey need much more energy to heat water. The reason for this can be attributed to low tap water temperatures in the east.

The useful energy output for the solar heating systems was calculated according to the different tilt angles for 129 sites of Turkey. Results indicated that tilt angles of the solar water heaters receiving the highest solar radiation during the entire year varied according to the absorber plate type (Tables 2 to 4). By using the selective absorber plate, the tilt angles were 25^o at minimum and 35^o at maximum with an average of 29.32 $\pm$ 1.68^o. In the copper absorber plate, the minimum, maximum and average tilt angles were 22, 33 and 27.09 $\pm$ 1.75^o, respectively. These values were similar for the galvanized absorber plates: 24^o (min.), 33^o (max.) and 27.1 $\pm$ 1.70^o (mean). The tilt angles for sites can be seen from Tables 2 to 4.

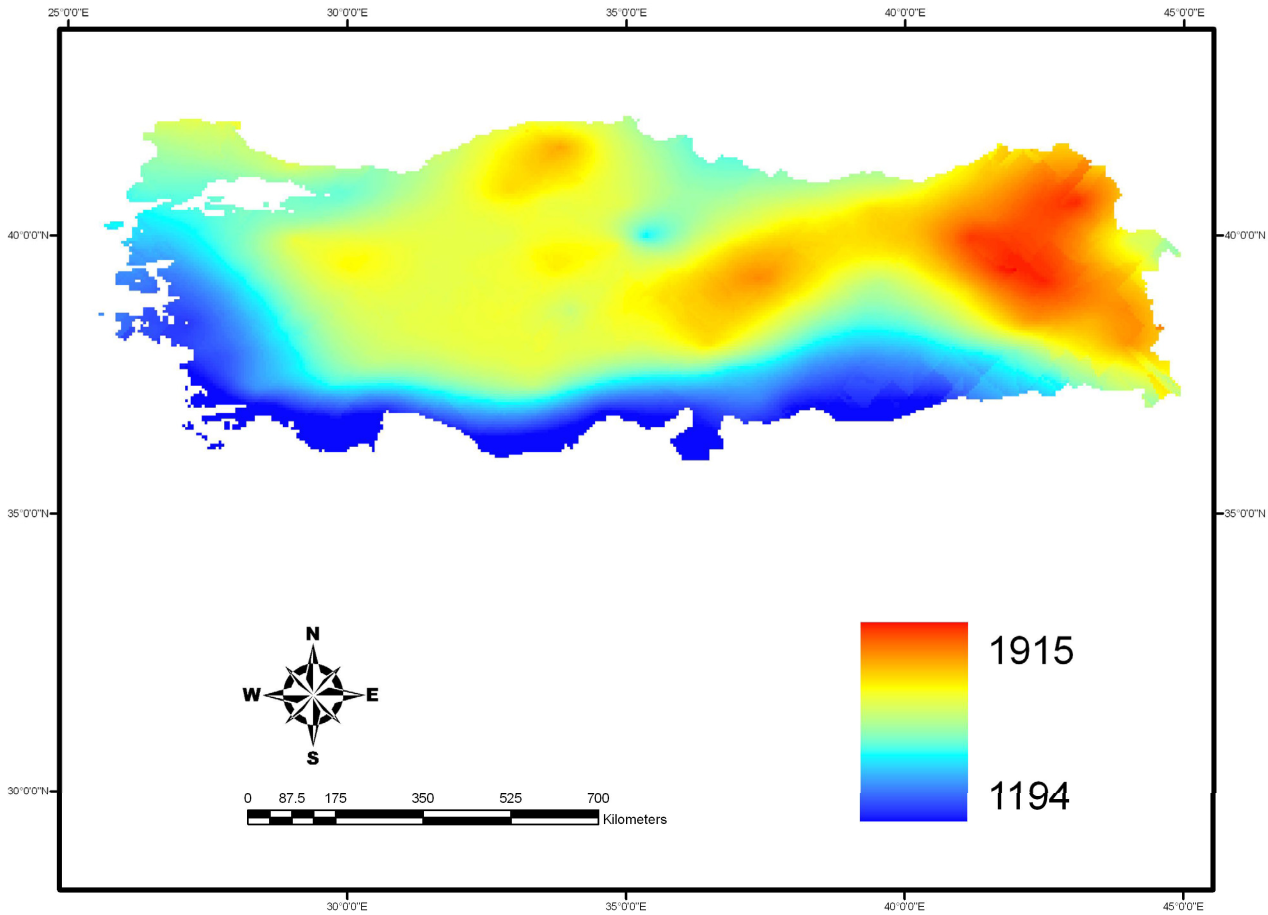

Figure 2. Map of energy requirement (kWh $year^{-1}$) for heating water to the desired temperature of 55°C over Turkey based on universal kriging with a grid resolution of 500 m x 500 m.

Table 2. Locations, optimum tilt angles, and economic performance indicators of selective absorber plates for 129 sites in Turkey.

	Latitude (decimal degree)	Longitude (decimal degree)	Altitude (m)	Tilt angle (degree)	PBP for electricity (year)	NPV for electricity (USD)	PBP for LPG (year)	NPV for LPG (USD)
ADANA	39.99	35.34	50	29	5.91	1677.40	3.76	2412.06
ADIYAMAN	37.75	38.28	620	30	6.30	1598.38	3.97	2302.59
AFYON	38.75	30.52	1253	29	5.24	1840.34	3.38	2637.75
AKCAKOCA	41.07	31.17	71	31	8.00	1346.63	4.86	1953.89
AKHISAR	38.93	27.84	100	28	5.34	1813.68	3.44	2600.82
AKSARAY	38.63	33.99	1320	29	5.35	1810.45	3.45	2596.36
AKSEHIR	38.35	31.42	1042	29	5.18	1855.46	3.35	2658.70
ANAMUR	36.08	32.83	83	27	5.85	1689.29	3.73	2428.52
ANKARA	39.95	32.88	900	30	6.08	1640.88	3.85	2361.47
ANTAKYA	36.20	36.17	158	28	6.98	1481.48	4.34	2140.67

ANTALYA	36.90	30.73	63	27	5.71	1720.41	3.65	2471.63
ARTVIN	41.18	41.82	624	32	5.20	1851.70	3.36	2653.49
AYDIN	37.85	27.85	72	29	5.78	1704.05	3.69	2448.97
AYVALIK	39.30	26.70	25	29	6.37	1585.19	4.01	2284.33
BALIKESIR	39.63	27.91	118	30	7.10	1464.43	4.40	2117.06
BASKALE	38.05	44.02	2296	25	4.09	2247.09	2.71	3201.16
BERGAMA	39.13	27.18	100	28	5.67	1729.67	3.63	2484.46
BILECIK	40.15	29.97	569	31	5.76	1710.68	3.67	2458.16
BINGOL	38.87	40.50	1148	29	5.49	1773.16	3.53	2544.70
BIRECIK	37.03	37.98	400	27	6.07	1642.90	3.85	2364.27
BITLIS	38.37	42.10	1500	28	5.50	1770.72	3.53	2541.32
BODRUM	37.04	27.43	50	28	5.82	1697.16	3.71	2439.43
BORNOVA	38.47	27.22	50	31	6.45	1570.23	4.05	2263.61
BOZKURT	41.95	34.02	104	32	7.29	1436.37	4.50	2078.18
BOZUYUK	39.92	30.03	800	30	5.28	1829.66	3.40	2622.96
BURDUR	37.67	30.33	1263	27	5.01	1907.53	3.25	2730.83
BURSA	40.19	29.07	200	31	6.63	1539.05	4.15	2220.41
CANAKKALE	40.10	26.39	8	30	6.29	1599.39	3.97	2304.00
CANKIRI	40.60	33.62	774	31	5.97	1662.68	3.80	2391.67
CERKES	40.82	32.90	1200	32	6.67	1531.41	4.17	2209.84
CESME	38.30	26.35	48	29	6.38	1582.90	4.02	2281.16
CIHANBEYLI	38.65	32.92	968	30	5.34	1813.67	3.44	2600.81
CORUM	40.55	34.95	795	31	5.30	1823.19	3.42	2614.00
DENIZLI	37.78	29.08	408	29	6.35	1588.44	4.00	2288.83
DEVELI	38.38	35.50	1305	25	4.58	2046.84	3.00	2923.79
DEVREKANI	41.58	33.83	1150	33	5.11	1876.88	3.31	2688.37
DIKILI	39.07	26.89	46	30	6.02	1654.09	3.82	2379.76
DIYARBAKIR	37.90	40.19	677	27	5.72	1718.90	3.65	2469.54
DORTYOL	36.85	36.22	55	27	5.54	1762.81	3.55	2530.36
DURSUNBEY	39.58	28.62	604	30	5.37	1804.29	3.46	2587.81
DUZCE	40.83	31.17	200	31	6.51	1559.55	4.09	2248.81
EDIRNE	41.67	26.57	50	32	8.37	1304.96	5.04	1896.16
EDREMIT	39.58	27.02	43	28	5.39	1798.54	3.47	2579.85
ELAZIG	38.65	39.25	1000	29	6.25	1606.84	3.95	2314.31
ELBISTAN	38.20	37.18	1226	30	5.32	1817.17	3.43	2605.66
EREGLI	37.50	34.05	1053	27	5.14	1867.00	3.33	2674.68
ERGANI	38.28	39.77	1068	28	5.54	1762.35	3.55	2529.73
ERZINCAN	39.75	39.50	1200	31	5.36	1808.66	3.45	2593.88
ERZURUM	39.95	41.17	1781	30	4.84	1959.98	3.15	2803.48
ESKISEHIR	39.78	30.57	800	30	6.57	1548.22	4.12	2233.12

ETIMESGUT	39.95	32.68	800	30	5.73	1717.54	3.66	2467.66
FLORYA	40.98	28.80	41	31	6.82	1506.65	4.25	2175.54
GAZIANTEP	37.08	37.37	851	28	6.12	1633.07	3.88	2350.65
GEMEREK	39.18	36.07	1230	27	4.72	1999.22	3.08	2857.83
GIRESUN	40.91	38.38	86	33	6.44	1571.05	4.05	2264.73
GOKSUN	38.03	36.50	1358	29	5.52	1766.53	3.54	2535.51
GONEN	40.10	27.65	50	30	6.26	1605.12	3.95	2311.93
GOZTEPE	40.97	29.08	34	30	6.51	1559.51	4.09	2248.76
GUMUSHANE	40.47	39.47	1300	29	5.39	1800.76	3.47	2582.92
HAKKARI	37.57	43.77	1300	28	5.03	1900.37	3.26	2720.91
HINIZ	39.37	41.70	1700	28	4.45	2096.51	2.92	2992.60
IGDIR	39.93	44.05	866	32	5.90	1679.17	3.75	2414.51
IPSALA	40.93	26.40	25	31	6.06	1643.89	3.85	2365.64
ISPARTA	37.75	30.55	1101	30	5.36	1806.99	3.45	2591.55
GUZELYALI	38.43	27.17	19	28	5.88	1682.15	3.75	2418.64
K.MARAS	37.60	36.92	696	27	5.81	1697.45	3.71	2439.83
KAMAN	39.40	33.78	1007	27	4.44	2099.87	2.92	2997.24
KANGAL	39.23	37.38	1550	30	4.96	1922.24	3.22	2751.19
KARAMAN	37.30	33.33	1025	26	4.98	1916.05	3.23	2742.63
KARAPINAR	37.73	33.55	1000	26	4.92	1935.13	3.20	2769.05
KARS	40.62	43.10	1800	32	4.68	2013.57	3.06	2877.71
KASTAMONU	41.37	33.78	900	33	6.24	1609.96	3.94	2318.63
KELES	39.92	29.07	746	30	5.31	1819.53	3.43	2608.93
KESKIN	39.68	33.62	1121	27	4.54	2062.00	2.98	2944.79
KILIS	36.72	37.12	682	27	5.47	1779.18	3.51	2553.03
KIRSEHIR	39.15	34.17	1019	30	5.15	1864.37	3.33	2671.03
KOCAELI	40.77	29.93	94	32	7.65	1388.80	4.68	2012.30
KONYA	37.97	32.55	1029	29	5.14	1868.72	3.32	2677.06
KOYCEGIZ	36.97	28.68	33	29	5.92	1674.30	3.77	2407.76
KUMKOY	41.24	29.03	37	31	6.61	1541.35	4.14	2223.60
KUSADASI	37.87	27.28	181	29	5.63	1739.59	3.60	2498.19
KUTAHYA	39.42	29.97	1000	29	5.51	1769.95	3.53	2540.26
MALATYA	38.35	38.32	959	28	5.91	1675.51	3.76	2409.44
MALAZGIRT	39.15	42.53	1500	28	4.69	2009.90	3.06	2872.62
MARMARIS	36.86	28.27	37	28	6.09	1638.32	3.86	2357.92
MERSIN	36.80	34.63	9	27	5.68	1727.20	3.63	2481.03
MILAS	37.32	27.78	93	29	6.38	1583.39	4.02	2281.83
MUGLA	37.22	28.37	733	29	5.80	1701.57	3.70	2445.53
MURADIYE	38.98	43.77	1700	29	4.65	2024.01	3.04	2892.16
MUS	38.73	41.52	1330	28	5.79	1703.41	3.69	2448.07

NAZILLI	37.92	28.33	91	28	5.29	1826.91	3.41	2619.14
NEVSEHIR	38.62	34.70	1225	29	5.49	1772.98	3.53	2544.45
NIGDE	37.97	34.68	1250	25	4.54	2061.43	2.98	2944.00
ORDU	40.98	37.90	13	33	6.18	1621.03	3.91	2333.97
OZALP	38.67	43.98	2245	30	4.91	1937.83	3.19	2772.80
POLATLI	39.58	32.15	850	28	5.08	1886.40	3.29	2701.56
RIZE	41.02	40.51	47	35	6.10	1637.79	3.86	2357.18
SAKARYA	40.78	30.42	71	32	6.08	1640.91	3.85	2361.51
SAMSUN	41.28	36.30	100	33	6.16	1625.34	3.90	2339.94
SANLIURFA	37.13	38.77	633	27	6.24	1608.69	3.94	2316.88
SELCUK	37.95	27.36	50	28	5.87	1685.77	3.74	2423.64
SENIRKENT	38.10	30.55	1170	27	5.18	1855.18	3.35	2658.31
SEYDISEHIR	37.42	31.83	1150	29	5.85	1689.90	3.73	2429.37
SIIRT	37.92	41.95	998	28	5.55	1760.19	3.56	2526.73
SILIFKE	36.38	33.93	50	28	5.61	1743.78	3.60	2504.00
SINOP	42.03	35.17	176	32	6.94	1488.68	4.31	2150.65
SIVAS	39.75	37.02	1300	30	6.52	1557.71	4.09	2246.26
SIVEREK	37.77	39.32	800	27	5.78	1704.86	3.69	2450.09
SIVRIHISAR	39.45	31.53	1100	31	6.90	1493.89	4.30	2157.86
SOLHAN	38.97	41.07	1439	30	4.92	1932.28	3.20	2765.10
SILE	41.18	29.62	8	31	7.17	1453.67	4.44	2102.14
TATVAN	38.48	42.30	1686	28	6.82	1507.53	4.25	2176.76
TEFENNI	37.32	29.77	1176	26	5.09	1881.07	3.30	2694.17
TEKIRDAG	40.98	27.55	62	31	6.84	1504.33	4.26	2172.32
TERCAN	39.78	40.38	1500	30	4.95	1924.39	3.22	2754.17
TOKAT	40.30	36.57	1000	31	5.52	1767.78	3.54	2537.25
TORTUM	40.30	41.55	1601	32	4.82	1964.57	3.14	2809.84
TRABZON	41.00	39.72	97	34	5.99	1660.34	3.80	2388.42
TUNCELI	39.12	39.53	1000	28	5.61	1745.66	3.59	2506.60
USAK	38.68	29.40	911	31	5.94	1670.22	3.78	2402.11
UZUNKOPRU	41.27	26.68	25	31	7.09	1465.46	4.39	2118.48
VAN	38.47	43.35	1667	27	4.65	2023.25	3.04	2891.11
YALOVA	40.68	29.37	37	30	6.94	1487.76	4.32	2149.37
YALVAC	38.30	31.18	1106	28	4.84	1959.35	3.15	2802.60
YATAGAN	37.35	28.13	400	26	5.06	1890.20	3.28	2706.81
YENISEHIR	40.25	29.55	239	32	8.29	1314.25	5.00	1909.03
YOZGAT	39.82	34.80	1300	30	5.23	1841.79	3.38	2639.76
YUNAK	38.82	31.73	1131	27	4.73	1995.71	3.09	2852.96
ZONGULDAK	41.45	31.80	100	31	6.49	1563.18	4.08	2253.84

The price of the heating system is 740.49 USD. PBP: payback period; NPV: net present value; LPG: liquid petroleum gas.

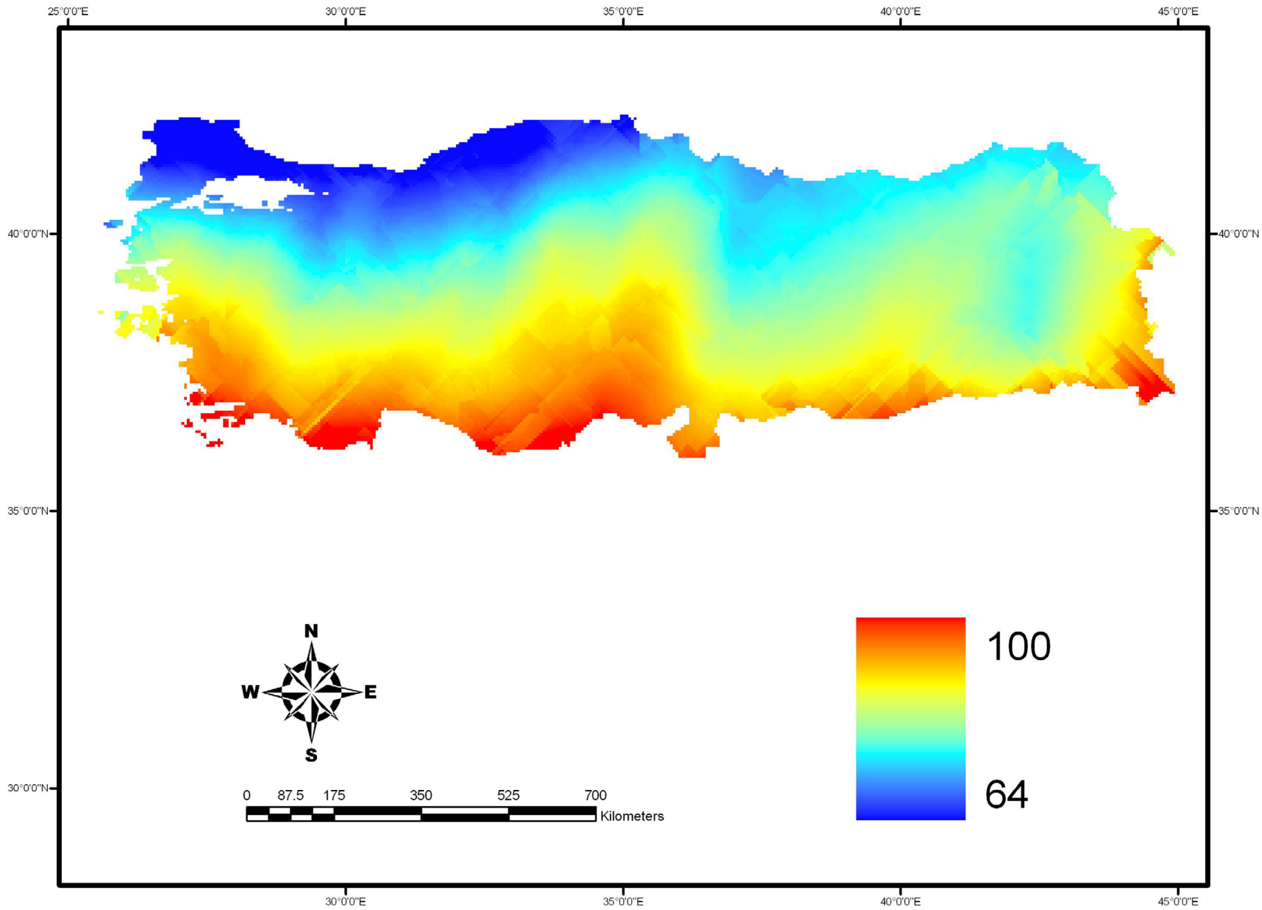

Figure 3. Map of coverage rate (%) of energy requirement for water-heating by selective absorber plates over Turkey based on universal kriging with a grid resolution of 500 m x 500 m.

The shares of the solar water heaters to overcome the annual energy requirements were closely related to the collector types over Turkey. The minimum, maximum and mean values were 63.95%, 97.27% and 82.12% $\pm$ 7.46% for the selective absorber collectors; 42.75%, 87.87% and 64.26% $\pm$ 9.8% for the copper absorber collectors; and 41.06%, 86.62% and 62.62% $\pm$ 9.79% for the galvanized collectors, respectively. It is clear from Figs. 3 to 5 that the selective absorber plate covered the highest percentage of energy requirement all over Turkey. Annual solar contribution of the simulated system was as high as 79% in Cyprus [44]. Annual energy savings by using solar water heater could amount to 85% for Sydney, 72% for Melbourne in Australia, 76% for Kumamoto in Japan, 86% for Miami in USA and 82% for Rome in Italy [45]. With solar irradiance of about 5.5 kWh/m^2/d, a typical Jordanian solar water heater with 4 m^2 net area and 25% average system efficiency over the lifetime has the potential to produce around 150 L of hot water at 55 ^{o}C per day for about 330 sunny days per year [5].

Table 3. Locations, optimum tilt angles, and economic performance indicators of copper absorber plates for 129 sites in Turkey.

	Latitude (decimal degree)	Longitude (decimal degree)	Altitude (m)	Tilt angle (degree)	PBP for electricity (year)	NPV for electricity (USD)	PBP for LPG (year)	NPV for LPG (USD)
ADANA	39.99	35.34	50	27	5.87	1401.52	3.74	2014.98
ADIYAMAN	37.75	38.28	620	27	7.12	1214.39	4.41	1755.78
AFYON	38.75	30.52	1253	26	5.57	1459.18	3.57	2094.85
AKCAKOCA	41.07	31.17	71	27	10.51	937.99	6.03	1372.91
AKHISAR	38.93	27.84	100	27	5.16	1548.99	3.34	2219.25
AKSARAY	38.63	33.99	1320	28	5.70	1432.26	3.65	2057.56
AKSEHIR	38.35	31.42	1042	28	5.33	1508.66	3.44	2163.39
ANAMUR	36.08	32.83	83	26	5.59	1455.02	3.58	2089.10
ANKARA	39.95	32.88	900	26	7.28	1196.07	4.49	1730.40
ANTAKYA	36.2	36.17	158	24	7.78	1140.96	4.75	1654.06
ANTALYA	36.9	30.73	63	26	5.56	1460.38	3.57	2096.52
ARTVIN	41.18	41.82	624	30	5.60	1451.97	3.59	2084.87
AYDIN	37.85	27.85	72	28	5.71	1431.07	3.65	2055.92
AYVALIK	39.3	26.7	25	26	6.86	1248.02	4.27	1802.36
BALIKESIR	39.63	27.91	118	26	8.80	1049.98	5.25	1528.05
BASKALE	38.05	44.02	2296	24	3.92	1936.95	2.60	2756.65
BERGAMA	39.13	27.18	100	27	5.92	1392.75	3.76	2002.84
BILECIK	40.15	29.97	569	27	7.15	1210.66	4.43	1750.61
BINGOL	38.87	40.5	1148	27	5.92	1392.09	3.77	2001.92
BIRECIK	37.03	37.98	400	27	6.02	1374.13	3.82	1977.04
BITLIS	38.37	42.1	1500	24	6.51	1295.97	4.09	1868.79
BODRUM	37.04	27.43	50	27	5.55	1462.26	3.56	2099.12
BORNOVA	38.47	27.22	50	29	7.62	1157.94	4.67	1677.58
BOZKURT	41.95	34.02	104	27	9.93	971.68	5.77	1419.59
BOZUYUK	39.92	30.03	800	28	5.73	1426.77	3.66	2049.96
BURDUR	37.67	30.33	1263	26	5.07	1570.32	3.29	2248.80
BURSA	40.19	29.07	200	28	8.45	1078.47	5.08	1567.51
CANAKKALE	40.1	26.39	8	26	7.66	1153.52	4.69	1671.46
CANKIRI	40.6	33.62	774	28	6.54	1291.53	4.11	1862.63
CERKES	40.82	32.9	1200	28	10.77	924.45	6.14	1354.16
CESME	38.3	26.35	48	27	7.09	1218.59	4.39	1761.60
CIHANBEYLI	38.65	32.92	968	28	6.59	1285.58	4.13	1854.39
CORUM	40.55	34.95	795	29	5.84	1405.74	3.72	2020.82
DENIZLI	37.78	29.08	408	27	7.03	1226.08	4.36	1771.97

DEVELI	38.38	35.5	1305	25	4.38	1765.57	2.88	2519.25
DEVREKANI	41.58	33.83	1150	32	6.27	1333.59	3.96	1920.89
DIKILI	39.07	26.89	46	29	6.40	1312.99	4.03	1892.35
DIYARBAKIR	37.9	40.19	677	27	5.84	1406.34	3.72	2021.66
DORTYOL	36.85	36.22	55	27	5.05	1575.69	3.27	2256.23
DURSUNBEY	39.58	28.62	604	29	5.70	1433.90	3.64	2059.83
DUZCE	40.83	31.17	200	28	7.57	1163.22	4.64	1684.90
EDIRNE	41.67	26.57	50	27	10.79	923.66	6.15	1353.07
EDREMIT	39.58	27.02	43	28	5.33	1510.39	3.43	2165.78
ELAZIG	38.65	39.25	1000	25	6.89	1243.72	4.29	1796.40
ELBISTAN	38.2	37.18	1226	26	5.94	1388.82	3.78	1997.40
EREGLI	37.5	34.05	1053	26	5.19	1540.12	3.36	2206.97
ERGANI	38.28	39.77	1068	27	5.75	1423.35	3.67	2045.22
ERZINCAN	39.75	39.5	1200	28	6.20	1343.93	3.92	1935.22
ERZURUM	39.95	41.17	1781	28	6.18	1348.07	3.91	1940.95
ESKISEHIR	39.78	30.57	800	27	8.55	1070.19	5.13	1556.04
ETIMESGUT	39.95	32.68	800	27	6.33	1323.96	3.99	1907.56
FLORYA	40.98	28.8	41	28	8.70	1057.84	5.20	1538.93
GAZIANTEP	37.08	37.37	851	27	6.60	1282.83	4.14	1850.58
GEMEREK	39.18	36.07	1230	26	4.82	1633.50	3.14	2336.32
GIRESUN	40.91	38.38	86	31	8.34	1088.21	5.03	1581.00
GOKSUN	38.03	36.5	1358	26	6.96	1234.81	4.33	1784.06
GONEN	40.1	27.65	50	27	7.14	1212.64	4.42	1753.36
GOZTEPE	40.97	29.08	34	26	7.62	1157.30	4.67	1676.71
GUMUSHANE	40.47	39.47	1300	25	5.39	1496.59	3.47	2146.68
HAKKARI	37.57	43.77	1300	27	5.32	1511.27	3.43	2167.00
HINIZ	39.37	41.7	1700	27	4.60	1697.25	3.01	2424.62
IGDIR	39.93	44.05	866	28	6.62	1280.74	4.15	1847.69
IPSALA	40.93	26.4	25	27	7.21	1203.90	4.46	1741.24
ISPARTA	37.75	30.55	1101	28	6.19	1346.28	3.91	1938.46
GUZELYALI	38.43	27.17	19	27	6.04	1371.16	3.83	1972.94
K.MARAS	37.6	36.92	696	26	5.92	1392.03	3.77	2001.84
KAMAN	39.4	33.78	1007	26	4.26	1805.26	2.81	2574.23
KANGAL	39.23	37.38	1550	27	6.24	1338.46	3.94	1927.63
KARAMAN	37.3	33.33	1025	25	5.11	1560.26	3.31	2234.87
KARAPINAR	37.73	33.55	1000	26	5.06	1572.15	3.28	2251.34
KARS	40.62	43.1	1800	30	5.93	1390.47	3.77	1999.67
KASTAMONU	41.37	33.78	900	31	8.12	1107.67	4.92	1607.96
KELES	39.92	29.07	746	27	6.45	1305.64	4.05	1882.18
KESKIN	39.68	33.62	1121	26	4.37	1768.04	2.88	2522.68

KILIS	36.72	37.12	682	25	5.33	1508.95	3.44	2163.79
KIRSEHIR	39.15	34.17	1019	29	5.36	1503.22	3.45	2155.86
KOCAELI	40.77	29.93	94	28	10.49	939.40	6.02	1374.88
KONYA	37.97	32.55	1029	28	5.32	1511.40	3.43	2167.18
KOYCEGIZ	36.97	28.68	33	29	5.66	1439.76	3.62	2067.95
KUMKOY	41.24	29.03	37	25	8.78	1051.03	5.24	1529.50
KUSADASI	37.87	27.28	181	28	5.70	1433.23	3.64	2058.90
KUTAHYA	39.42	29.97	1000	26	6.07	1366.47	3.85	1966.43
MALATYA	38.35	38.32	959	27	6.19	1346.35	3.91	1938.56
MALAZGIRT	39.15	42.53	1500	24	5.39	1496.43	3.47	2146.45
MARMARIS	36.86	28.27	37	27	6.20	1343.70	3.92	1934.90
MERSIN	36.8	34.63	9	27	5.04	1576.85	3.27	2257.85
MILAS	37.32	27.78	93	28	6.63	1278.64	4.15	1844.77
MUGLA	37.22	28.37	733	26	6.64	1278.29	4.15	1844.30
MURADIYE	38.98	43.77	1700	28	4.74	1655.16	3.10	2366.31
MUS	38.73	41.52	1330	25	6.39	1313.90	4.02	1893.61
NAZILLI	37.92	28.33	91	28	5.08	1568.45	3.29	2246.21
NEVSEHIR	38.62	34.7	1225	24	6.72	1266.66	4.20	1828.19
NIGDE	37.97	34.68	1250	24	4.56	1710.54	2.99	2443.03
ORDU	40.98	37.9	13	30	7.62	1157.35	4.67	1676.77
OZALP	38.67	43.98	2245	30	5.90	1395.36	3.76	2006.46
POLATLI	39.58	32.15	850	26	5.22	1534.93	3.37	2199.78
RIZE	41.02	40.51	47	33	8.42	1080.78	5.07	1570.70
SAKARYA	40.78	30.42	71	28	6.97	1233.60	4.33	1782.39
SAMSUN	41.28	36.3	100	30	7.63	1156.36	4.67	1675.40
SANLIURFA	37.13	38.77	633	27	6.43	1307.67	4.05	1884.99
SELCUK	37.95	27.36	50	27	6.03	1372.80	3.83	1975.20
SENIRKENT	38.1	30.55	1170	26	5.15	1550.23	3.33	2220.97
SEYDISEHIR	37.42	31.83	1150	25	7.22	1202.60	4.46	1739.45
SIIRT	37.92	41.95	998	27	5.72	1429.68	3.65	2053.99
SILIFKE	36.38	33.93	50	26	5.40	1495.17	3.47	2144.70
SINOP	42.03	35.17	176	28	9.45	1002.51	5.55	1462.28
SIVAS	39.75	37.02	1300	27	8.60	1065.74	5.15	1549.88
SIVEREK	37.77	39.32	800	26	6.26	1334.38	3.95	1921.99
SIVRIHISAR	39.45	31.53	1100	27	9.87	974.87	5.75	1424.01
SOLHAN	38.97	41.07	1439	29	5.39	1496.05	3.47	2145.92
SILE	41.18	29.62	8	25	9.52	997.64	5.59	1455.54
TATVAN	38.48	42.3	1686	22	8.29	1092.61	5.00	1587.09
TEFENNI	37.32	29.77	1176	25	5.29	1519.22	3.41	2178.02
TEKIRDAG	40.98	27.55	62	27	8.52	1072.22	5.12	1558.84

TERCAN	39.78	40.38	1500	28	5.56	1460.99	3.56	2097.36
TOKAT	40.3	36.57	1000	28	6.10	1360.21	3.87	1957.76
TORTUM	40.3	41.55	1601	31	5.43	1487.78	3.49	2134.47
TRABZON	41	39.72	97	33	7.51	1169.93	4.61	1694.19
TUNCELI	39.12	39.53	1000	27	5.97	1383.35	3.79	1989.82
USAK	38.68	29.4	911	28	7.54	1166.51	4.63	1689.46
UZUNKOPRU	41.27	26.68	25	27	9.45	1002.24	5.55	1461.92
VAN	38.47	43.35	1667	26	4.77	1647.96	3.11	2356.34
YALOVA	40.68	29.37	37	25	7.74	1145.09	4.73	1659.78
YALVAC	38.3	31.18	1106	27	4.94	1601.74	3.21	2292.33
YATAGAN	37.35	28.13	400	26	4.68	1673.50	3.06	2391.73
YENISEHIR	40.25	29.55	239	26	12.28	857.33	6.76	1261.19
YOZGAT	39.82	34.8	1300	27	6.31	1326.49	3.98	1911.05
YUNAK	38.82	31.73	1131	26	4.66	1679.16	3.05	2399.56
ZONGULDAK	41.45	31.8	100	27	7.51	1169.03	4.61	1692.95

The price of the heating system is 615.69 USD. PBP: payback period; NPV: net present value; LPG: liquid petroleum gas.

The economic comparisons were quantified according to the different conventional options of electricity and LPG (Tables 2 to 4). The PBP for using the selective surface collector was in the range of 4.09 to 8.37 years for electricity and 2.71 to 5.04 years for LPG. While the energy cost was between 0.077 and 0.147 USD/kWh with an average of 0.107 USD/kWh ± 0.015 USD/kWh for electricity and between 0.084 and 0.179 USD/kWh with an average of 0.123 USD/kWh ± 0.021 USD/kWh for LPG. The calculated NPV values ranged from 1304.96 to 2247.09 USD for electricity and from 1896.16 to 3201.16 USD for LPG.

In the copper collector, the PBP varied between 3.92 and 12.28 years for electricity and between 2.60 and 6.76 years for LPG. The energy cost ranged from 0.093 to 0.181 USD/kWh with an average of 0.136 USD/kWh ± 0.020 USD/kWh for electricity and from 0.104 to 0.229 USD/kWh with an average of 0.167 USD/kWh ± 0.029 USD/kWh for LPG. The NPV changed from 857.33 to 1936.95 USD for electricity and from 1261.19 to 2756.65 USD for LPG.

In the galvanized collector, when compared to electricity, the PBP varied between 2.98 and 8.24 years, the energy cost was between 0.083 and 0.173 USD/kWh with an average of 0.128 USD/kWh ± 0.0021 USD/kWh over Turkey. The NPV also changed from 874.58 to 1952.32 USD. When compared to LPG, the PBP changed from 2.02 to 4.98 years. While the energy cost varied between 0.094 and 0.224 USD/kWh with an average of 0.161 USD/kWh ± 0.029 USD/kWh, the NPV ranged between 1270.15 and 2763.01 USD. The PBP of the system was 8 years in Cyprus, the present worth of life cycle savings was equal to 293 USD, and annualized total cost with solar energy was 0.098 USD/kWh [44]. The cost of useful heating energy from solar power was around 0.035 USD/kWh in Saudi Arabia [46]. The PBP was 8.6 years in Jordan. Net energy collected was about 1807 kWh/year and using solar water heater instead of LPG to heat water resulted in savings of 16.4 USD/m^2 collector surface in Jordan [47]. The PBP of solar water heaters in Taiwan was about 5-6 years [48]. The PBP ranged from 2.92 years with respect to electricity to 4.53 years with respect to kerosene in India [18]. Lebanon had a PBP of 7 years and cash savings of 2610 USD during the 20-year use of the galvanized collector [3]. Life cycle savings for the use of the galvanized collector in Italy were in the range of 5957 to 10328 Euro [49].

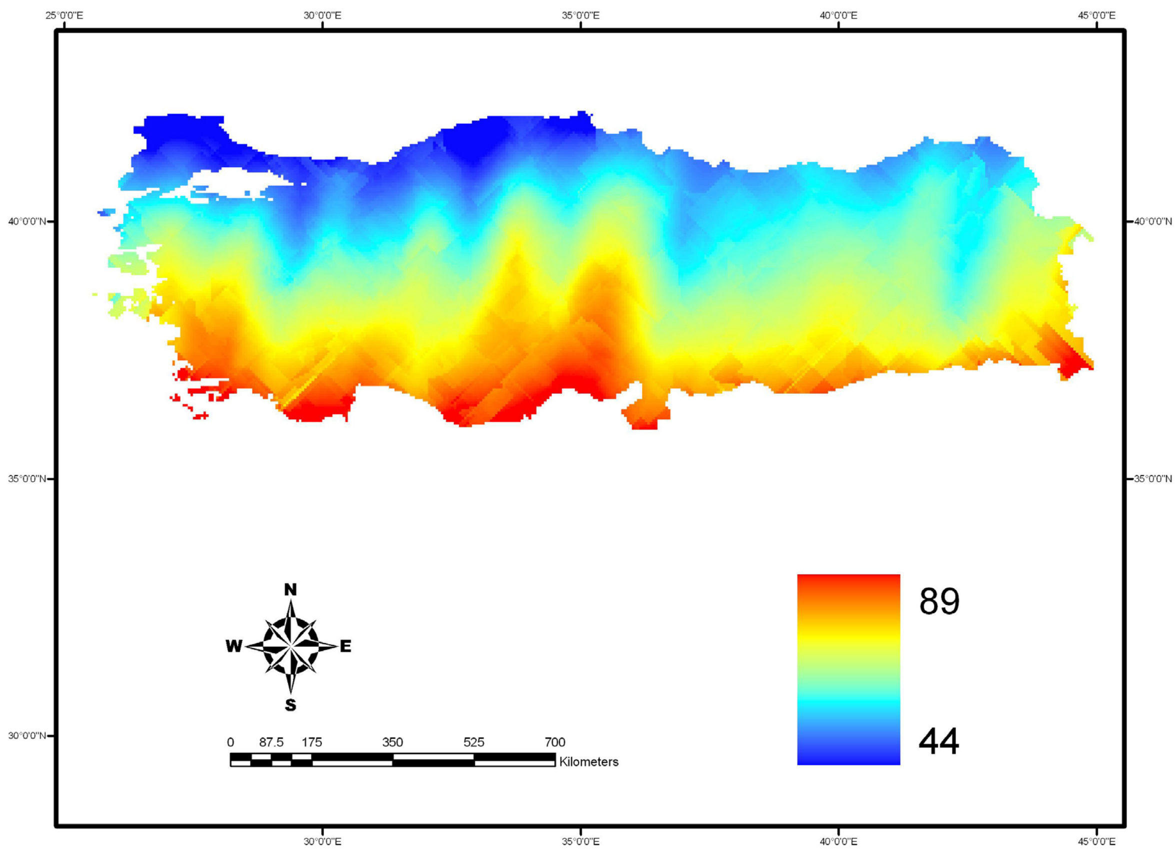

Figure 4. Map of coverage rate (%) of energy requirement for water-heating by copper absorber plates over Turkey based on universal kriging with a grid resolution of 500 m x 500 m.

Table 4. Locations, optimum tilt angles, and economic performance indicators of galvanized absorber plates for 129 sites in Turkey.

	Latitude (decimal degree)	Longitude (decimal degree)	Altitude (m)	Tilt angle (degree)	PBP for electricity (year)	NPV for electricity (USD)	PBP for LPG (year)	NPV for LPG (USD)
ADANA	39.99	35.34	50	27	4.36	1412.06	2.87	2014.66
ADIYAMAN	37.75	38.28	620	27	5.20	1227.12	3.36	1758.49
AFYON	38.75	30.52	1253	26	4.16	1468.52	2.75	2092.86
AKCAKOCA	41.07	31.17	71	27	7.29	952.43	4.50	1378.00
AKHISAR	38.93	27.84	100	27	3.88	1556.01	2.58	2214.05
AKSARAY	38.63	33.99	1320	28	4.26	1439.41	2.81	2052.55
AKSEHIR	38.35	31.42	1042	28	4.01	1515.67	2.66	2158.17
ANAMUR	36.08	32.83	83	26	4.15	1471.94	2.74	2097.60

ANKARA	39.95	32.88	900	26	5.32	1205.97	3.43	1729.19
ANTAKYA	36.2	36.17	158	24	5.58	1161.50	3.58	1667.59
ANTALYA	36.9	30.73	63	26	4.13	1477.51	2.73	2105.32
ARTVIN	41.18	41.82	624	30	4.21	1453.75	2.78	2072.40
AYDIN	37.85	27.85	72	28	4.26	1441.83	2.81	2055.89
AYVALIK	39.3	26.7	25	26	4.99	1267.91	3.24	1814.99
BALIKESIR	39.63	27.91	118	26	6.23	1067.71	3.94	1537.67
BASKALE	38.05	44.02	2296	24	2.98	1952.32	2.02	2763.01
BERGAMA	39.13	27.18	100	27	4.38	1406.95	2.88	2007.58
BILECIK	40.15	29.97	569	27	5.23	1220.75	3.38	1749.66
BINGOL	38.87	40.5	1148	27	4.45	1390.44	2.92	1984.71
BIRECIK	37.03	37.98	400	27	4.47	1384.91	2.94	1977.06
BITLIS	38.37	42.1	1500	24	4.81	1305.00	3.14	1866.36
BODRUM	37.04	27.43	50	27	4.15	1472.49	2.74	2098.36
BORNOVA	38.47	27.22	50	29	5.56	1165.24	3.56	1672.77
BOZKURT	41.95	34.02	104	27	6.96	984.88	4.32	1422.94
BOZUYUK	39.92	30.03	800	28	4.31	1427.74	2.84	2036.37
BURDUR	37.67	30.33	1263	26	3.81	1581.95	2.54	2249.98
BURSA	40.19	29.07	200	28	6.04	1093.20	3.83	1572.99
CANAKKALE	40.1	26.39	8	26	5.58	1161.74	3.57	1667.93
CANKIRI	40.6	33.62	774	28	4.86	1295.25	3.16	1852.86
CERKES	40.82	32.9	1200	28	7.64	921.14	4.68	1334.65
CESME	38.3	26.35	48	27	5.13	1239.40	3.32	1775.50
CIHANBEYLI	38.65	32.92	968	28	4.88	1290.17	3.18	1845.81
CORUM	40.55	34.95	795	29	4.38	1407.89	2.88	2008.88
DENIZLI	37.78	29.08	408	27	5.17	1232.45	3.34	1765.86
DEVELI	38.38	35.5	1305	25	3.31	1780.92	2.23	2525.60
DEVREKANI	41.58	33.83	1150	32	4.68	1333.88	3.06	1906.37
DIKILI	39.07	26.89	46	29	4.69	1331.41	3.07	1902.95
DIYARBAKIR	37.9	40.19	677	27	4.33	1421.11	2.85	2027.20
DORTYOL	36.85	36.22	55	27	4.33	1421.11	2.85	2027.20
DURSUNBEY	39.58	28.62	604	29	4.26	1441.14	2.81	2054.94
DUZCE	40.83	31.17	200	28	5.48	1177.52	3.52	1689.78
EDIRNE	41.67	26.57	50	27	7.36	945.79	4.53	1368.79
EDREMIT	39.58	27.02	43	28	3.99	1519.41	2.65	2163.35
ELAZIG	38.65	39.25	1000	25	5.06	1253.73	3.28	1795.35
ELBISTAN	38.2	37.18	1226	26	4.45	1390.94	2.92	1985.40
EREGLI	37.5	34.05	1053	26	3.89	1553.00	2.59	2209.88
ERGANI	38.28	39.77	1068	27	4.26	1440.30	2.81	2053.77
ERZINCAN	39.75	39.5	1200	28	4.62	1348.52	3.02	1926.65
ERZURUM	39.95	41.17	1781	28	4.64	1344.11	3.03	1920.53

ESKISEHIR	39.78	30.57	800	27	6.16	1077.74	3.90	1551.56
ETIMESGUT	39.95	32.68	800	27	4.70	1330.35	3.07	1901.48
FLORYA	40.98	28.8	41	28	6.18	1074.38	3.91	1546.91
GAZIANTEP	37.08	37.37	851	27	4.84	1299.79	3.15	1859.14
GEMEREK	39.18	36.07	1230	26	3.63	1645.35	2.43	2337.80
GIRESUN	40.91	38.38	86	31	6.02	1095.99	3.82	1576.85
GOKSUN	38.03	36.5	1358	26	5.16	1234.27	3.34	1768.38
GONEN	40.1	27.65	50	27	5.23	1221.73	3.38	1751.02
GOZTEPE	40.97	29.08	34	26	5.53	1169.24	3.55	1678.31
GUMUSHANE	40.47	39.47	1300	25	4.03	1508.78	2.67	2148.63
HAKKARI	37.57	43.77	1300	27	4.01	1512.90	2.66	2154.34
HINIZ	39.37	41.7	1700	27	3.52	1688.91	2.36	2398.14
IGDIR	39.93	44.05	866	28	4.90	1285.92	3.19	1839.92
IPSALA	40.93	26.4	25	27	5.28	1212.07	3.41	1737.64
ISPARTA	37.75	30.55	1101	28	4.61	1350.04	3.02	1928.75
GUZELYALI	38.43	27.17	19	28	4.61	1350.04	3.02	1928.75
K.MARAS	37.6	36.92	696	27	4.49	1381.03	2.94	1971.68
KAMAN	39.4	33.78	1007	26	3.24	1813.72	2.19	2571.03
KANGAL	39.23	37.38	1550	27	4.67	1336.42	3.05	1909.89
KARAMAN	37.3	33.33	1025	25	3.83	1574.44	2.55	2239.57
KARAPINAR	37.73	33.55	1000	26	3.79	1586.17	2.53	2255.83
KARS	40.62	43.1	1800	30	4.46	1387.44	2.93	1980.55
KASTAMONU	41.37	33.78	900	31	5.88	1115.05	3.75	1603.25
KELES	39.92	29.07	746	27	4.76	1315.72	3.11	1881.22
KESKIN	39.68	33.62	1121	26	3.31	1781.89	2.23	2526.93
KILIS	36.72	37.12	682	25	4.00	1516.85	2.65	2159.81
KIRSEHIR	39.15	34.17	1019	29	4.06	1499.87	2.69	2136.29
KOCAELI	40.77	29.93	94	28	7.20	960.70	4.45	1389.45
KONYA	37.97	32.55	1029	28	3.99	1520.41	2.65	2164.74
KOYCEGIZ	36.97	28.68	33	29	4.23	1447.89	2.79	2064.28
KUMKOY	41.24	29.03	37	25	6.24	1067.01	3.94	1536.70
KUSADASI	37.87	27.28	181	28	4.25	1444.67	2.80	2059.82
KUTAHYA	39.42	29.97	1000	26	4.52	1371.70	2.97	1958.76
MALATYA	38.35	38.32	959	27	4.54	1368.53	2.97	1954.36
MALAZGIRT	39.15	42.53	1500	24	4.06	1499.88	2.69	2136.31
MARMARIS	36.86	28.27	37	27	4.59	1355.75	3.01	1936.65
MERSIN	36.8	34.63	9	27	3.78	1590.47	2.52	2261.78
MILAS	37.32	27.78	93	28	4.84	1297.82	3.16	1856.42
MUGLA	37.22	28.37	733	26	4.91	1283.97	3.19	1837.22
MURADIYE	38.98	43.77	1700	28	3.63	1644.72	2.43	2336.93
MUS	38.73	41.52	1330	25	4.74	1320.11	3.10	1887.30

NAZILLI	37.92	28.33	91	28	3.83	1574.26	2.55	2239.33
NEVSEHIR	38.62	34.7	1225	24	4.95	1275.20	3.22	1825.08
NIGDE	37.97	34.68	1250	24	3.46	1716.81	2.32	2436.78
ORDU	40.98	37.9	13	30	5.52	1171.10	3.54	1680.89
OZALP	38.67	43.98	2245	30	4.47	1385.94	2.93	1978.47
POLATLI	39.58	32.15	850	26	3.91	1548.06	2.60	2203.04
RIZE	41.02	40.51	47	33	6.27	1062.45	3.96	1530.39
SAKARYA	40.78	30.42	71	28	5.12	1242.34	3.31	1779.56
SAMSUN	41.28	36.3	100	30	5.53	1169.38	3.55	1678.50
SANLIURFA	37.13	38.77	633	27	4.72	1324.46	3.08	1893.32
SELCUK	37.95	27.36	50	27	4.46	1388.23	2.93	1981.65
SENIRKENT	38.1	30.55	1170	26	3.86	1563.93	2.57	2225.02
SEYDISEHIR	37.42	31.83	1150	25	5.30	1209.42	3.42	1733.97
SIIRT	37.92	41.95	998	27	4.25	1443.61	2.80	2058.36
SILIFKE	36.38	33.93	50	26	4.04	1504.36	2.68	2142.51
SINOP	42.03	35.17	176	28	6.62	1021.54	4.14	1473.71
SIVAS	39.75	37.02	1300	27	6.18	1074.57	3.91	1547.18
SIVEREK	37.77	39.32	800	26	4.61	1350.60	3.02	1929.52
SIVRIHISAR	39.45	31.53	1100	27	6.95	985.40	4.32	1423.66
SOLHAN	38.97	41.07	1439	27	6.95	985.40	4.32	1423.66
SILE	41.18	29.62	8	25	6.63	1019.65	4.15	1471.11
TATVAN	38.48	42.3	1686	25	6.63	1019.65	4.15	1471.11
TEFENNI	37.32	29.77	1176	25	3.96	1530.60	2.63	2178.86
TEKIRDAG	40.98	27.55	62	27	6.08	1087.29	3.86	1564.80
TERCAN	39.78	40.38	1500	28	4.20	1458.78	2.77	2079.37
TOKAT	40.3	36.57	1000	28	4.56	1361.60	2.99	1944.76
TORTUM	40.3	41.55	1601	31	4.12	1482.14	2.72	2111.73
TRABZON	41	39.72	97	33	5.51	1172.19	3.54	1682.39
TUNCELI	39.12	39.53	1000	27	4.41	1400.47	2.90	1998.61
USAK	38.68	29.4	911	28	5.48	1177.64	3.52	1689.95
UZUNKOPRU	41.27	26.68	25	27	6.62	1020.79	4.15	1472.68
VAN	38.47	43.35	1667	26	3.60	1658.73	2.41	2356.33
YALOVA	40.68	29.37	37	25	5.58	1161.86	3.57	1668.09
YALVAC	38.3	31.18	1106	25	5.58	1161.86	3.57	1668.09
YATAGAN	37.35	28.13	400	26	3.53	1687.80	2.36	2396.61
YENISEHIR	40.25	29.55	239	26	8.24	874.58	4.98	1270.15
YOZGAT	39.82	34.8	1300	27	4.68	1335.04	3.06	1907.97
YUNAK	38.82	31.73	1131	26	3.53	1687.80	2.36	2396.61
ZONGULDAK	41.45	31.8	100	27	5.45	1182.39	3.50	1696.52

The price of the heating system is 490.89 USD. PBP: payback period; NPV: net present value; LPG: liquid petroleum gas.

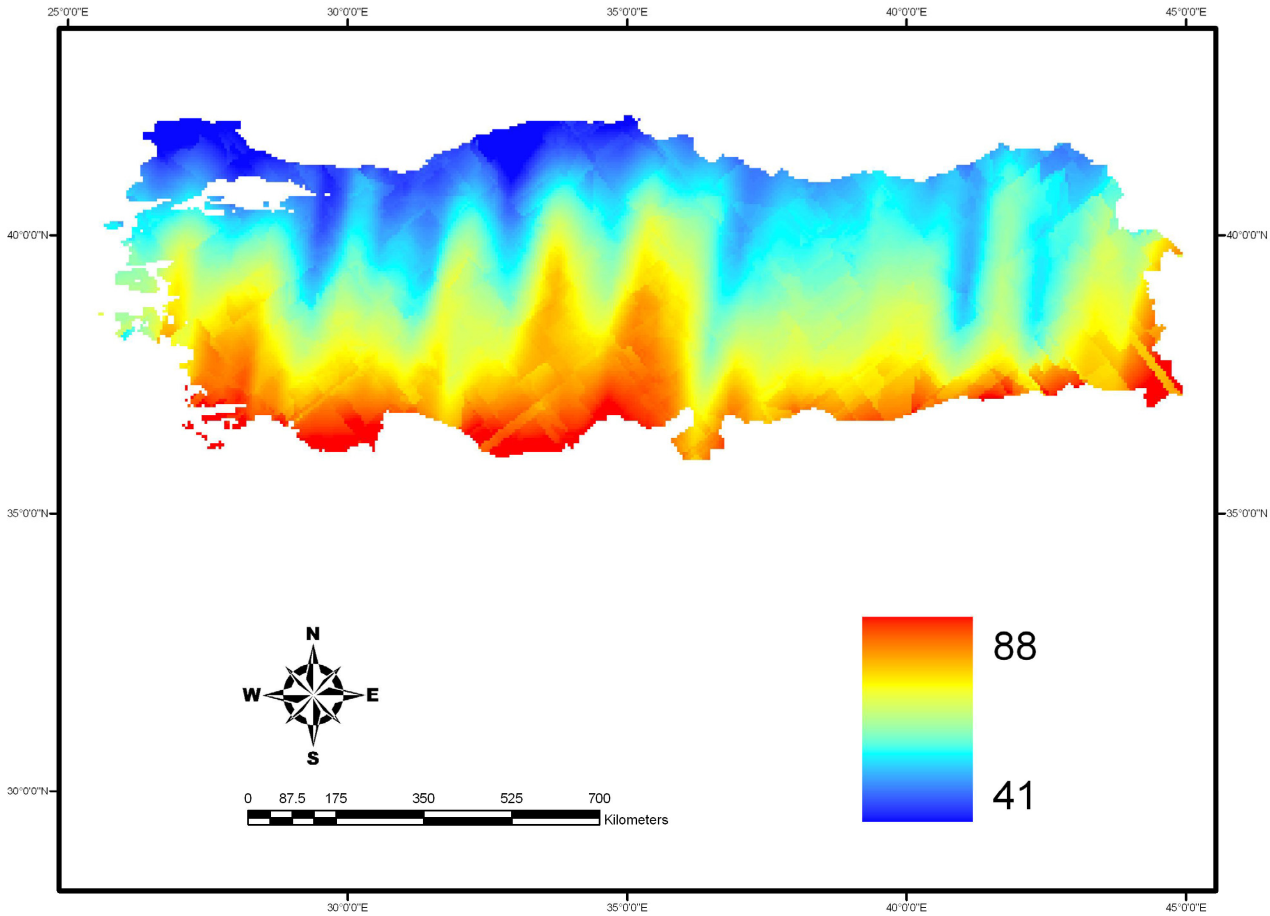

Figure 5. Map of coverage rate (%) of energy requirement for water-heating by galvanized absorber plates over Turkey based on universal kriging with a grid resolution of 500 m x 500 m.

If we used only electricity to overcome the heat requirement for hot water for one family, the energy cost would be between 0.173 and 0.179 USD/kWh with an average of 0.175 USD/kWh $\pm$ 0.001 USD/kWh. This varies between 0.233 and 0.240 USD/kWh with an average of 0.236 USD/kWh $\pm$ 0.002 USD/kWh for using LPG in the process.

6. Conclusions

Cleaner energy technologies towards increasing eco-efficiency and reducing risks to both humans and the environment are becoming increasingly significant for domestic and different industrial sectors. For Turkey, three options of solar water heating systems were identified as having both economic and environmental advantages. For each option, the most economical advantages that can be achieved in energy savings along with its simple payback periods were quantified. Based on their economic, environmental, and product quality advantages, implementing the galvanized solar water heater was favored due to its shorter payback period. The selective solar water heaters had a higher NPV than the others. Thus, in order to achieve the best solution, the galvanized solar water heaters could be built wherever the energy requirement is low, while the selective solar waters should be preferred if the energy requirement is high in Turkey.

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