District Heating Planning with Focus on Solar Energy and Heat Pump Using GIS and the Supervised Learning Method: Case study of Gaziantep, Turkey

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Highlights

- Site selection to operate district heating based on solar energy
- Heating demand forecasting by support vector regression
- Economic and environmental objective function to reach sustainability
- Energy planning and modeling by EnergyPLAN software

Abstract

In the present context, the global concern on energy consumption and management have been significantly increased due to the environmental issues, such as global warming and greenhouse gas emission. The heating supply is one of the most energy-intensive applications at present, and this study presents an effective model for planning and utilizing a district heating system. Further, the model is applied to a province in Turkey to fulfill environmental, technical, and economic goals. In the first step, indices have been used, including demographics, efficiency of the buildings, and the number of households, to predict the required heating load by support vector regression (SVR) as a supervised machine learning method until 2030. The heat energy demand would be increased by 9% in 2030 compared to 2020.. Thereafter, most suitable regions are evaluated to establish district heating systems based on geographic information system (GIS). The classification of Gaziantep province shows that more than 70% of the area is suitable for establishing a solar-based district heating system. The center of the province including Shahinbey, Sehitkamil, and Araban, is the highest priority to integrate a solar energy system into the existing energy system to maximize its share of the energy system. Therefore,, in this research, five general scenarios including different combinations of heat pump (HP), solar thermal (ST), photovoltaic (PV) system, battery (BT), and heat storage (HS) are defined and analyzed to determine the most effective scenario, in terms of economic and environmental aspects. Finally, results show all scenarios could reduce the CO2 emissions; however, the combination of ST and HP has the least costs due to the 21.8% reduction in the total primary energy (TPE) supply compared to BAU. Applying solar energy with a heat pump (S5) leads a 37% reduction in CO2 emissions compared to BAU. Overall, the minimum emissions is belonged to scenario 5, including solar heat pump and storage. Moreover, the effects of parameters such as carbon taxes, technological advancements, and electricity prices are evaluated by to sensitivity analysis to confirm the reliability of the results.

Keywords: District heating; energy consumption prediction; GIS; heat pump; solar thermal; Planning

Nomenclatures

Abbreviation	Description	Abbreviation	Description
ANN	Artificial Neural Network	*PPP*	Purchasing Power Parities
BAU	Business as Usual	*PV*	Photovoltaic
BT	Battery	*RES*	Renewable Energy Resources
CDD	Cooling Degree Day	*S*	Scenario
COP	Coefficient of Performance	*ST*	Solar Thermal
CHP	Combine Heat and Power	*SVM*	Support Vector Machine
CO_2	Carbone dioxide	*SVR*	Support Vector Regression
EU	European Union	*TAC*	Total Annual Cost
GIS	Geographic Information System	*TPE*	Total Primary Energy
HDD	Heating Degree Day		
HP	Heat Pump		
HS	Heat Storage		
IEA	International Energy Agency		
O&M	Operation and maintenance		

1. Introduction

Nowadays, due to the environmental and climate change concerns, people frequently consume renewable energy sources (RESs) than decades before [1]. This movement can provide background to achieve sustainable energy system as studied in [2] and [3] that operated an energy system based on RESs to meet sustainable goals [4]. For instance, the renewable share in final energy consumption has increased globally from 6.4% in 1990 to 11.5% in 2019 [5]. Moreover, the total final energy consumption in this sector has grown by about 40% ,and carbon dioxide emissions is increased by approximately 8% [6], [7]. The usage of RES in Turkey is investigated according to the perspective of the European Union (EU) from different aspects, such as technical, potential, and rules and regulations [8]. The potential of Turkey in achieving 100% renewable energy by 2050 is explored in two different phases by Kilickaplan et al. [9]. Further, Bayraktar concluded that Turkey has the potential to meet the Paris agreement goals ,and could play a key role in the region by producing and supplying different renewable technologies, especially solar energy [10]. Turkey is relatively a large country that has two different climates as Mediterranean climate and continental climate [11]. In Turkey, Natural gas and coal are primly contributed to electricity generation. For instance, fossil fuels account for 83% of the total primary energy (TPE) supply and 73% of the total final energy [12]. The district heating system is one of the efficient solutions in terms of the environmental impact and CO2 emissions, which could increase the overall efficiency of the system and gain benefits from scalability. The general concept of the district heating system is to supply heat from one or more central heating sources through a network of pipes containing hot water or steam to meet the demand. However, in Turkey, a small proportion of the heat demand is met through district heating. According to the EU, in the heating sector, centralized district systems contribute 9% of the EU, and the heating is primarily supplied by fossil fuels such as gas (40%) and coal (29%) [13]. In [14], heating system in Iran was investigated by a simulation to compare renewable energy systems and natural gas-based system.

As the 18th largest global economy, Turkey has gained a 3% economic growth during the last 30 years [15]. The energy dependence of 76% in Turkey and the growing importance of energy in the current world have influenced the country to pursue its energy policies with two priorities such as renewable energy development and energy efficiency increment [16]. According to the 11th development plan, Turkey intends to increase the renewable energy share to 38.37% by 2030. Many researchers observed that Turkey has the highest potential for using and expanding renewable energy, primly geothermal and wind energy, among all other European countries [17]. For example, the capacities of geothermal, wind, and solar in Turkey are estimated at around 64GW, 114GW, and 56 GW, respectively, which is the highest wind potential and the second-highest solar potential among other European countries [18].

However, in Turkey, only a small proportion of the heating demand is met by district heating. Generally, district heating systems are classified into five generations in history. In the first generation, coal-fired steam boilers were used for steaming and steel pipes used to transfer the steam (1880-1930) [13,19]. Thereafter, in the second generation, the heat carrier was pressurized hot water at 100 °C, which was generated by coal and oil-fired CHPs and boilers (1930-1980) [13,19]. In the third generation, pressurized hot water under 100 °C is used as the heat carrier, and large-scale CHPs, biomass, waste, and fossil fuels were usually utilized to generate the energy (1980-onwards) [13]. Moreover, in the fourth generation, water temperature of heat carriers has been decreased to 50-70 °C. In addition to the conventional methods, renewable energy sources and excess industrial heat were applied during this period (2014-onwards)[19]. Eventually, the fifth generation of the district heating systems has applied comparatively low-temperature water at around 10-40 °C [19], [13]. Further, a heat source with a low temperature, such as a local waste heat recovery unit or a renewable energy source is required in this period (2016-onwards) [19].In the feasibility study Huang et al.[20], has observed solar-based district heating systems, and applied the PEST and SWOT methods to analyze the case study. An economic and environmental analysis was presented in [21], where the required heating load was accomplished by the district heating system along with the excess heat produced by the industry to reduce carbon dioxide emissions. Noorollahi et al. has surveyed four different structures based on heat pumps (HP) and renewable energy to find the optimum scheme for the energy hub [22]. Further in [23], different energy system structures based on district heating with different components were investigated to select the most suitable combination of the district heating systems by comparing the efficiency and energy consumption of each system. In order to satisfy heating, cooling and hot water demands, research [24] designed and optimized a solar assisted ground source HP. Nouri et al. surveyed heating system with ground source HP with solar systems considering the performances of each system [25].

Different computer programs could apply to study each of the energy systems. For instance, software and models such as EnergyPLAN, HOMER, and MESSAGE are utilized for bottom-up models. In this way, Eslami et al. modeled a hybrid energy system in RETScreen in company of TSOL and PVsyst software to investigate thermal component and photovoltaic (PV) systems [26].

In [27], the current electric power system in Qatar was modeled using EnergyPLAN. The current system has combined with RES including wind turbines, solar panels, and centralized solar systems to achieve economic and environmental constraints. Noorollahi et al. in [28] using EnergyPLAN software and considering energy system of Ebino (located in Japan) as the case study to maximize share of RESs. Ronkallo et al. used the EnergyPLAN software to model the electric power system in Colombia to study the technical-economic effects on battery (BT) and energy storage systems with RES. Moreover, in that research, the flexibility to the power grid has been provided by different RESs and the requirement for integrating these energy sources is the existence of storage systems in the energy system [29].

In [30], Noorollahi et al. have utilized the support vector machine (SVM) model to predict the amount of energy required for an Iranian province in a 10-year outlook and carried out a feasibility study using EnergyPLAN, to evaluate the energy system based on solar energy sources. The reason for the focus on solar sources in the current study was the high potential of the province under study. Numerous studies have applied SVM to predict the regional electric load and energy consumption [31]. For instance, Paudel et al. forecasted household energy consumption in France by SVM in [32], based on two different approaches for the relevant and all data to determine the accuracy of each approach. Further, Lei et al. formed a hybrid model based on GA-SVM to mid-term predict electricity consumption for crude oil pipelines as a case study in China [33].In addition, Jung et al. developed a novel SVM called the least-squares support vector machine (LSSVM) to forecast daily energy demand in the residential areas in Korea [34]. Wang et al. proposed an SVM model for forecasting the annual electricity consumption in Beijing, and this method was compared with an artificial neural network and regression model to evaluate the effectiveness [35]. With respect to the previous studies, the SVM method provides an accurate energy consumption forecast for medium and long-term planning and performs greater than artificial neural network (ANN) [36], [37], and [38].

In the research [39], where EnergyPLAN was applied to simulate a case study in Portugal, different types of RES including wind turbines, solar systems, waves, and biomass, were performed to minimize the total energy costs and carbon dioxide (CO_2) emissions. In addition, Krajakic et al. have utilized the EnergyPLAN program for Macedonia, which aims to maximize the contribution of wind turbines and reduce electricity imports and energy consumption. In this study, the heating and electric power were evaluated in terms of mentioned objectives and RES [40]. Furthermore, to reduce the CO_2 emissions and the overall system costs, literature [41] has introduced a model based on the LEAP software to simulate the heating, cooling, electric power, and transportation sectors in a city in China, and photovoltaic systems were mainly applied to reach the objective function. Another research energy model was provided by Aalborg University as an outlook for Europe in 2050 [42].

Most literature studies have focused on a single aspect of those discussed above, related to the thermal demand forecast, geographic information system (GIS)-based potential assessment, and energy planning. To bridge the gaps in the literature, this paper aims to define a comprehensive approach to demand forecasting and energy planning of district heating networks. In detail, in the present study, new indicators such as efficiency in building, number of households, and purchasing power parities are discussed and considered in the demand forecasting section. Furthermore, in GIS-based assessment, new layers such as heating degree day (HDD) and cooling degree day (CDD) of the case study area and energy*population (energy multiplied by population) are applied to evaluate better the district heating network based on solar energy.

In this work, Gaziantep province was selected for the case study because nearly 80% of the energy consumption in residential areas is dedicated to heating [43], [44]. According to energy companies, approximately 70% of the housing heat storage (HS) is supplied by coal facilities, 15% by electric heaters, 6% by natural gas heaters, 5% and 4% by wood equipment and fuel heaters, respectively [43], [44].

In addition, this research also applies EnergyPLAN as the modeling tool for district heating systems and RES. According to the literature, most of the works have merely studied the prediction and modeling of energy systems for different scales. Nevertheless, in the current research, the high-potential regions to establish the district heating systems are determined based on appropriate indicators. In particular, this research provides a comprehensive study t from the beginning stages to the utilization of a district heating system in the Gaziantep Province.

Another novelty aspect of this research is the comprehensive view of the energy system planner. This means that in most of the past studies, the energy system planner forecasts the energy demand in the future by considering several parameters and plans the energy system accordingly. Furthermore, spatial planning is slightly considered in previous studies.; As a result, most of these studies have focused on load forecasting, modeling, and planning, regardless of the land use planning and geographical features. In the current research, the system planner has used various indices to predict the heating load. According to the mentioned indices, both aspects related to population density and energy-related issues are considered. In other words, in terms of heating load prediction, this research considers parameters that can address both population and energy issues. In addition, spatial planning, load forecasting, energy modeling and planning, through integration of suitable models and leveraging the engineering tools, are among other distinguished feature of the current, research which provide the energy system planner with a more comprehensive vision on economic, technical, environmental, and geographical features to present a long-term energy plan.

2. Methodology

To model and carry out optimal planning for Gaziantep Province, as the first step, it is necessary to understand the energy system and geographical location of the province and study the historical information. Thereafter, high-potential locations for establishing a solar-based district heating system are evaluated In the final step, the energy forecasting is carried out for the year 2030 according to the historical information , energy and environmental outlooks in Turkey. A Finally, using the

EnergyPLAN software, a modeling and feasibility study is carried out regarding the utilization of district heating systems. This research is studied in three general sections according to Figure 1. The first phase identifies the cities prone to solar-based district heating. The heating demand is forecasted in the second phase with a 10-year perspective. These two phases are not significantly related to each other. In other words, these two phases are calculated and simulated independently of each other. In the third phase, the plan to meet the economic and environmental goals is modelled in the district heating system by combining the previous two phases.

Further, Table 1 depicts economic and technical assumptions to investigate the proposed energy system in Gaziantep, Turkey.

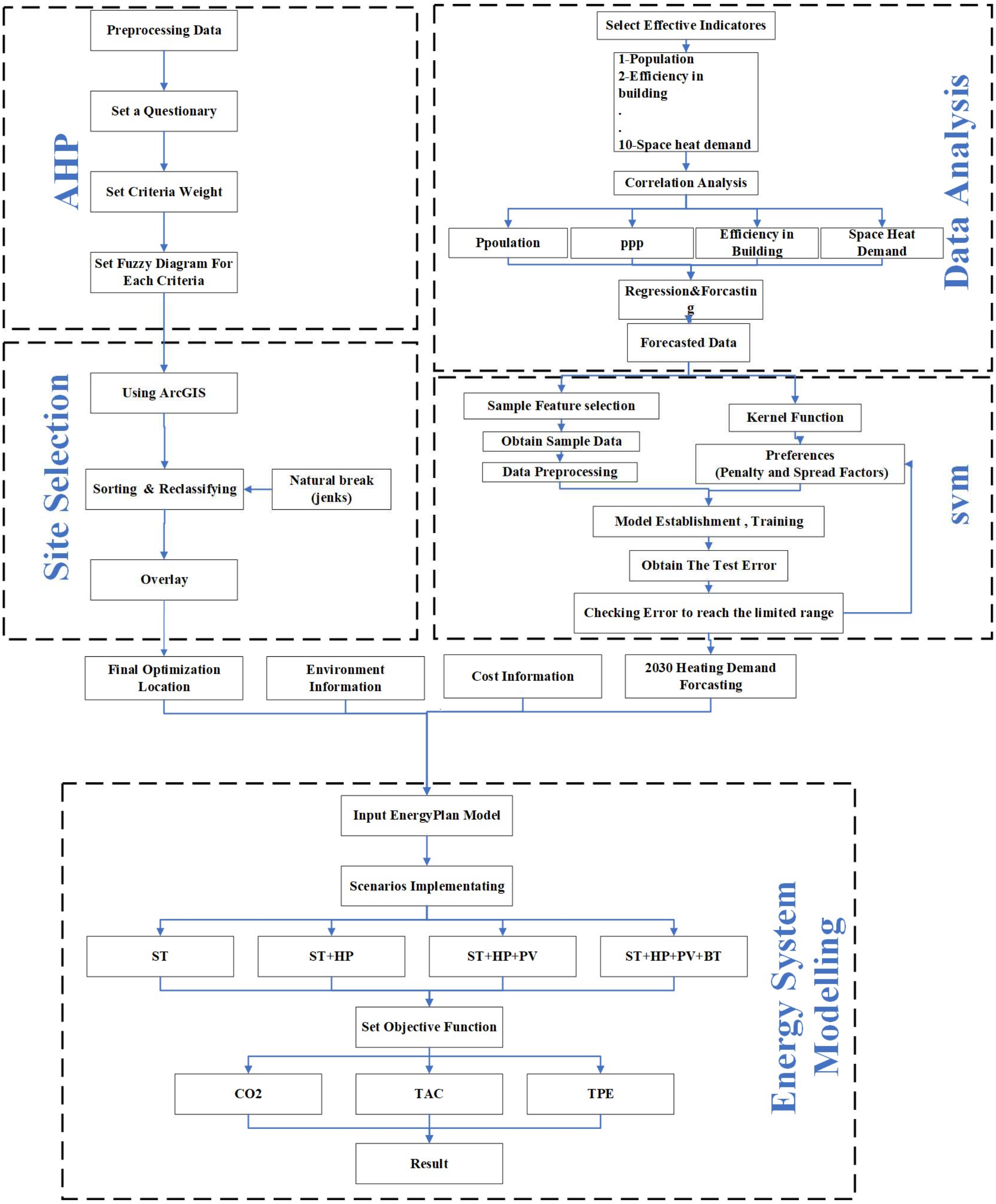


Figure 1. The procedure of this study

Table 1. Key assumptions for energy modeling

Assumption	Value	Comment
Network heating losses	~ 6 Percent	District heating network losses are considered in EnergyPLAN software
Electricity Price	150 Euro/MWh	For import and export in the electricity market
Interest rate	13.35 %	Based on world bank 2020 for Turkey
Coordinated geographic system	UTM	For studying in ArcMap software

2.1. Study area

Gaziantep province (Turkish: Gaziantep ili) is in southeast Anatolia in Turkey that had a population of 2,069,364 in 2019 [45]. The Mediterranean is in the west of the region and the Eastern Anatolia is in the north of the region (Figure 2). The elevation of the Gaziantep region varies between 450 and 1500 m approximately. In this region, usually summers are dry and hot, while winters are cold and rainy. Table 2 shows the parameters related to the geographical location of Gaziantep province [46], [43]. Figure 2 shows the location of Gaziantep province and its neighbors in Turkey.

Table 2. Summarized some information about the case area.

Latitude	Longitude	Area	Climate	Elevation	HDD	CDD
37.066666	37.383331	6000 Km^2	Mediterranean climate	450-1500	1500-2000	250-350

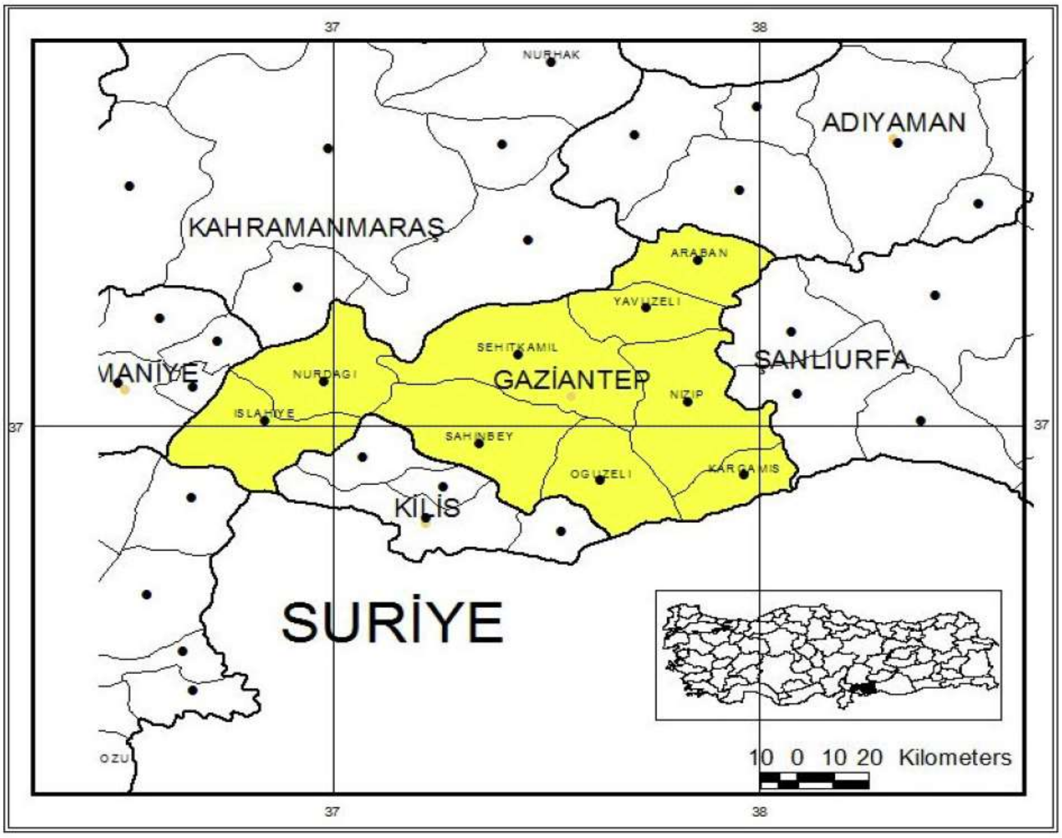


Figure 2. Study region (Gaziantep Province in Turkey) [47]

2.2. Solar-based district heating potential assessment

The most appropriate location for a solar power plant depends on the precise observation of several factors[48]. Numerous studies have been conducted on the factors affecting the performance of photovoltaic and thermal solar power plants[49]. In this study, several factors were selected such as geographical, economic, and environmental, whichare illustrated in Figure 3.

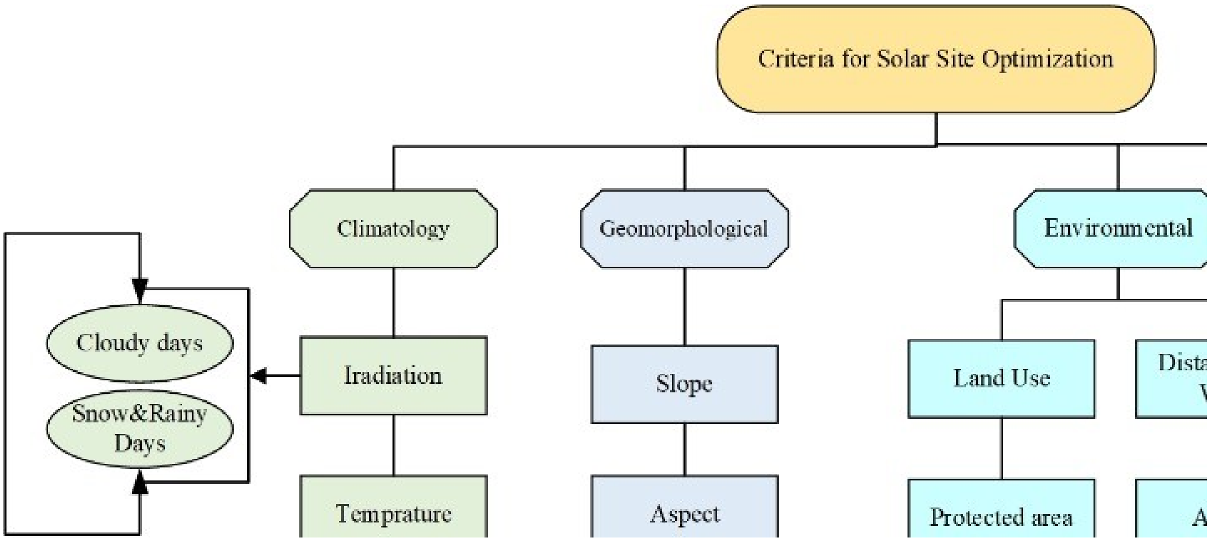


Figure 3. Indicators used in assessing the potential of solar-based sources

After specifying the evaluation criteria, the combining method of these layers is discussed [50]. However, a fuzzy method is used to combine the data in this study. It is essential to evaluate different regions with appropriate criteria and parameters to extract the most suitable areas in the province to install solar-based district heating systems [49]. Table 3 provides the fuzzy numbers and the weight (a number between zero to a hundred) allocated to each parameter. Triangular and trapezoidal fuzzy numbers are considered to model the following indicators, therefore, a, b, and c and a, b, c, and d depict each type of fuzzy number, respectively.

- Distance to urban areas: The radius of 500m around the urban areas is considered to maintain an adequate distance between the power plant and the urban area. However, there is a possibility to reduce the transmission line and the loss when considering nearby urban areas. The black dots in Figure 4(1) show the urban areas and the distance from them.

- Aspect: This is one of the parameters affecting the panels' power output. The panels are to be installed in the places where most of the solar irradiation is available throughout the different seasons. Since Turkey is located in the northern hemisphere, orienting the panels toward the south is convenient. In other words, an azimuth of zero degrees is preferred over different directions. Further, this parameter is demonstrated in Figure 4(2).

- Global Horizontal Radiation (GHI): Solar radiation is divided into two categories; horizontal and direct (DNI). Further, GHI is utilized for PV potential measurement and CSP potential measurement , which are performed by DNI. In this research, the minimum amount of solar radiation energy considers 1500 kWh per square meter per year, and radiation less than this amount are regarded as undesirable radiation. Figure 4(3) shows the annual radiation of the province.

- Elevation: The height of an area above sea level is inversely proportional to the atmosphere thickness. This means that the thicker the air layer, the more factors such as dust and concentration of air pollutants that could reflect radiation [51]. Hence, high-altitude areas have a greater potential than low-altitude areas. As shown in Figure 4(4), by moving to the east of the region, the height decreases and in central region mountain area can be seen.

- Distance to roads: The costs associated with the transportation of equipment and personnel, access, and maintenance services are proportional with the distance from the plant to the main road However, in addition a 300 meters limit must be considered as a safe space along the road [25]. Figure 4(5) specifies the distance from different roads in the province.

- Distance to power transmission lines: A large distance between the power plant and power transmission lines could lead to several drawbacks such as voltage drop, reduction of overall efficiency, and high energy loss in the system. Proximity to power lines can reduce the building and maintenance costs of solar thermal (ST) and PV power plants. Figure 4(6) specifies the distances to power transmission lines.

- Slope: In general, it is preferred to install solar collectors and panels on the smooth ground with a slight concerning numerous articles, the slope value varies from zero degrees to 10 degrees. Moreover, the slope affects the cost of the plant installation, and it is possible that panels installed on steeper slopes would result in shadows on the next rows at certain times of the day, which could the overall plant performance. Figure 4(7) investigates the ground slope in different parts of the province.

- Ambient temperature: According to the characteristics of photovoltaic panels, the increased temperature can reduce the efficiency of solar panels. On the other hand, higher ambient temperatures raise the temperature of the ST collectors. As shown in Figure 4(8), the western and northwestern regions of the province have lower temperatures than the eastern and southeastern regions.

- Distance to wetlands and rivers: In terms of ecological value potential, and the quality of the environment, these areas are completely unsuitable for the construction of solar power plants. Figure 4(9) demonstrates the distances to wetlands.

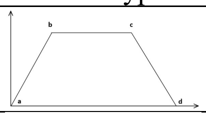
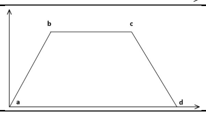
- Energy population (EP): This parameter is applied to calculate the energy required for a selected region and to determine the energy and population density in a single parameter. Figure 4(10) illustrates this parameter in Gaziantep Province.

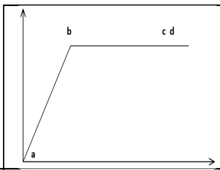
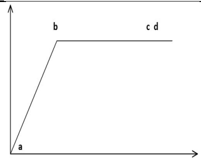
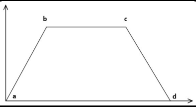
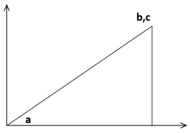
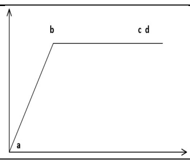
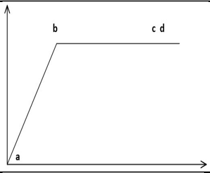
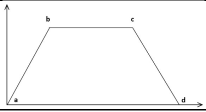
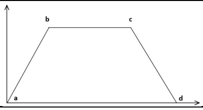
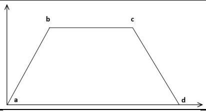
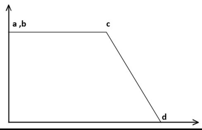
- HDD: This parameter refers to the amount of thermal energy required to bring the room temperature to thermal comfort. Figure 4(11) shows this parameter in different cities.

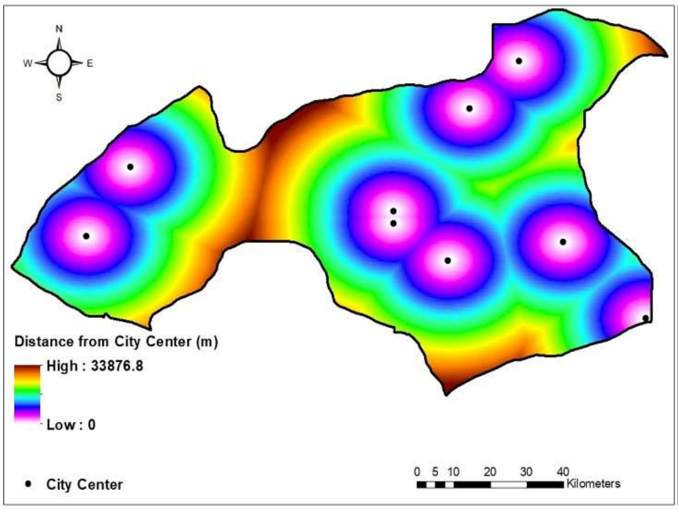
- Energy per number of households: This parameter considers the number of households and energy consumption, where each household is accounted for as one energy-consuming unit. Figure 4(12) provides the respective values for each city.

The final outputs after executing the fuzzy operations and multi-criteria decision making, which evaluates the potential of solar-based district heating systems, are presented in Figure 5.

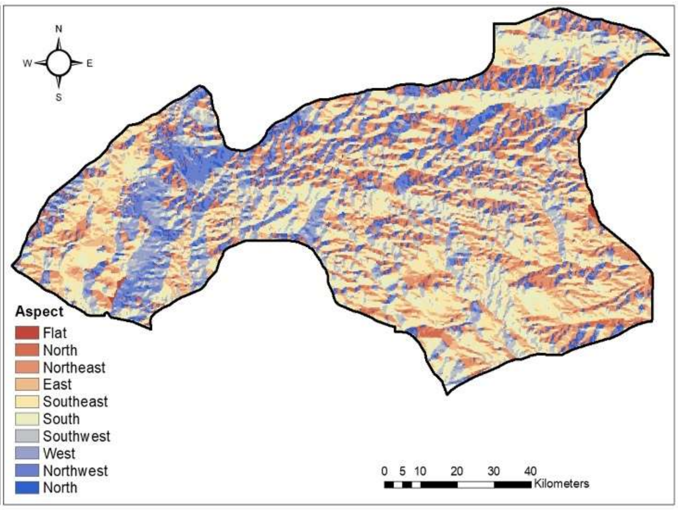
Table 3. Spatial parameters for fuzzification with each weight

Criteria	a	b	c	d	Chart type	Weight (0-100)
Slope	0	10	50	60		7
Distance from city	1000	1500	7000	15000		5

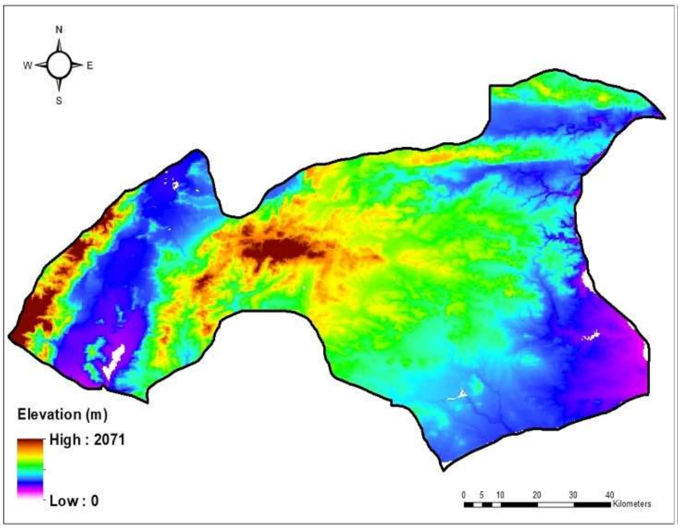
HDD	0	1450	1450	1450		6
E*Population	0	11000000	11000000	11000000		9
Distance from road	300	400	5000	15000		8
Distance from water	0	60000	60000	*		2
E*Households	0	50000	50000	50000		7
GHI	0	1700	1700	1700		21
Elevation	300	1100	1800	2070		5
Distance from powerline	50	400	1000	5000		13
Aspect	0	157.5	202.5	360		5
Temperature	0	0	18	37		12


N
W
E
S
Distance from City Center (m)
High : 33876.8
Low : 0
City Center
0 5 10 20 30 40
Kilometers

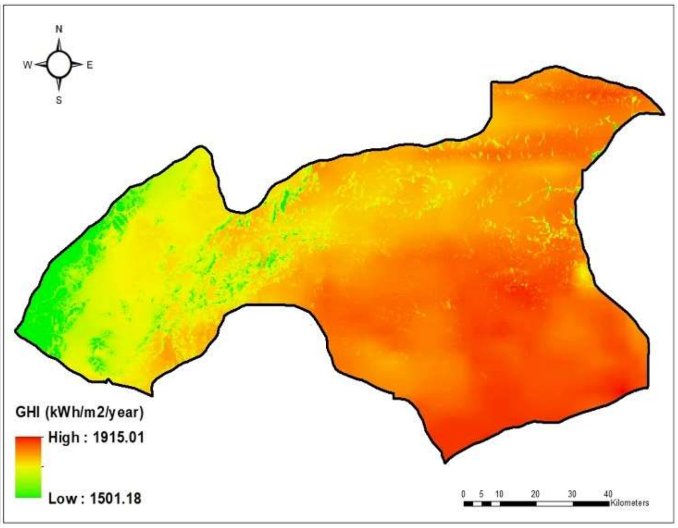
(1)


N
W
E
S
Aspect
Flat
North
Northeast
East
Southeast
South
Southwest
West
Northwest
North
0 5 10 20 30 40
Kilometers

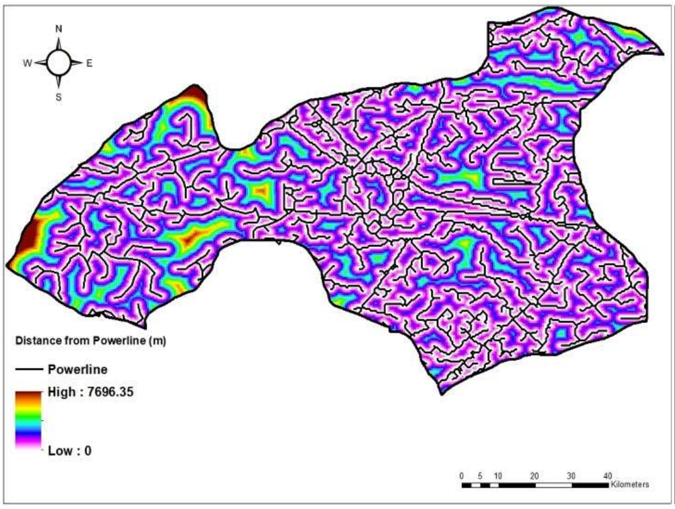
(2)


N
W
E
S
Elevation (m)
High : 2071
Low : 0

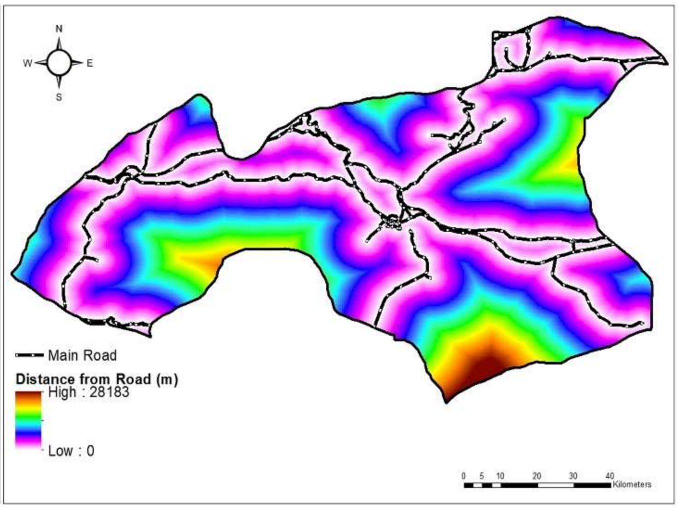
(3)


N
W
E
S
GHI (kWh/m2/year)
High : 1915.01
Low : 1501.18

(4)


N
W
E
S
Distance from Powerline (m)
Powerline
High : 7696.35
Low : 0

(5)


N
W
E
S
Main Road
Distance from Road (m)
High : 28183
Low : 0

(6)

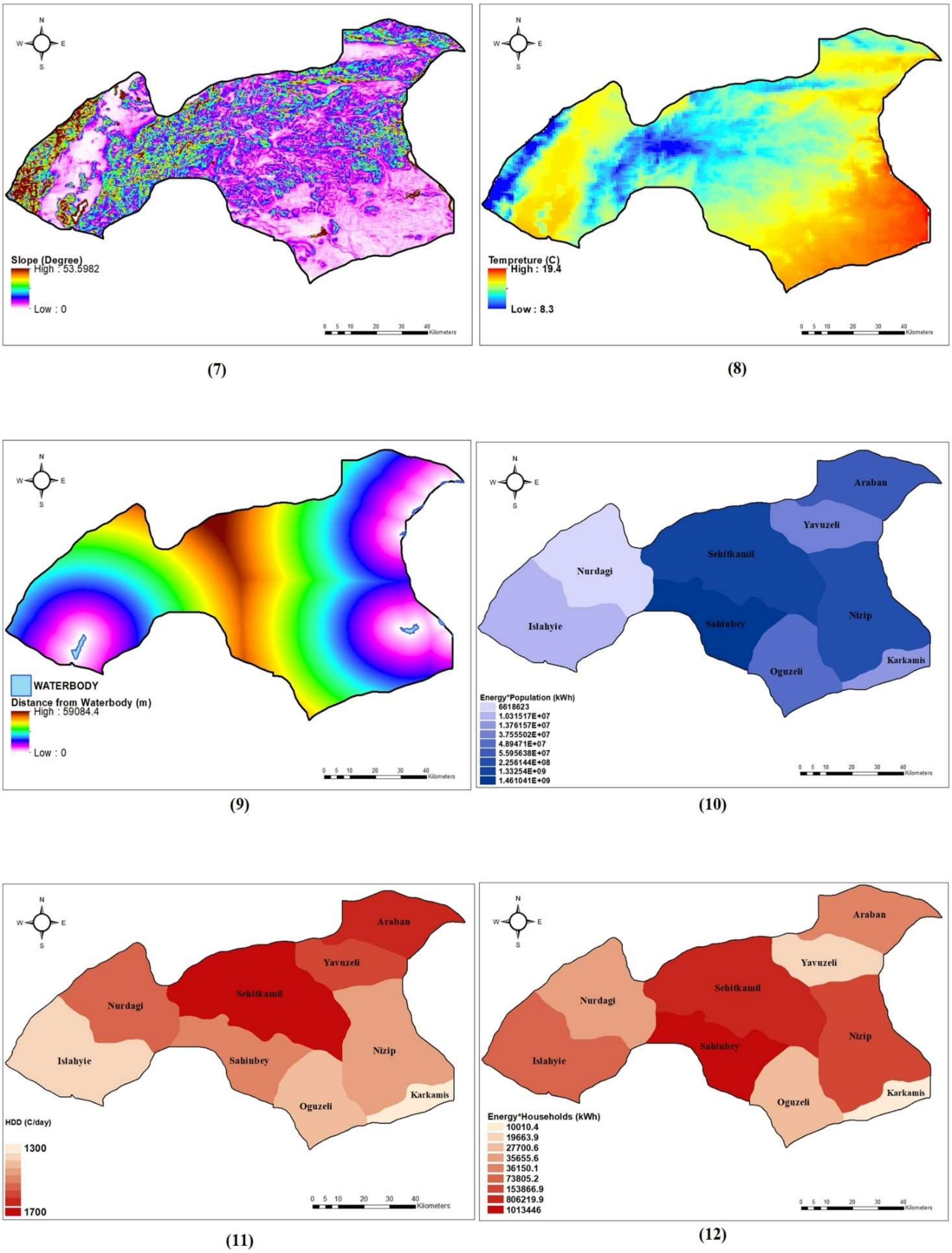


Figure 4. Displays indexes intended to assess solar potential, 1) distance to city center, 2) aspect, 3) elevation, 4) GHI, 5) distance to power line, 6) distance to road, 7) slope, 8) temperature, 9) distance to water body, 10) Energy*Population, 11) HDD, 12) Energy*Households

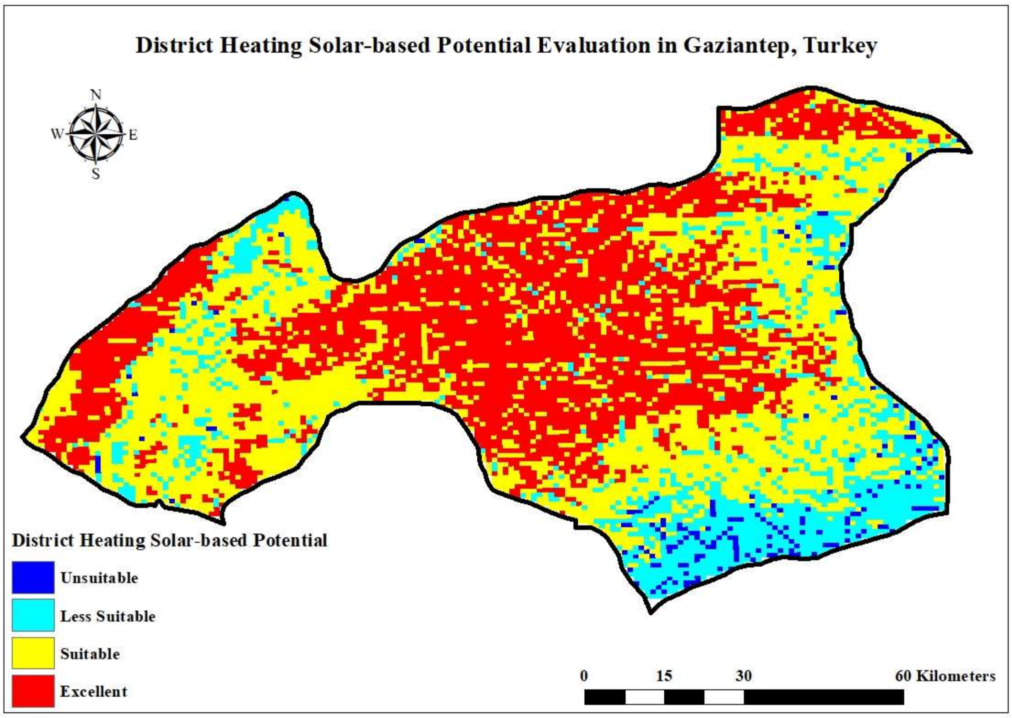


Figure 5. Classification of Gaziantep Province regions for the establishment of a solar-based district heating system

2.3. Energy demand forecasting

In the first step, the factors that could affect the heating demand in the population are examined, and information over the last 20 years is extracted (i.e., from 2000 to 2020). In the next step, the influential factors are evaluated by multivariate regression to determine the effectiveness of each parameter. In this method, after applying multivariate regression to the available data, the resulting P-values are calculated, and the variables with P-values above 5% have been removed from the calculation process. This is because, a P-value greater than 5% indicates that the desired parameter does not affect the final output, which is heating consumption. Finally, after this procedure, the system parameters are identified including, population, purchasing power parities (PPP), efficiency in building, and the number of households. Table 4 shows the detailed statistics and information for each parameter and Table 5 provides the P-values for each of the variables under study.

The historical data and the SVM method were used to predict the residential heating load. The historical data were extracted from the International Energy Agency (IEA) database over 20 years from 2000 to 2020. In this relation, the heat load demand of the residential sector in the region is equal to 1130 GWh in 2000 and about 1584 GWh in 2020.

The supervised machine learning method have been applied frequently during recent years duo to the ability of making a relationship between complex non-linear datasets, [52]. SVM is one of the best supervised machine learning methods that was developed in the early 1990s with two important applications such as classification and regression [52]. According to the theoretical statistical background of SVM, this method has improved classic mathematical and artificial intelligent methods in terms of performance aspects [52]. SVM utilizes historical data to identify the effect of each parameter on the system under study, and predict the process that can be attributed to the output variable based on the historical data. In this method, the prediction curve is drawn based on the intervals considered for the variable under study. Therefore, it is as close as possible to the characteristics of training data.

As seen in Figure 6, a boundary with center f is clarified. The dashed line shows the boundary ε width, which the user defines. ζ shows the distance between points out of the boundary and boundary lines. C is a factor that improves function performance by decreasing training error. Eq.1 to Eq.4 represents support vector regression (SVR) mathematical model.

$$\mathbf{X}= [\boldsymbol{X_1} + \boldsymbol{X_2} + \cdots + \boldsymbol{X_n}] \tag{Eq.1}$$

$$\boldsymbol{f}(\boldsymbol{w_1}, \dots, \boldsymbol{w_n}, \boldsymbol{b}) = \boldsymbol{y} = \boldsymbol{w}.\boldsymbol{x} + \boldsymbol{b} \tag{Eq.2}$$

$$\boldsymbol{minimize}\frac{\mathbf{1}}{\mathbf{2}}\|w\|^2 + \boldsymbol{C}\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}}(\boldsymbol{\zeta_i^*} + \boldsymbol{\zeta_i}) \tag{Eq.3}$$

$$\boldsymbol{s.t}\begin{cases}\boldsymbol{y_i} - (\boldsymbol{w}.\boldsymbol{x_i} - \boldsymbol{b} \leq \boldsymbol{\varepsilon} + \boldsymbol{\zeta_i^*} \\ (\boldsymbol{w}.\boldsymbol{x_i}) + \boldsymbol{b} - \boldsymbol{y_i} \leq \boldsymbol{\varepsilon} + \boldsymbol{\zeta_i}\end{cases} \tag{Eq.4}$$

The Kernel function is applied in linear SVM to improve the performance of regression function. The linear kernel function is presented in Eq.5 and Eq.6, where X =$[x_1, x_2, \dots, x_m]$, Y=$[y_1, y_2, \dots, y_m]$ and $\widehat{w}$ are the calculated matrix of coefficients w_i, $\widehat{y_i}$ is the output of prediction function and b is an intercept.

$$\boldsymbol{K}(\boldsymbol{x}, \boldsymbol{y}) = \boldsymbol{x^T y} \tag{Eq.5}$$

$$\widehat{\boldsymbol{w}} = (\boldsymbol{X^T X})^{-\mathbf{1}}\boldsymbol{X^T Y} \tag{Eq.6}$$

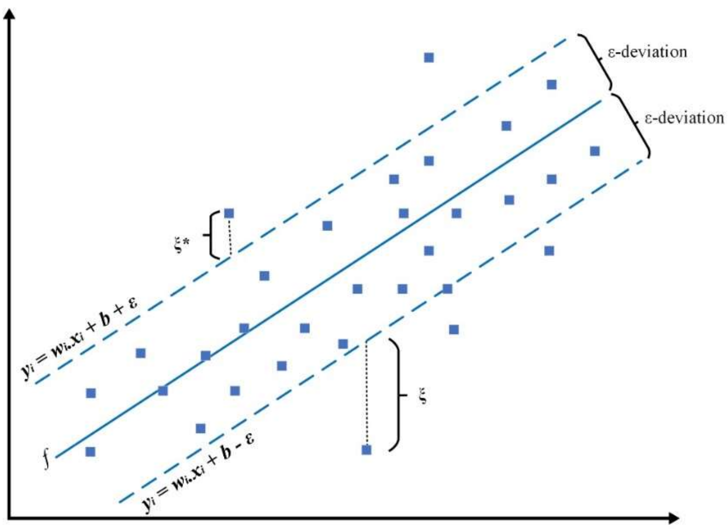


Figure 6. SVM model, its boundaries and parameters

Figure 7 shows the model errors (SVM) in predicting the heating load demand. R-squared, mean absolute error and root-mean-square error are respectively 0.9, 11.7, and 13.5. To evaluate the proposed model, the output data (red dots) are compared with the historical data (blue dots). In addition, the horizontal axis represents the years 2000 to 2020, and the vertical axis represents the amount of energy consumed in the heating sector. Moreover, the observations and the line predicted through SVM are illustrated in Figure 8, which shows the scattering of historical data around the predicted line. The equation of MEA calculation is presented in Eq.7.

$$MAE = \frac{\sum_{i=1}^{n}|y_i - f_i|}{n} \tag{Eq.7}$$

Table 4. Information about the studied index for 20 years [12,44,45,53]

Year	Population	PPP	Efficiency in Building	Person in a House	One Person Household	Militiaperson No-Family Person	Extended Family Household	One Family Household	Number of Households	SPACE HEAT DEMAND
2000	63240196	0.28	6.30	4.44	4.59	0.05	22.80	72.92	14.92	99997.20
2001	64192243	0.42	6.24	4.38	5.24	0.20	22.39	72.51	15.63	100469.41
2002	65145357	0.59	6.18	4.32	5.89	0.35	21.97	72.11	16.34	101441.60
2003	66089402	0.74	6.13	4.26	6.54	0.49	21.56	71.71	16.59	107135.89
2004	67010930	0.79	6.07	4.20	7.19	0.64	21.14	71.30	17.01	109691.37
2005	67903461	0.84	6.02	4.14	7.84	0.79	20.73	70.90	17.46	115968.98
2006	68756809	0.84	5.96	4.09	8.49	0.93	20.31	70.50	17.76	116663.40
2007	69581854	0.85	5.91	4.03	9.14	1.08	19.90	70.09	18.17	120163.30
2008	70418612	0.88	5.85	4.00	9.79	1.23	19.49	69.69	18.55	120079.97
2009	71321406	0.90	5.80	4.00	10.44	1.37	19.07	69.29	18.88	126885.34
2010	72326992	0.92	5.74	3.84	11.09	1.52	18.66	68.88	19.21	124996.50
2011	73443254	0.97	5.69	3.76	11.74	1.66	18.24	68.48	19.46	130551.90
2012	74651046	1.02	5.64	3.69	12.39	1.81	17.83	68.08	19.80	131107.44
2013	75925454	1.07	5.59	3.66	13.04	1.96	17.41	67.67	20.13	128524.18
2014	77229262	1.11	5.54	3.57	13.90	2.10	16.70	67.40	20.38	122774.34
2015	78529413	1.16	5.49	3.52	14.40	2.20	16.50	66.90	20.72	123940.97
2016	79827868	1.24	5.43	3.48	14.90	2.40	16.30	66.40	21.01	126107.58
2017	81116451	1.38	5.38	3.45	15.40	2.50	16.00	66.10	21.34	131940.75
2018	82340090	1.63	5.34	3.41	16.10	2.80	15.80	65.30	21.63	127774.20
2019	83429607	1.90	5.29	3.35	16.90	3.00	15.00	65.10	21.92	136385.07
2020	84339067	2.13	5.24	3.30	17.90	2.80	14.00	65.20	22.26	139471.59

Table 5. Variables and related P-values

Variables	P-value	Suitability
population	0.000487	✓
ppp	0.000628	✓
efficiency in building	0.000802	✓
person in a house	0.7144	×
one-person household	0.278596	×
multi person household	0.728481	×
extended family household	0.474839	×
one family household	0.755865	×
number of household family	0.003091	✓

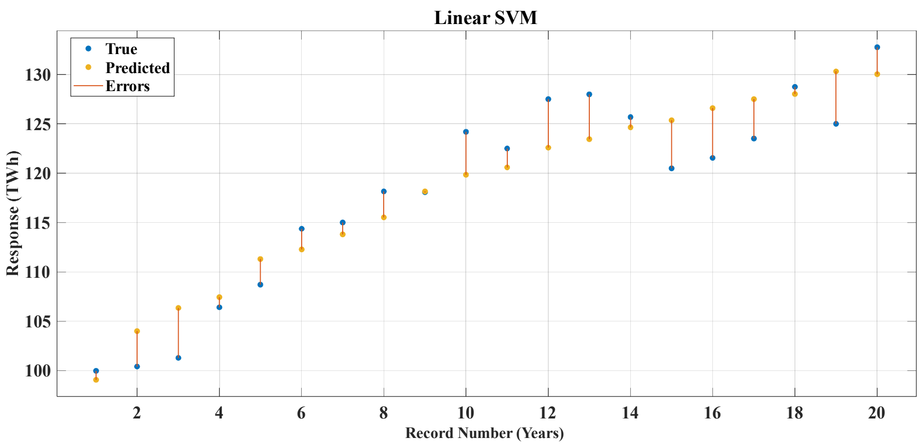


Figure 7. Display of historical, predicted, and error information for SVM.

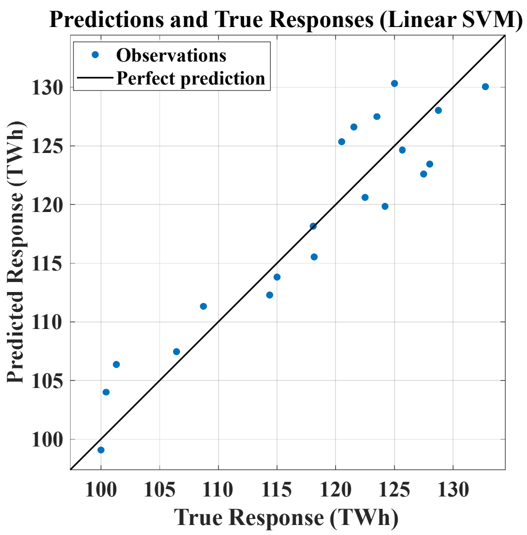


Figure 8. The resulting line from the SVM and the scattering of historical information.

Figures 9 and 10 present the heating load prediction for Turkey and Gaziantep p up to 2030. In fact, until 2020, the historical data is considered as inputs and from 2020 onwards, and the predictions are made based on the learning. The short time interval was selected due to the limited available information as input data.

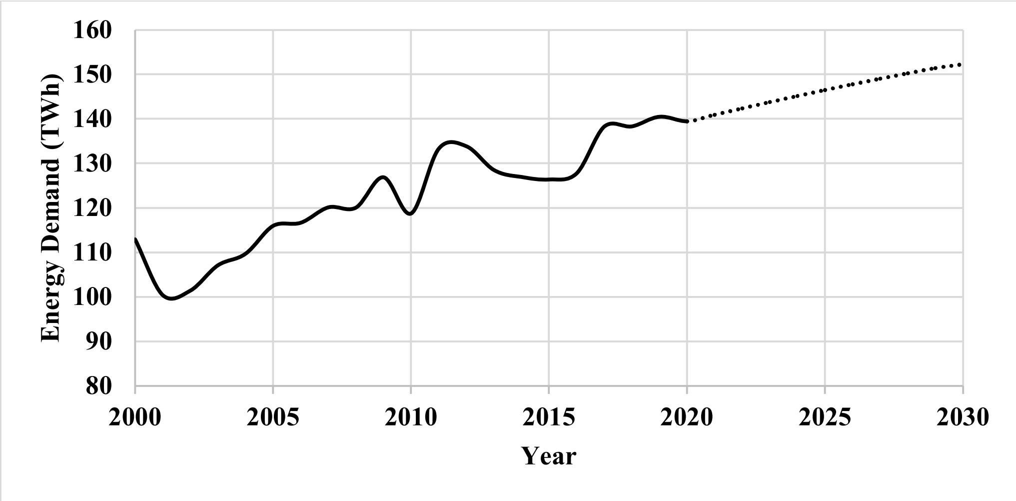


Figure 9. Heating demand trend and forecast for Turkey.

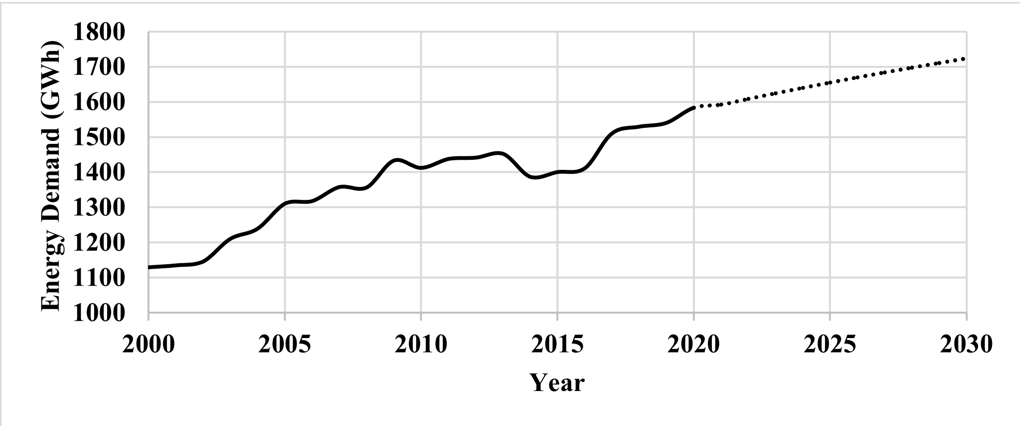


Figure 10. Heating demand trend and forecast for Gaziantep province.

2.4. Scenario development for energy system modeling

The main scenario (S) business as usual (BAU) involves modeling the heating load for the city of Gaziantep in 2020. In the current situation, the heating load is supplied from different sources. Heat is mainly provided by fossil fuels and a less proportion is by electricity (about 70% coal, 15% electric heaters, 6% natural gas, 5% biomass, and 4% oil) [28]. The heating load in the residential part of this area was around 1584 GWh in 2020 and the load distribution is based on the HDD distribution curve. Figures 11 and 12 present the HDD distribution curve (per unit), space heating consumption, and hot water consumption in this area, respectively. Moreover, the distribution is calculated with HDD of Gaziantep at each time divided by HDD maximum. Table 6 shows the equipment combinations used in different sub-scenarios, and each sub-scenario is simulated according to the type of utilization. Tables 7 and 8 illustrate the investment cost, operation and maintenance (O&M), efficiency, coefficient of performance (COP) and service life of different technologies utilized in the different scenarios and the emission coefficient and cost of each fuel. Further, the contribution of each fuel in supplying the required heating load is presented in Table 9.

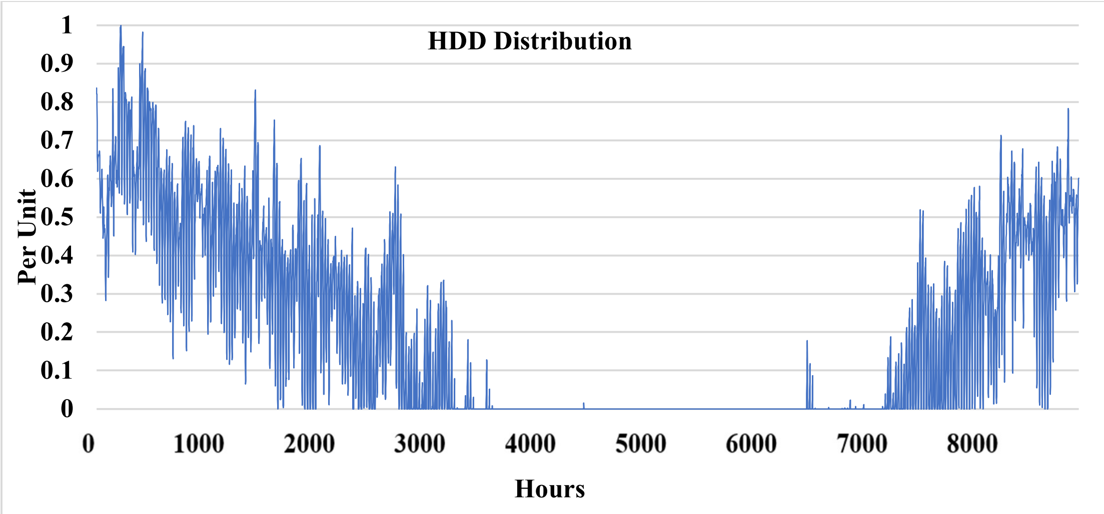


Figure 11. HDD distribution over one year.

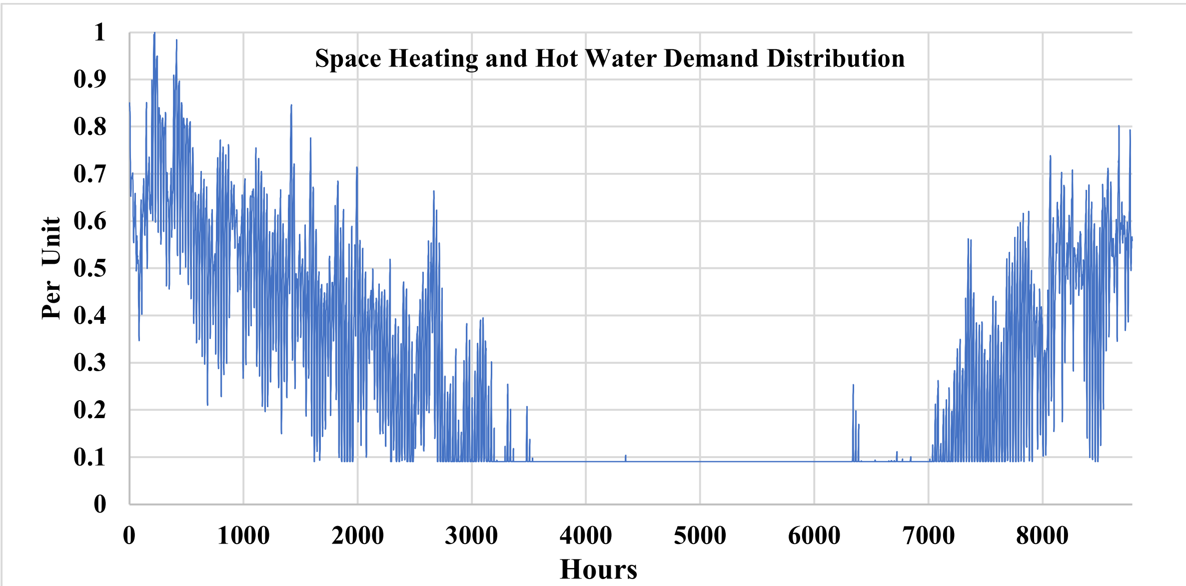


Figure 12. Space heating and hot water demand distribution over one year.

Table 6 . Type of Components in each scenario.

Scenario	Heating					
	Fossil fuel	Solar Thermal	Photovoltaic	Heat pump	Heat Storage	Electrical Storage
BAU	✓	×	×	×	✓	×
ST	✓	✓	×	×	✓	×
ST+HP	✓	✓	×	✓	✓	×
ST+HP+PV	✓	✓	✓	✓	✓	✓
ST+HP+PV+BT	✓	✓	✓	✓	✓	✓

Table 7. Cost information for each component [54].

Product Type	Investment (MEuro/unit)		Service life (Year)		O&M (% of Inv.)		Efficiency Thermal (reference: energy plan turkey)
	2020	2030	2020	2030	2020	2030	
Individual Boilers (1000 households)	4.5	4.3	20	20	5.38	5.42	0.7
Solar Thermal (TWh/year)	386	307	30	30	0.13	0.15	0.8
Large PV (MW)	.83	.69	35	40	1.31	1.28	0.9
Heat Storage (GWh)	.5	.5	20	20	.7	.7	0.7
Individual Electric heating (1000 households)	1	1	30	30	0.8	.0.8	-
Electrical storage (GWh)	-	1.2	-	15	-	0	-
Heat Pump (1000 unit)	1.7	1.9	10	10	11.05	9.31	3(COP)

Table 8. Fuel price and CO_2 emissions.

	Oil	NG	Coal
Fuel Price (EUR/GJ)	18.33	2.69	4.5
CO_2 Emissions (kg/GJ)	75.1	57.9	95

Table 9. Contribution of each fuel in meeting the heating demand.

Year	Total Heating Load (TWH)	Coal	NGs	Oil	Bio	Electric Heating
2020	906.6	0.9032	0.045	0.065	0.06	0.13
2030	986.6	0.9866	.072	0.054	.062	.144

3. Results

3.1. Simulation and numerical results

S1 is the current energy system model of Gaziantep in 2020 while S2 is a BAU scenario related to 2030, which is based on the current energy trend in the study area. Furthermore, the purpose of scenario S3 is to achieve an approximately 4% reduction in CO_2 emissions compared to the 2030 BAU scenario. In S4, CO_2 emissions have not grown significantly compared to the year 2020. Finally, in S5, the scenario is developed, hence the region would have net zero emissions by the year 2050. The goal is achieved by the annual reduction of 3.3% in emissions starting from 2020. This means that by the year 2030, CO_2 emissions will be reduced by 33.3%.

In Table 10, four objective functions are presented for different scenarios, which include CO_2 emissions, the contribution of renewable energy sources, the total initial energy consumption of the system, and the total cost of the system. These could be obtained through simulation in the EnergyPLAN software.

Table 10. Objective functions for different scenarios.

	scenarios	CO_2 Emissions (Mtone)	RES shares (%)	Total primary energy consumption (TWh)	Total annual cost (Meuro)
S 1	**Current model**	0.334	5.6	1.07	59
S 2	**BAU**	0.366	5.3	1.17	77
S 3	**S (ST4%)**	0.338	11.8	1.17	93
	S (ST+HP4%)	0.338	8.8	1.13	81
	S (ST+HP+PV4%)	0.338	10.1	1.15	82
	S (ST+HP+PV+BT4%)	0.338	10.1	1.15	84
S 4	**S (ST 0%)**	0.335	13.6	1.17	97
	S (ST +HP0%)	0.335	9.2	1.12	81
	S (ST+HP+PV0%)	0.335	10.9	1.14	81
	S (ST+HP+PV+BT0%)	0.335	10.9	1.15	83
S 5	**S (ST ZeroE up to 2050)**	0.242	33.6	1.13	162
	S (ST +HP ZeroE up to 2050)	0.242	21.8	0.96	97
	S (ST+HP+PV ZeroE up to 2050)	0.242	25.7	1.01	98
	S (ST+HP+PV+BT ZeroE up to 2050)	0.242	25.7	1.01	100

Figure 13 shows the amount of CO_2 emissions for different scenarios formed by combining different equipment. As presented in the figure, for the 2030 scenarios, BAU has the highest amount of CO_2 emissions due to the minimal use of renewable energy sources. Moreover, in the scenario 2030ZeroE, which has the highest contribution of renewable energy sources with the lowest amount of emissions.

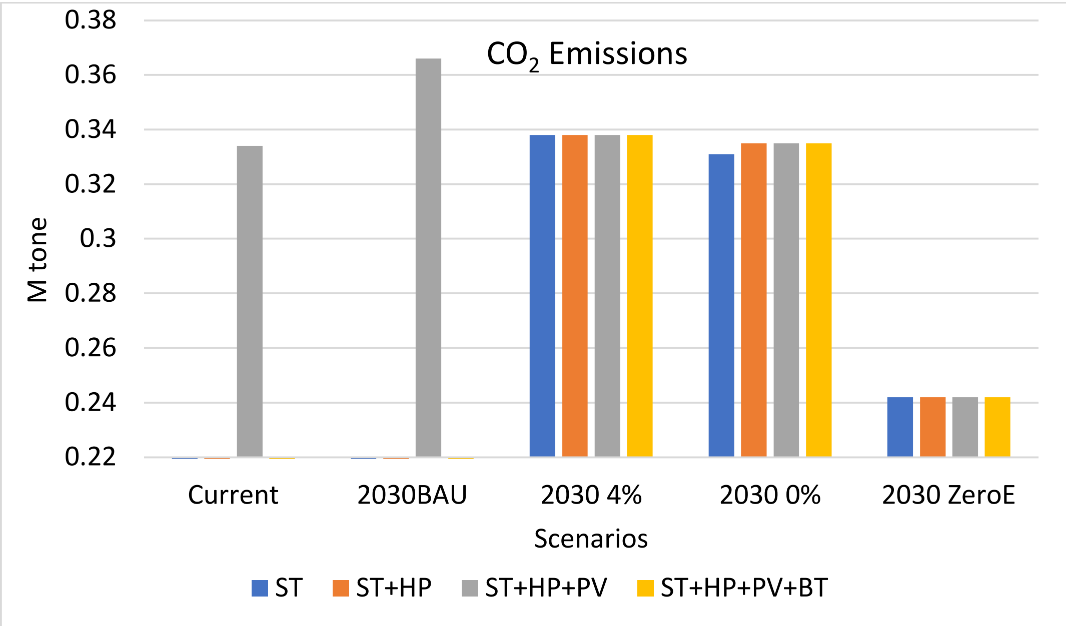


Figure 10. Carbon dioxide emissions in different scenarios.

The contribution of renewable sources is specified in Figure 14. According to the figure, the largest share of renewable energy belongs to the zero-energy scenario and Gaziantep region will become a zero-energy area by 2050. In addition, the BAU scenario also has the lowest level of renewable energy.

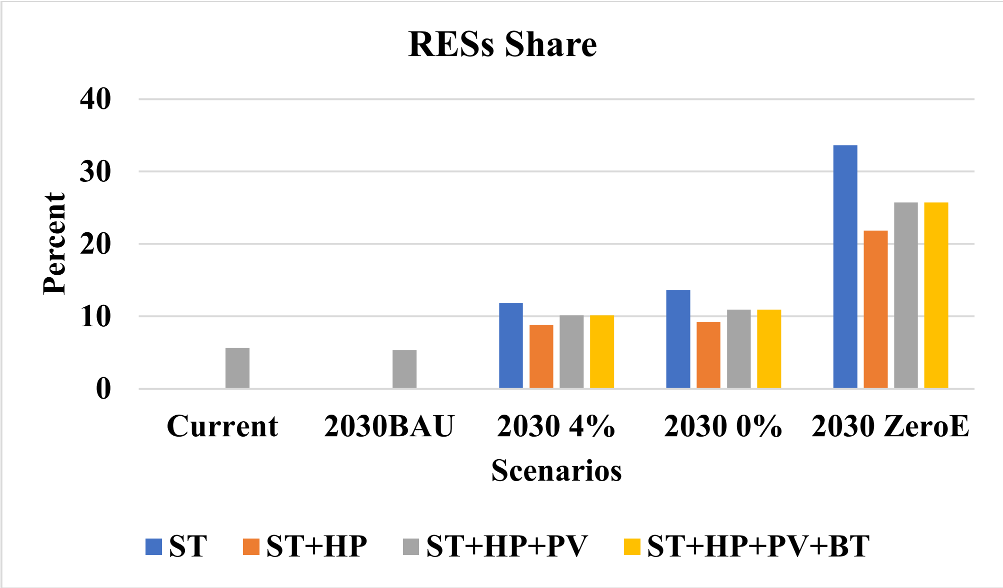


Figure 11. Contribution of renewable energy sources in each of the scenarios.

Figure 15 shows the amount of energy consumption in different scenarios. In this figure, an important advantage of hybridization is demonstrated. In this relation, the energy consumption can be reduced by creating interaction between the different components of the system. This significant fact is deduced in Figure 16. Moreover, the hybridization of systems is highly economical from a long-term perspective. As can be seen in Figure 15. Scenario 5 is the best scenario in terms of primary energy consumption, and the integration of solar thermal and HPs consumes minimum energy compared to other combinations.

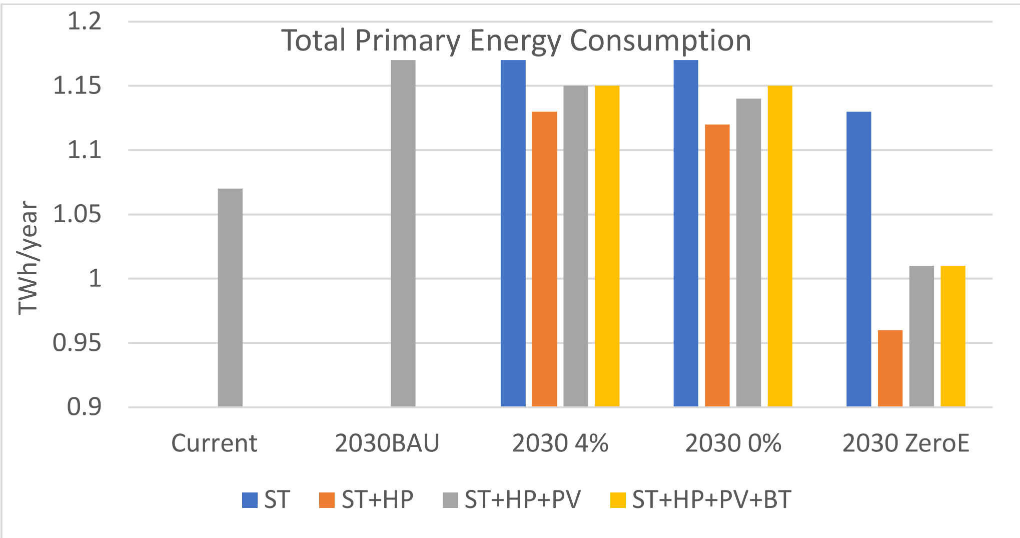


Figure 12. Total energy consumption in each scenario.

By comparing different combinations of energy sources in different proposed scenarios (S3, S4, S5) in terms of price in Figure 16; hybrid solar heating and HP has the lowest total annual cost (TAC) in all sub scenarios. The highest cost in renewable scenarios is related to thermal solar alone. Generally, the lowest cost is related to the BAU, given the assumption that gas and electricity prices are stable. Also, for surveying completely, in Table 11, the contribution of each heating source is provided.

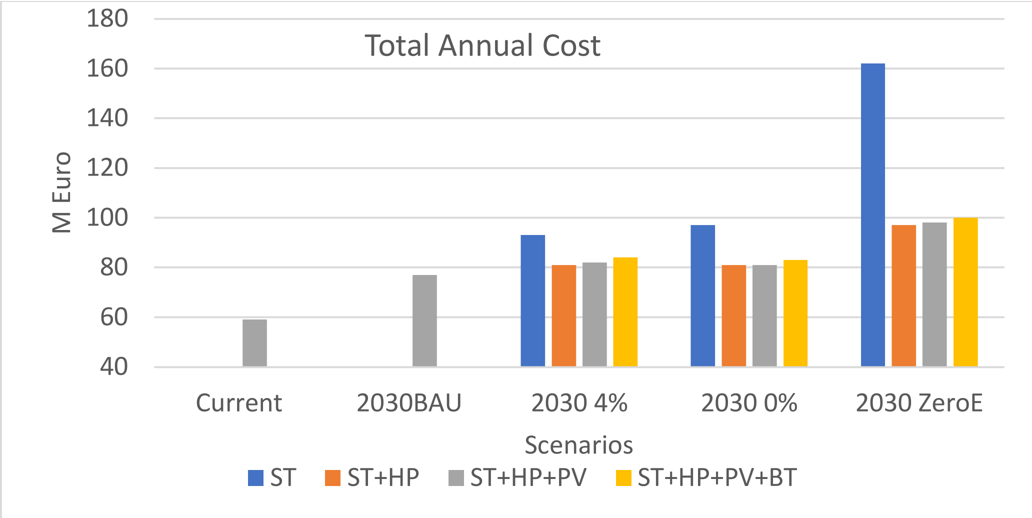


Figure 13. The total cost of the system in each of the scenarios.

Table 11. Participation of each piece of equipment in the energy supply.

component	ST		ST+HP			ST+HP+PV				ST+HP+PV+BT				
	ST (TWh)	**HS**	**ST**	**HS**	**HP (MW)**	**ST**	**HS**	**HP**	**PV (MW)**	**ST**	**HS**	**HP**	**PV**	**BT (GWh)**
S3	0.5	0.5	0.2	0.2	2	0.2	0.2	2	10	0.2	0.2	2	10	10
S4	0.6	0.9	0.2	0.2	2	0.2	0.2	2	15	0.2	0.2	2	15	10
S5	2.5	3.5	0.9	1.8	12	0.9	1.8	12	30	0.9	1.8	12	30	15

The amount of available data is one of the limitations of the proposed model of this system. Since the proposed model uses supervised learning methods, the model will have higher accuracy in case of more valid historical data. Another limitation of the proposed model is the number of available geographic layers to identify areas with high solar potential. More applicable layers in GIS-based software could achieve more accurate GIS results. Further, bottom-up models such as EnergyPLAN have limitations. For instance, less concentration on market conditions and macroeconomic indexes, and therefore these models can not consider the feedback of economic growth or behavioral responses of market activity.

3.2. Sensitivity analysis and discussion

Sensitivity analysis based on-grid electricity prices: It seems that electricity prices had an increasing trend in all countries, and countries with energy dependency have a higher potential for increased prices in the future. Sensitivity analysis based on PV prices and renewable technologies: In recent years, the price of renewable technologies such as photovoltaic systems has been declined and expect to even less expensive in the future. Sensitivity analysis based on carbon prices: Air pollution penalties and carbon prices could directly impact the growth of renewable and district heating systems. As can be seen in Table 12 and Figure 17, the overall system costs present an increasing trend in all scenarios with the increment in electricity prices. At each step, a 10% growth in the price of electricity is considered and the effect of this amount in increasing the overall system cost is logical. However, the remarkable point is in Scenario 4, where this 10% increment had less impact on its increasing trend due to the greater contribution of RESs in this system.

Table 12. Sensitivity analysis of the impact of upstream grid electricity prices on the overall system cost.

	scenarios	Total annual cost	TAC	TAC	TAC	TAC	TAC
S 2	BAU	77	78	79	79	80	81
S 3	S (ST4%)	93	94	95	96	97	98
	S (ST+HP4%)	81	82	83	84	85	86
	S (ST+HP+PV4%)	82	83	83	84	85	86
	S (ST+HP+PV+BT4%)	84	85	86	86	87	88
S 4	S (ST 0%)	97	97	98	99	100	101
	S (ST +HP0%)	81	82	82	83	84	85
	S (ST+HP+PV0%)	81	82	82	83	84	86
	S (ST+HP+PV+BT0%)	83	83	84	85	86	86
S 5	S (ST ZeroE 4 2050)	162	163	164	165	166	167
	S (ST +HP ZeroE up to 2050)	97	98	99	100	100	101
	S (ST+HP+PV ZeroE up to 2050)	98	99	100	101	102	103
	S (ST+HP+PV+BT ZeroE up to 2050)	100	101	102	103	104	105

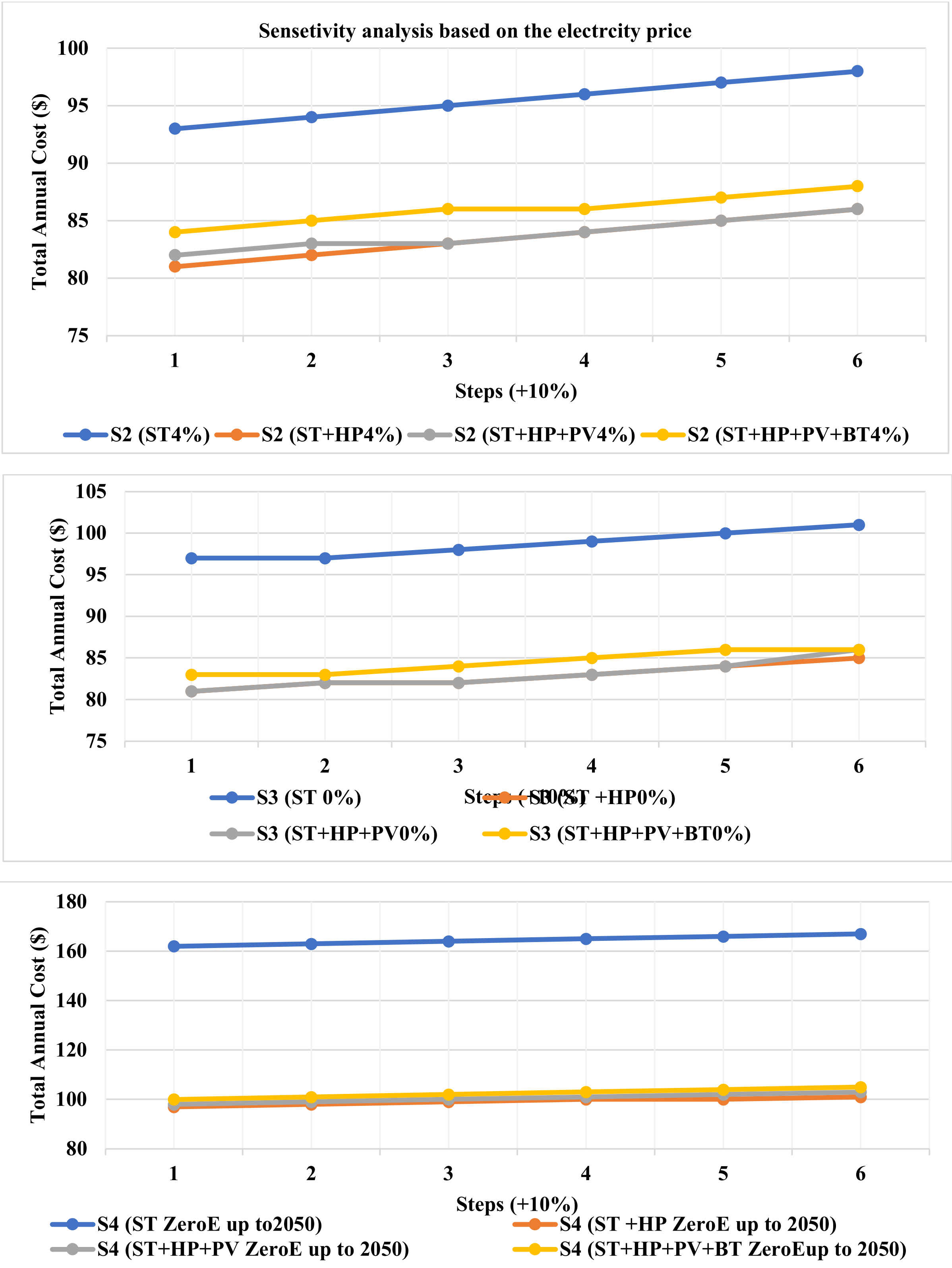


Figure 14. Sensitivity analysis and demonstration of the effect of 10% power price changes with each step on the overall system cost for different scenarios.

As shown in Table 13 and Figure 18, the overall system cost performs an increasing trend with a low slope when the carbon taxes increase. Further, each step involves a 20% growth in carbon taxes. Since this value is negligible compared to the investment and utilization costs, it is observed that the effect of this value when increasing the overall system cost results a low slope. In all scenarios, a significant difference is presented between the first sub-scenario and the other sub-scenarios due to the simple system and distance from the thought process of multi-carrier systems. In Scenario 4, the impact of increased carbon taxes i could be ignored because of the high contribution of RESs.

Table 13. Sensitivity analysis of the impact of carbon taxation on the overall system cost.

	scenario	Ctax	Ctax	Ctax	Ctax	Ctax	Ctax
S 2	**BAU**	77	78	78	79	79	80
S 3	**S (ST4%)**	93	94	94	95	95	96
	S (ST+HP4%)	81	82	82	83	83	84
	S (ST+HP+PV4%)	82	82	83	83	84	84
	S (ST+HP+PV+BT4%)	84	84	85	85	86	86
S 4	**S (ST 0%)**	97	97	98	98	98	99
	S (ST +HP0%)	81	81	82	82	83	83
	S (ST+HP+PV0%)	81	81	82	82	83	84
	S (ST+HP+PV+BT0%)	83	83	84	84	85	85
S 5	**S (ST ZeroE 4 2050)**	162	163	163	163	164	164
	S (ST +HP ZeroE up to 2050)	97	97	98	98	98	99
	S (ST+HP+PV ZeroE up to 2050)	98	98	99	99	99	100
	S (ST+HP+PV+BT ZeroE up to 2050)	100	101	101	101	102	102

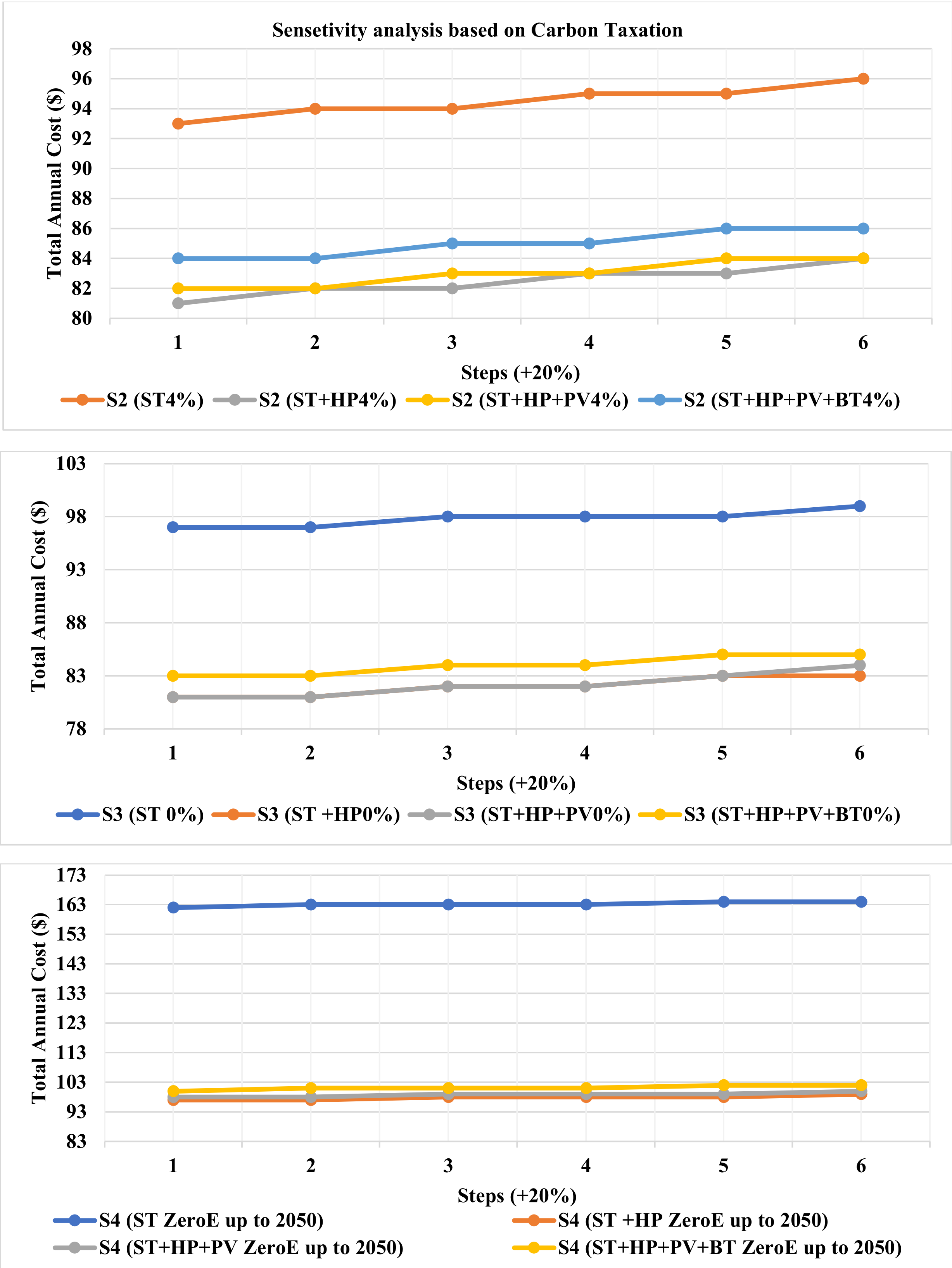


Figure 18. Sensitivity analysis and display of the effect of 20% carbon tax changes with each step on the overall system cost for different scenarios.

According to Table 14 and Figure 19, the overall system cost has decreased in different scenarios with the reduction of renewable technology costs due to an essential component of the system costs is the investment costin RESs. . In S3, S4, and S5, this cost reduction has a higher slope since the first sub-scenario uses only one source. .

Table 14. Sensitivity analysis of the impact of reduced cost of renewable energy technology on the overall system cost.

Sen.		**Tech**	**Tech - 10%**	**Tech- 20%**	**Tech - 30%**	**Tech- 40%**	**Tech- 50%**
S 2	**BAU**	77	77	77	77	77	77
S 3	**S (ST4%)**	93	91	89	87	85	83
	S (ST+HP4%)	81	80	80	79	78	77
	S (ST+HP+PV4%)	82	81	80	79	78	77
	S (ST+HP+PV+BT4%)	84	83	82	81	80	79
S 4	**S (ST 0%)**	97	94	91	89	86	84
	S (ST +HP0%)	81	80	79	78	77	76
	S (ST+HP+PV0%)	81	80	79	78	77	77
	S (ST+HP+PV+BT0%)	83	82	81	80	79	78
S 5	**S (ST ZeroE up to 2050)**	162	152	141	130	120	109
	S (ST +HP ZeroE up to 2050)	97	93	89	85	82	78
	S (ST+HP+PV ZeroE up to 2050)	98	94	90	86	83	77
	S (ST+HP+PV+BT ZeroE up to 2050)	100	96	92	88	84	80

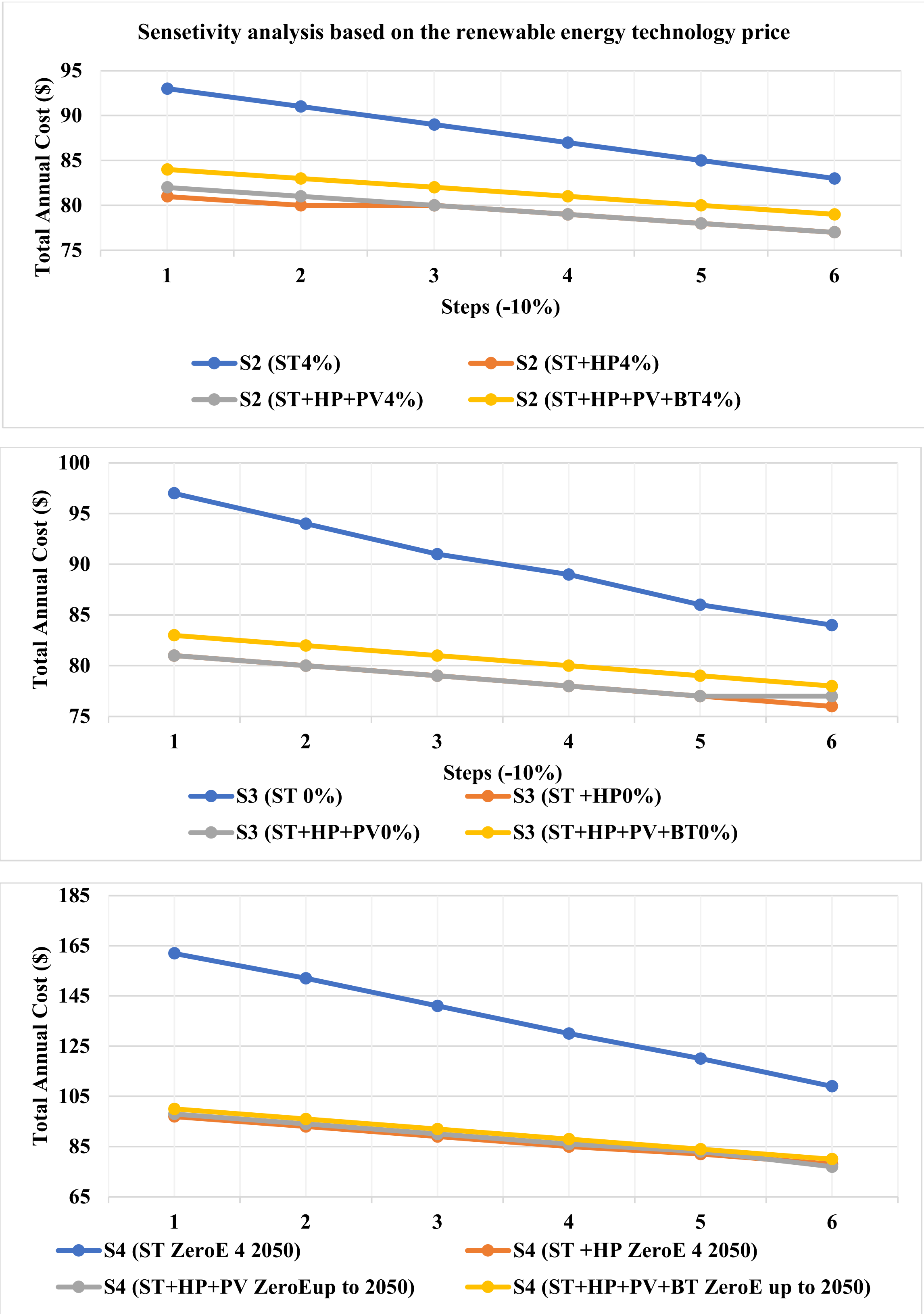


Figure 19. Sensitivity analysis and display of the effect of changing the cost of renewable resource technology with 10% steps on the total cost of the system for different scenarios.

Conclusion

CO_2 emission could increase by the population growth and the frequent energy consumption. and heating is one of the most widely used energy consumption methods Thereby, this research investigates the most suitable model in terms of environmental, technical, and economic aspects by comparing different energy models for Gaziantep province, Turkey. Firstly, the heating load for the future years was predicted by the population, PPP, efficiency in building, and the number of households. It was observed that the heat demand of study area in 2020 was about 1584 GWh and for 2030, it is forecasted as 1724 GWh. Further, the heat demand would increase by 9% over the next decade. In the proposed study, ARCGIS software and the AHP tool were used to determine the suitable locations to install a solar-based district heating system, based on economic, technical, and environmental indicators. The results show that, the center of the study area is the most effective area for the solar energy and 70% of the land could be used for solar panels. In addition, different hybrid models were simulated by EnergyPLAN software for Gaziantep province until 2030, considering minimum CO2 emission and the maximum RES contribution In the simulation, a multi-objective function was considered and therefore, , the overall system cost and initial energy consumption were also minimized. According to the results, by comparing different models in terms of price, the hybrid solution based on solar heating and HP possess the lowest annual cost in all scenarios. Overall, scenario 5 was the best scenario for the selected location considering primary energy consumption, where the integration of ST and HPs has consumed comparatively a minimum energy. Overall, . For instance, this system has decreased the CO2 emissions by 37% due to the 21.8% reduction in the total primary energy supply compared to other business. However, carbon taxation was an influential parameter in energy modeling, which considered in the sensitivity analysis in this research. On the flip side, there was a reduction in investment costs in this sector because of the significant growth of technology, as presented in the sensitivity analysis. Eventually, the upstream grid electricity prices were also considered in the sensitivity analysis as an influential parameter in determining the consumer patterns.

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