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Forecasting the biomass-based energy potential using artificial intelligence and geographic information systems: A case study

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A B S T R A C T

To meet the energy demand in a sustainable way, fossil fuels must be substituted with alternative resources and technologies. This transformation is encouraged to reduce greenhouse gases using environmental-friendly practices. Although our country is rich in biomass resources due to climate, land conditions, agriculture and animal husbandry activities, the installed power is quite below its potential. Focusing on this point, the aim of this study is to propose a forecasting method that determines the quantities, distributions, production amounts, waste amounts and energy potential of various biomass resources consistently. The integrated method used in the solution utilizes statistical data and consists of artificial intelligence and geographic information systems. First of all, various bioenergy sources that can be used as energy resources have been determined, and the amount, yield, and energy potential of animal and agricultural wastes expected to occur in the following years have been estimated using an artificial intelligence-based method, support vector regression. Then, spatial analysis has been carried out using geographic information systems, and the distribution of existing and possible agricultural lands has been determined. Finally, the amount of energy that can be obtained using wastes from different biomass sources under various scenarios has been calculated and solutions have been compared. To the best of our knowledge, this study is the first proposing an integrated method consisting of support vector regression and geographic information systems to forecast the biomass-based energy potential in Turkey. The integrated method was applied to Acıpayam district in Denizli. Among the various scenario approaches, the cultivation of rapeseed (canola) plants on non-utilized arable land and the use of its wastes in bioenergy production have been found to yield the highest energy potential. The results showed that approximately 29,2%, 27,8%, and 27,6% energy increase could be obtained from agricultural residues of rapeseed in the next three years if it was planted on the quarter of the idle land. Besides, under this scenario, the total annual electricity demand of 6972, 6663 and 6545 houses could be met from agricultural residues in a sustainable and clean manner. The proposed method can be applied to different regions, various biomass resources and used to make strategic decisions in this field.

1. Introduction

With the increase of population and technological developments, energy demand and consumption have been rising rapidly. Fossil fuels, which have been used at a high rate today to meet global energy needs, cause climate change by creating greenhouse gases and are in danger of depletion. The use of renewable energy resources to meet the world's energy demand by reducing the damage to the ecosystem have been proliferating day by day with the development of conversion methods and increasing their efficiency. Governments, scientists, and companies have been working to obtain energy with sustainable methods and establish legal regulations for improvements. In this context, the use of sustainable energy resources in energy production has been encouraged and the share of fossil fuel-based energy has been gradually reduced. This year, it was the first time in the member countries of the European Union that 40% of electricity generation was obtained from renewable energy sources and 34% from fossil fuels [1].

Biomass energy, which is one of the renewable energy sources and constitutes the main subject of this study, has been obtained from organic materials and wastes by various methods. Today, two-thirds of biomass energy, which contributes 10% of the global energy supply, is produced in developing countries [2]. The interest

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in biomass-based energy has been rapidly growing due to its ability to be grown almost everywhere where climate and land conditions permit, to be stored by converting into raw materials or different types of energy, and to be obtained from various wastes. The number of academic studies investigating the biomass potential has also increased in recent years. These studies can be divided into subgroups according to type of biomass resource, method used to solve the problem, and scenario approach. The contents and scopes of the studies in the literature are summarized in Table 1, Table 2, and Table 3.

In Table 1, the biomass resources used in the studies on the projection of biomass-based energy are given. Biomass resources are mainly grouped as agricultural and forestry residues, animal waste, municipal and sewage waste, energy crops, food crops and general energy amount calculation.

In Table 2, methods used to solve the problems in the literature are shown in five main groups as statistical, artificial intelligence-based, geographic information systems (GIS), mathematical modeling and simulation approaches.

Table 3 shows whether different scenarios were used to solve the problems in the literature. The number of different scenarios has been stated in parentheses if scenarios have been adopted. Different scenarios involve considering factors such as maintaining the current situation and policies in the same way, focusing on renewable energy, increasing the area allocated to biomass raw materials, using different raw materials in energy production, changing production costs, and increasing the efficiency of raw materials in order to incorporate uncertainty into the solution.

Among the studies investigating biomass potential and distribution of resources, Hernández et al. [3] presented a model based on two different scenarios in order to estimate the biomass obtained from forest residues in a short term. In the first scenario, it was assumed that the conditions would continue at a normal level, while in the second scenario, it was assumed that the forest areas that utilized for biomass-based energy would be increased sustainably. In the investigation of biomass energy potential, numerical modeling, Holt-Winters exponential smoothing, and regression analysis were used taking into account factors such as soil degradation, land slope and level of mechanization. Avcıoğlu et al. [4] explored the available agricultural bioenergy potential of Turkey. In the study, agricultural residue characteristics (residue-crop ratio, moisture content, lower heating value, and energy value) of various resources were determined considering data of different countries. To calculate total biomass potential a mathematical model was utilized. Namsaraev et al. [5] investigated the technical bioenergy potential of Russia. In the study, it was predicted that the biomass resource with the highest rate in the future will be agricultural residues which are followed by municipal solid waste, forest residues, livestock manure and sewage waste. Ma et al. [6] proposed a forecasting method based on artificial neural networks to model and estimate renewable energy (biomass and hydroelectric) production and consumption values. Mantziaris et al. [7] studied the extent to which some energy crops (arundo, miscanthus, poplar) could replace traditional fuels in Greece under certain constraints, and what should be done for this. Welfle [8] estimated the biomass potential with the help of the biomass resource model, taking into account three different scenarios (current policy, focus on renewable energy, 100% renewable energy target). Population, settled land area, agricultural yield for different energy crops, agricultural residue amounts, forest areas, energy crop fields were used as inputs in the estimation. Chen [9] predicted the biomass potential that could be obtained from agricultural residues by using a mathematical model. While rice residues constituted the largest proportion of biomass, it was followed by corn and wheat residues. In the mathematical model, the amount of cultivated area and production level data between 2001 and 2010 was used as input. Thrän et al. [10] proposed an integrated modeling approach for determining bioenergy strategies taking into account the link between the national bioenergy system and the national land use system. Deng et al. [11] projected biofuel potential covering a total of fifty-five countries by using factors such as land use, crop productivity, and food demand under various scenarios (bad, medium, good availability). In the study, some energy crops, lignocellulosic plants, agricultural and forest residues were considered as biomass sources. Özcan et al. [12] determined total electrical energy potential of Turkey from various biomass resources including municipal solid waste, energy crops, animal waste, and wastewater sludge. In the study, different data sources were utilized such as Water and Sewage Administration of Istanbul, Turkish Electricity Transmission Company, and Turkey Statistical Institute. Günlü et al. [13] focused on forest-based aboveground biomass and forecasted biomass potential using remote sensing and statistical methods. Satellite image and multiple stepwise regression were used to solve the problem. Hiloidhari et al. [14] determined the energy potential that can be obtained from various agricultural residues with the help of statistical calculations. It was determined that the sources with the highest energy efficiency for the application area were rice, sugar cane, wheat, and cotton. Welfle et al. [15] proposed the biomass resource model that takes into account the climate, food and cultivation area in order to determine the biomass potential. As a result of the study, it was estimated that the biomass-based energy in 2050 would be 44% of the energy used in the assumption of the best scenario. Welfle et al. [16] investigated how bioenergy resources would take shape

Table 1
Classification of studies based on biomass resources.

	Agricultural and forestry residues	Animal waste	Municipal and sewage waste	Energy crops	Food crops	General
Hernández et al. [3]	●					
Avcıoğlu et al. [4]	●			●		
Namsaraev et al. [5]	●	●	●			
Ma et al. [6]						●
Mantziaris et al. [7]				●		
Welfle [8]	●		●	●	●	
Chen [9]	●			●	●	
Thrän et al. [10]	●	●		●	●	
Deng et al. [11]	●			●	●	
Özcan et al. [12]		●	●	●		
Günlü et al. [13]	●					
Hiloidhari et al. [14]	●					
Welfle et al. [15]	●	●	●	●	●	
Welfle et al. [16]	●	●	●	●	●	
Jiang et al. [17]	●					
Onurbaş Avcıoğlu and Türker [18]		●				
This study	●	●		●		

Table 2
Classification of studies based on solution methods.

	Statistical	Artificial intelligence-based	GIS	Mathematical modeling	Simulation
Hernández et al. [3]	●		●		
Avcıoğlu et al. [4]	●			●	
Namsaraev et al. [5]	●				
Ma et al. [6]		●			
Mantziaris et al. [7]	●				
Welfle [8]	●				
Chen [9]				●	
Thrän et al. [10]	●		●		●
Deng et al. [11]				●	
Özcan et al. [12]	●				
Günlü et al. [13]	●		●		
Hiloidhari et al. [14]	●				
Welfle et al. [15]				●	
Welfle et al. [16]				●	
Jiang et al. [17]	●		●		
Onurbaş Avcıoğlu and Türker [18]	●				
This study		●	●		

Table 3
Classification of studies based on scenario approaches.

	Adopted	Not adopted
Hernández et al. [3]	● (2)	
Avcıoğlu et al. [4]		●
Namsaraev et al. [5]		●
Ma et al. [6]		●
Mantziaris et al. [7]		●
Welfle [8]	● (3)	
Chen [9]	● (6)	
Thrän et al. [10]	● (4)	
Deng et al. [11]	● (2)	
Özcan et al. [12]	● (2)	
Günlü et al. [13]		●
Hiloidhari et al. [14]		●
Welfle et al. [15]	● (4)	
Welfle et al. [16]		●
Jiang et al. [17]		●
Onurbaş Avcıoğlu and Türker [18]		●
This study	● (4)	

in the coming years. It was estimated that there could be a contribution of 115 TWh from household wastes, 100 TWh from energy crops, and over 80 TWh from agricultural residues. Jiang et al. [17] calculated the amount of energy that can be obtained from agricultural residues with a GIS-based approach that takes biomass resources, economy, environment, and technology into account. The ratio of the crops to agricultural residues over a period 2000–2009 was calculated and then the spatial analysis was carried out. In the study, today's projection and distribution was given without using forward-looking calculations. Another successful application in bioenergy projection is the estimation of biogas potential of Turkey by Onurbaş Avcıoğlu and Türker [18]. Animal waste-based biogas potential was calculated for all provinces considering availability and dry matter loss.

Our country, Turkey is very suitable for the cultivation of energy crops due to both climate and land conditions. In addition, it has a lot of agricultural and animal wastes due to the widespread use of agricultural production and animal husbandry. Although the amount of energy that can be obtained from biomass resources is high, the role of bioenergy in our country in terms of installed power lags behind hydroelectric, geothermal and wind energy. Determining the amount and distribution of biomass resources as accurately as possible is very important in making strategic decisions such as energy management policies. Considering the studies reviewed it is found that covering such important features of renewable energy projection have been applied to only few case studies in Turkey [4,12,13,18]. Among these studies, mostly statistical approaches have been utilized for prediction and scenario approaches have rarely been adopted to catch uncertainties properly. However, what-if scenarios enable decision-makers to evaluate the possible outcomes of each situation and to act according to these assessments. Therefore, adopting various scenario approaches considering uncertain elements of the problem might result in better outcomes. Another important gap found in the literature is the need for reliable, analytical, and flexible forecasting methods for bioenergy potential. By adopting such a systematic integrated approach, energy management decisions can be made more effectively. Moreover, spatial analysis and geographical data can be used to capture and analyze the distribution of resources and energy potential precisely. In the light of the results obtained from the literature review, this study proposes a decision support method that enables estimation of the amount, distribution of resources and energy that can be produced from biomass. The proposed decision support method integrates artificial intelligence and GIS methods based on statistical data. To the best of our knowledge this is the first approach consisting of artificial intelligence and GIS methods in this field. Using statistical data, the amount of agricultural production, the amount of cultivated area, production yield, the amount of wastes that may be generated, and the amount of potential energy in the future have been obtained by using support vector regression (SVR), an artificial intelligence-based method. Although support vector machines, which are a supervised learning method, have emerged for classification purposes, they have been used for forecasting later [19] and in different study areas (carbon nanotube simulation time [20], hydrogen production process [21], parameters estimation of biomass gasification process [22]… etc.) consistent results have been obtained. The main advantages of SVR are obtaining nonlinear results and solving complex problems in a short time with an acceptable error rate. In the next phase, spatial analysis has been carried out using GIS, a system that allows collecting, analyzing, and managing geographical data, the distribution of biomass resources and the distribution of existing and possible agricultural lands have been determined spatially. GIS can be used as a decision support system in the solution of various problems (housing satisfaction research [23], determination of electric vehicle charging stations [24], modeling of rooftop solar panels [25]… etc.), as well as for visualizing the results. In addition to these features, it can be applied to complex problems in order to obtain relatively rapid results. Finally, a scenario-based approach has been developed to incorporate uncertainties in the decision-making phase into the solution and different results have been evaluated. Combining the advantages of SVR and GIS, it is expected that the proposed method can consider multiple future situations and uncertainties so that it can be applied to relatively large size problems and yield consistent results.

This study consists of four parts. In the first section, the subject has been introduced and a comprehensive literature review has been given. In the second part, the proposed method for forecasting the biomass potential has been explained in detail. In the next section, the application has been carried out using statistical data, GIS and SVR, and the findings obtained under various scenarios have been compared. Finally, in the fourth section, the conclusions reached as a result of the study have been stated and suggestions for future studies have been given.

2. The proposed methodology

Determining the biomass resources that can be used in bioenergy production effectively and calculating the energy potential that can be obtained from their wastes are important in strategic decision-making process. For the effectiveness of this planning, it is necessary to benefit from the previous data. From this point of view, statistical data regarding the agricultural production amount, agricultural production yield, the amount of land used for agricultural production, and the number of poultry has been used to solve the problem. In order to make long-term decisions, the amount of agricultural and animal wastes that can be obtained in the following years has been predicted using an artificial intelligence-based forecasting method, SVR, taking into account the rate of increase in yield in agricultural production. The spatial distribution of arable lands and biomass energy resources have been determined using GIS. The amount of energy that can be obtained from agricultural residues as a result of planting various agricultural products on idle but arable lands has been evaluated under different scenarios.

2.1. Support vector regression (SVR)

SVR is a supervised learning method for modelling and prediction, which derived from support vector machines algorithm, was proposed by Vapnik and his co-workers in 1996 [26]. The method has emerged from the problem of separating different data classes from each other. Using the approach, the endpoints of two or more data sets called support vectors, and the regression line passing through the middle of these vectors representing the data sets are determined. Data sets are not always linearly separable. For this reason, the nonlinear problem is projected to a high dimensional space and the most suitable function for the problem is determined and expressed again linearly with kernel functions. Kernel functions can be linear, quadratic, cubic and radial based. The interested reader may refer to Smola and Schölkopf [27] and Awad and Khanna [28] for further information on SVR.

2.2. Geographic information systems (GIS)

GIS can be defined as a system that allows users to collect, analyze and manage spatial and geographical data. Displaying a layered structure, GIS makes it possible to analyze and integrate different data spatially. In this way, GIS enables different vector and raster data to be expressed on the same plane and various analyzes to be made. As computer technology increases, spatial analysis has become important in designing and managing biomass supply chains. GIS has been used to estimate population, biomass raw material availability and distribution, and accessibility to the transportation network [29]. In addition to these, it is frequently used in bioenergy supply chains [30,31,32] to visualize the results, to allocate sources, to determine plant locations, and to design transportation systems.

The proposed method includes the uncertainties existing in the decision process by adopting the scenario approach. The forecasting of the biomass potential has been carried out with the help of statistical data, using artificial intelligence and GIS, with an integrated approach that has not previously been proposed in the literature. The study, which is unique in this respect, can be applied to different regions and countries and can be used as a decision support system in decision processes at various levels.

The steps of the integrated method are shown in Fig. 1.

First of all, the data including annual crop production and poultry numbers have been estimated using SVR method for plant/animal raw material resources that are frequently grown/available in the region and have high bioenergy potential that can be obtained from their wastes. In the next step, the amount of wastes and bioenergy potentials have been calculated. Then, using GIS, various layers have been formed, the arable lands in the region have been analyzed and their amount has been determined. Finally, the bioenergy potentials that can be obtained as a result of applying different scenarios in the field of agriculture have been determined.

3. The case study

In this section, the forecasting of the amounts of various agricultural and animal-based biomass resources in the following years and the spatial analysis of their distributions has been made. Acıpayam district of Denizli province has been determined as an application area due to the intensity of agricultural and animal husbandry activities. Various forecasting and spatial analyses have been carried out with MATLAB R2019b and ArcGIS 10.6.1, respectively, using artificial intelligence and GIS methods.

Data sets containing agricultural production, agricultural area, and the number of poultry in Acıpayam between 2004 and 2019 have been gathered from the website of Turkey Statistical Institute (TSI) and presented in Table 4, Table 5, Table 6, and Table 7.

Among the crop production statistics, the agricultural lands, and the distribution of the areas according to various agricultural products are shown in Table 4 as hectare (ha).

The agricultural areas used in the production of some cereals and other crop products, which are important raw materials for biomass-based energy, are given in Table 5. The study mainly focuses on some cereal and other products frequently grown in the application area from which high amount of energy can be obtained.

Table 6 shows the production amounts of cereal and other crop products with high biomass potential grown in the application area.

Another prominent biomass raw material frequently found in the application area is laying hen wastes. Table 7 demonstrates the number of laying hens in the application area.

3.1. Forecasting application

Firstly, the amount of wastes and bioenergy potentials that may occur depending on the unit production of various agricultural or the number of animal-based biomass sources were determined. The coefficients used in the calculations have been gathered from TSI statistics [33,34] and Republic of Turkey Ministry of Energy and Natural Resources Energy Affairs General Directorate Biomass Energy Potential Atlas [35]

Table 8 presents the data table for the region, which is organized according to agricultural production, number of poultry animals and annual waste amounts, and shows the energy potentials

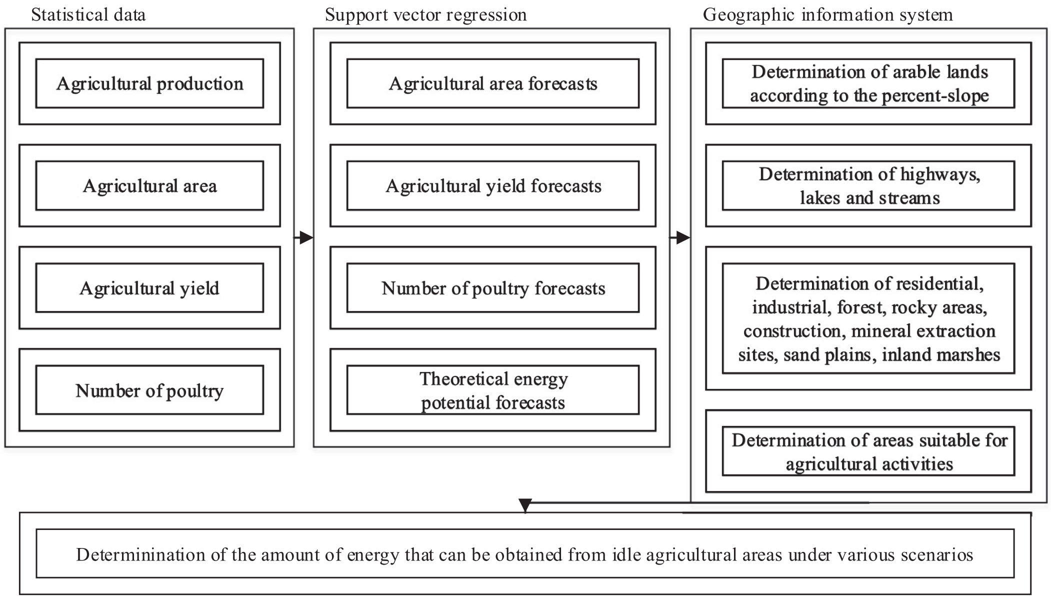

Fig. 1. The steps of the proposed approach.

Table 4
Agricultural land statistics [33].

Years	Area of fruits, beverage and spice crops (ha)	Fallow land (ha)	Area of vegetable gardens (ha)	Area of cereals and other crop products (ha)	Total agricultural land (ha)
2004	2625	150	5258	38,328	46,361
2005	2733	100	5357	37,511	45,701
2006	2817,6	70	5484,2	35812,5	44184,3
2007	2985,6	142,9	5493,7	34266,7	42888,9
2008	2893,7	461,8	5720	33120,9	42196,4
2009	2820,7	49,2	5734,6	33463,4	42067,9
2010	3481,2	880,7	5651,4	35771,5	45784,8
2011	3481,1	580,7	5651,4	33818,3	43531,5
2012	3609,1	1346,6	5836	34057,3	44,849
2013	2105,6	2627,2	4425,1	35726,6	44884,5
2014	1889,8	850,2	4791,9	36468,2	44000,1
2015	1927,3	817,6	4878,4	36051,8	43675,1
2016	1911,9	1533,4	4624,3	34508,2	42577,8
2017	2086,8	775	4660,2	34,237	41,759
2018	1745,6	588,3	4404,9	35356,9	42095,7
2019	1733,9	585,8	4557,2	35709,5	42586,4

Table 5
Agricultural area of cereals and other crop products [33].

Years	Wheat (ha)	Barley (ha)	Rye (ha)	Chickpea (ha)	Sugar beets (ha)	Poppy (ha)	Others (ha)
2004	16,020	11,965	1195	560	365	1473	6750
2005	16,548	11,150	396	560	385	1325	7147
2006	14167,1	11049,9	570	610	327,1	1831,6	7256,8
2007	14267,8	11,068	600	640	331,3	310,6	7049
2008	13689,5	10042,9	570	695	349,6	327,3	7446,6
2009	13427,5	10421,1	670	720	406	1366,7	6452,1
2010	15258,9	11,050	718,9	690	484	1951,9	5617,8
2011	14474,7	9800	690	690	454,2	2278,7	5430,7
2012	14400,5	8300	800	780	693,3	368	8715,5
2013	13345,5	8600	582,3	550	912,3	1416,8	10319,7
2014	14099,9	8999,7	610,8	711,9	930,2	947,9	10167,8
2015	13543,8	8591,2	600	840	448	2231,6	9797,2
2016	12137,9	9211,6	690	800	434,7	1018,7	10215,3
2017	11,596	8557,2	707,5	825,2	295,4	1201,5	11054,2
2018	11,116	8863,7	893,7	733,7	323,9	1308	12117,9
2019	10680,5	9181,7	1098,8	353,3	404	1513,7	12477,5

that can be produced from these raw material sources. While choosing the source of raw materials, besides the widespread cultivation and livestock activities in the region, materials with high biomass potential were taken into consideration.

Table 6
Production of cereals and other crop products [33].

Years	Wheat (ton)	Barley (ton)	Rye (ton)	Chickpea (ton)	Sugar beets (ton)	Poppy (ton)
2004	38,237	32,707	1150	559	15,334	2047
2005	39,153	27,074	394	560	13,596	1491
2006	47,604	46,661	2138	488	14,499	3580
2007	32,075	33,204	1800	448	12,205	227
2008	37,318	32,507	1881	556	14,564	237
2009	32,674	27,956	2144	576	18,295	1683
2010	35,446	30,586	1035	407	21,743	2069
2011	42,197	27,265	1035	407	20,760	2995
2012	60,440	21,511	1600	741	30,145	254
2013	46,340	25,540	1165	440	36,689	1350
2014	42,729	24,264	1492	578	42,426	1134
2015	35,369	20,742	1212	715	17,536	1386
2016	32,283	21,679	1346	737	21,469	1271
2017	35,244	28,065	1675	706	13,656	1542
2018	39,363	29,475	1460	595	14,027	1404
2019	39,136	30,779	1928	300	23,000	1078

Table 7
Number of laying hens [34].

Years	Number of laying hens	Years	Number of laying hens
2004	100,000	2012	60,000
2005	37,272	2013	62,000
2006	145,995	2014	62,000
2007	132,850	2015	73,500
2008	230,000	2016	87,000
2009	111,500	2017	218,000
2010	111,500	2018	151,230
2011	50,000	2019	61,686

Table 8
Energy potential and crop residue of various biomass feedstock [35].

Biomass raw material	Agricultural production (ton)/Number of poultry	Annual amount of waste (ton)	Energy potential (toe/year)
Laying hen	1	0,05475	0,01369
Wheat	1	0,95802	0,41451
Barley	1	0,68758	0,29296
Rye	1	0,21053	0,08729
Chickpea	1	1,5	0,59748
Sugar beets	1	0,04	0,01482
Poppy	1	1,5	0,59623

The agricultural land, yield, the number of poultry and theoretical energy potential forecasts of various biomass resources for the following three years have been estimated using SVR utilizing TSI data covering 2004–2019. The results are shown in Table 9 and Table 10, respectively.

When Table 9 is examined, it is observed that the agricultural product with the highest bioenergy potential is wheat residues, followed by barley and poppy residues. The amount of energy that can be obtained from cereals and other plants in 2020, 2021 and 2022 has been calculated as 26081,346, 25857,106 and 25509,267 toe/year, respectively. Similarly, the amount of energy that can be obtained from laying hen waste in 2020, 2021 and 2022 has been calculated as 1006,749, 1308,887 and 1353,106 toe/year (see Table 10).

The amount of energy that can be obtained from the wastes of agricultural and animal-based biomass resources in the region has been predicted for the next three years. The theoretical total energy that can be obtained from the specified sources are estimated as 27088,095, 27165,993 and 26862,373 toe/year, respectively.

3.2. Spatial and statistical analysis of the current state

In this section, the current state analysis of Acıpayam district has been carried out using statistical data, SVR and GIS software. First of all, using the data of TSI, the total agricultural area has been estimated for the next three years using SVR. In the next phase, existing land distributions and arable lands have been determined using GIS. In the last phase, various utilization methods of arable land under different scenarios and the effects of these situations on theoretical bioenergy potentials have been analyzed.

Firstly, the forecasting of the total agricultural areas used in agricultural activities given in Table 4 for the next three years have been carried out using SVR and the results are given in Table 11.

Then, for the analysis of land use in the application area, the distribution and amount of arable land has been determined taking

Table 9
Three-year agricultural land, yield and energy potential forecasts of various cereals and other crop products.

Years	Wheat	Barley	Rye	Chickpea	Sugar beets	Poppy
			Agricultural land (ha)			
2020	10,701	8717,3	1064,1	619,65	419,8	1525,7
2021	10,360	8684,6	1174,4	671,84	422,63	1575,6
2022	10,020	8671,1	1295,5	679,09	422,72	1587,5
			Yield (ton/ha)			
2020	3,5807	3,317	2,0165	0,8392	47,4188	1,0273
2021	3,66	3,2743	2,0543	0,836	47,7786	1,026
2022	3,7393	3,2024	2,0554	0,8346	48,1385	1,0257
			Theoretical energy potential of residues (toe)			
2020	15882,809	8471,022	187,303	310,697	295,013	934,502
2021	15717,224	8330,606	210,593	335,581	299,255	963,845
2022	15530,772	8135,010	232,433	338,637	301,574	970,841

Table 10
Three-year quantity and energy potential forecasts of laying hens.

Years	Laying hens
Number	
2020	73,539
2021	95,609
2022	98,839
Theoretical energy potential of wastes (toe)	
2020	1006,749
2021	1308,887
2022	1353,106

Table 11
Three-year forecast of total agricultural land.

Years	Agricultural land (ha)
2020	43,319
2021	43,610
2022	43,647

into account; percent-slope, urban/rural residential areas, industrial and commercial areas, construction sites, mining areas, forest lands, marshes, rocks, sandy areas, highways, rivers and lakes. The data used in the spatial analysis have been generated using the CORINE 2018 project [36], Open Street Map website [37] and NASA Shuttle Radar Topography Mission images [38].

Increasing slope in agricultural areas proliferates the risk of erosion and affects plant selection and irrigation method. According to the Soil and Land Classification Technical Instructions of the Ministry of Agriculture and Forestry, revised in 2008, when the slope of the agricultural lands is below 8%, it is considered as absolute agricultural land. If the slope of the land is above 12%, it is classified as marginal agricultural land and the yield of the product decreases although the land is suitable for agriculture [39].

The slope classes included in the technical instructions are shown in Table 12.

According to the technical instructions, the application area has been grouped according to the percent-slope. The percent-slope map is given in Fig. 2. The arable lands, the slope of the area below 12%, are shown with green color on the map.

It has been calculated that the total of the areas with suitable slope value (0 < percent slope < 12) to be used in agricultural activities in the application area is 65276,166 ha.

Buffers have been developed for streams (20 m) and lakes (30 m) layer to differentiate agricultural lands and water bodies. Another buffer zone has been created for highways. Using Highway Geometric Standards [40] (second class road up to 11,000 vehicles per day, lane width 3.5 m - shoulder width 1.5 m), the width of the highways used in the analysis has been determined as 10 m and applied to the highways layer. A different layer has been created for other factors considered (urban/rural residential areas, industrial and commercial areas, construction sites, mining areas, forest lands, marshes, rocks, sandy areas) and their distribution and amount of area have been determined.

Table 12
Percent-slope classes [39].

Symbol	Explanation	Percent-slope (%)
A	Nearly level	0–2
B	Gently sloping	3–6
C	Moderately sloping	7–12
D	Strongly sloping	13–20
E	Moderately steep	21–30
F	Steep	31–45
G	Very steep	45+

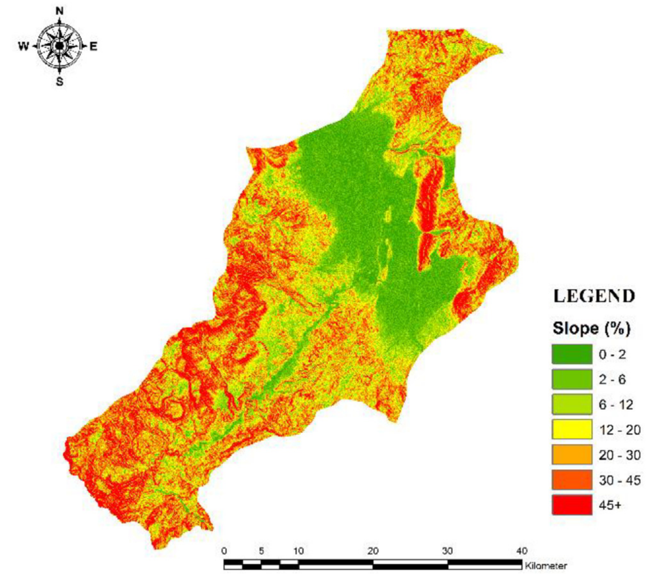

Fig. 2. Percent-slope classes of Acıpayam.

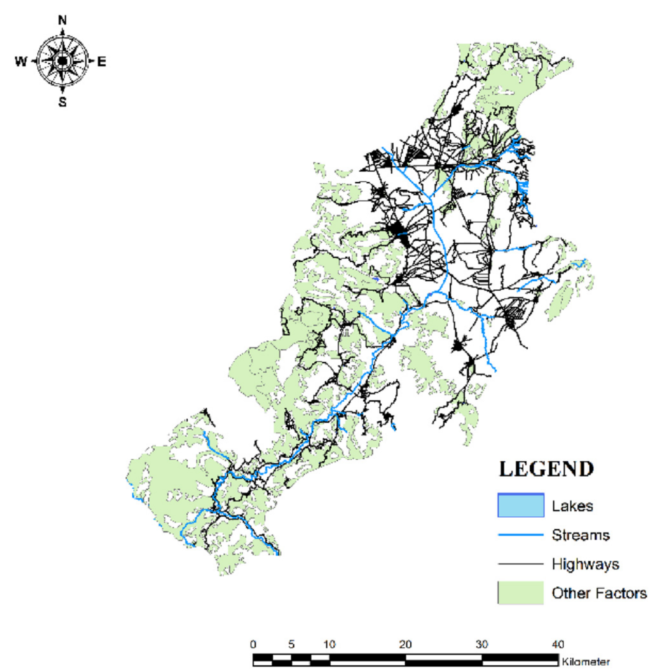

Fig. 3. Acıpayam streams, highways, lakes and other factors map.

The geographical distribution of lakes, rivers, highways and other factors in the application area is shown in Fig. 3.

The map in which the amount and distribution of land suitable for agriculture has been calculated and visualized taking into account the percent-slope, highways, streams, lakes and other factors, is given in Fig. 4.

First of all, spatial analysis has been performed according to the slope and the distribution and total amount of the areas suitable for agricultural activities have been determined. Then, the amount of agricultural areas that overlap with predetermined limits of lakes (30 m), rivers (20 m each), highways (10 m) and other factors have been determined. In the end, the ultimate amount of areas that are suitable for agriculture have been calculated. These values are shown in Table 13.

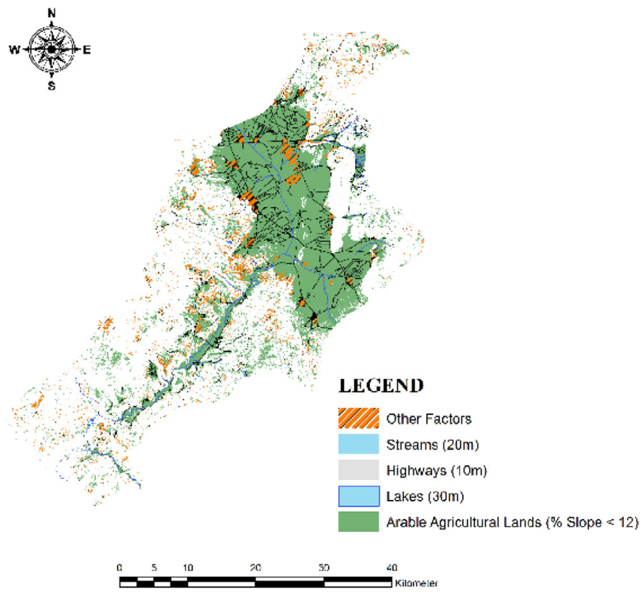

Fig. 4. Analysis of agricultural land.

It has been determined spatially that the total suitable area for agricultural activities, with a percent-slope less than 12, is 65276,166 ha. It has also been calculated that the total area of highways is 2425,906, the total area of rivers is 727,036, the total area of lakes is 8,561, and the total area of other factors is 9192,693 ha which overlaps with total suitable area for agricultural activities. Total 12354,2 ha area has been measured as a result of the sum of the lands that are not suitable for agriculture. However, due to the spatial overlap with each other, the spatial actual value of the integrated areas has been determined to be 11750,6 ha.

In the previous stage, using the data of TSI, the three-year forecasts of the areas actually used in agricultural activities in the application area have been made by SVR and calculated as 43319, 43,610 and 43647 ha, respectively. As a result of the spatial analysis, it has been determined that there is a net area of 53525,566 ha available for agricultural activities. And annually, arable but idle agricultural land has been measured as 10206,566, 9915,566 and 9878,566 ha, respectively. The annual change of idle areas suitable for agriculture is shown in Table 14.

3.3. Various scenario approaches

In this section, it was examined that how the theoretical energy potential obtained from wastes would change as a result of evaluating the arable but idle land calculated in section 3.2 with various percentages and different bioenergy sources. While making theoretical potential calculations, the unit of area has been taken as a basis. The planting and installation costs have been ignored. Thus, the energy projection for the same scenario can be easily calculated by changing the utilization rate of the idle land under different percentages.

Table 14
Total amount of unused agricultural lands.

	2020	2021	2022
Total amount of land suitable for agricultural activities (ha)	53525,566	53525,566	53525,566
The amount of land actually used in agricultural activities (ha)	43,319	43,610	43,647
The amount of idle area that can be used in agricultural activities (ha)	10206,566	9915,566	9878,566

3.3.1. Scenario 1

In this scenario, we assume that agricultural land would be increased using 25% of the idle land and sowing biomass resources in equal areas. The yearly total land increase in the next three years has been calculated as 2551,64, 2478,89 and 2469,64 ha, respectively. The cultivation areas of the six products selected as biomass sources are 425,274, 413,149 and 411,607 ha on a yearly basis. The amount of energy that could be obtained from agricultural residues using the product yields calculated annually in the previous sections are shown in Table 15 for agricultural products determined.

3.3.2. Scenario 2

In Scenario 2, it is assumed that agricultural land would be increased using 25% of the idle land as a result of sowing only barley and wheat from biomass resources in equal proportions. The yearly total land increase in the next three years has been calculated as 2551,64, 2478,89 and 2469,64 ha, respectively. The cultivation areas of cereal crops selected as biomass sources are 1275,821, 1239,446 and 1234,821 ha on an annual basis. The amount of energy that could be obtained from agricultural residues using the product yields calculated annually in the previous sections are shown in Table 16 for agricultural products determined.

3.3.3. Scenario 3

In this scenario, we assume that agricultural lands would be increased sowing biomass resources in equal areas as a result of making the marsh lands located in the application area suitable for agriculture. A total of 572,474 ha of land could be used in agricultural activities as a result of the complete drying of the marshes, which are among the highly productive and irrigated agricultural lands in Acıpayam district. The spatially determined geographical view of the marshes, which covers 25,851, 38,981, 39,468 and 468,174 ha areas, is shown in Fig. 5.

Assuming that the marshes would be drained 50% in the first year, 75% in the next year, and 100% in the third year, the yearly total agricultural land increase has been calculated as 286,237, 429,355 and 572,474 ha. The cultivation areas of cereal crops selected as biomass sources are 47,706, 71,559 and 95,412 ha on an annual basis. The amount of energy that could be obtained from

Table 13
Total areas of land cover classes.

Land class	Total area (ha)
Percent-slope is less than 12	65276,166
Lakes (30 m)	8,561
Streams (20 m each)	727,036
Highways (10 m)	2425,906
Other factors	9192,693
Cumulative total value of integrated areas	12354,2
Spatial total value of integrated areas	11750,6
Ultimate amount of areas suitable for agriculture	53525,566

Table 15
Three-year theoretical energy potential increase based on scenario 1.

	Years		
	2020	2021	2022
Wheat residues (toe)	631,206	626,790	637,981
Barley residues (toe)	413,259	396,308	386,159
Rye residues (toe)	74,857	74,086	73,849
Chickpea residues (toe)	213,234	206,365	205,251
Sugar beets residues (toe)	298,860	292,542	293,646
Poppy residues (toe)	260,483	252,736	251,719
Total (toe)	1891,899	1848,827	1848,605

Table 16
Three-year theoretical energy potential increase based on scenario 2.

	Years		
	2020	2021	2022
Wheat residues (toe)	1893,619	1880,371	1913,944
Barley residues (toe)	1239,777	1188,925	1158,478
Total (toe)	3133,396	3069,296	3072,422

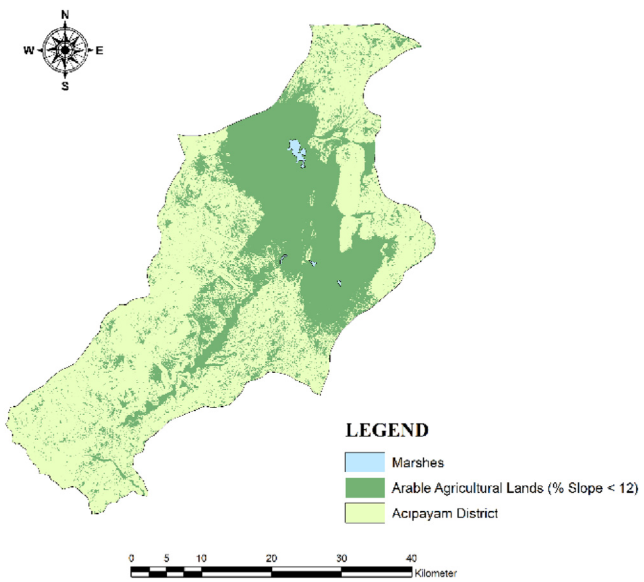

Fig. 5. Agricultural land and marshes map of Acıpayam.

agricultural residues using the product yields calculated annually in the previous sections are shown in Table 17 for agricultural products determined.

3.3.4. Scenario 4

In Scenario 4, it is assumed that agricultural land would be increased using 25% of the idle land and planting only rapeseed (canola) in the whole area. The yearly total land increase in the next three years has been calculated as 2551,64, 2478,89 and 2469,64 ha, respectively. Since the annual production, residue amount and energy potential of the rapeseed (canola) plant selected as the biomass source have not been calculated in the previous sections, they are shown in Table 18. Calculation of the yield for biomass source was carried out using all data of Turkey since rapeseed was not grown in the application area. The yield was estimated to be 3,3291, 3,2747 and 3,229 for three years using SVR, respectively. The amount of energy that could be obtained annually using the product yield are shown in Table 19.

Table 17
Three-year theoretical energy potential increase based on scenario 3.

	Years		
	2020	2021	2022
Wheat residues (toe)	70,807	108,563	147,887
Barley residues (toe)	46,358	68,642	89,513
Rye residues (toe)	8,397	12,832	17,118
Chickpea residues (toe)	23,920	35,743	47,578
Sugar beets residues (toe)	33,525	50,670	68,068
Poppy residues (toe)	29,220	43,775	58,350
Total (toe)	212,229	320,225	428,515

Table 18
Energy potential and crop residue of canola.

Biomass raw material	Agricultural production (ton)/Number of poultry	Annual amount of waste (ton)	Energy potential (toe/year)
Rapeseed (canola)	1	2,3	0,93156

Table 19
Three-year theoretical energy potential increase based on scenario 4.

	Years		
	2020	2021	2022
Rapeseed (canola) residues/Total (toe)	7913,295	7562,056	7428,700

Table 20
Three-year theoretical energy potential increase based on various scenarios.

	Years		
	2020	2021	2022
Scenario 1 (toe)	1891,899	1848,827	1848,605
Scenario 2 (toe)	3133,396	3069,296	3072,422
Scenario 3 (toe)	212,229	320,225	428,515
Scenario 4 (toe)	7913,295	7562,056	7428,700

Table 21
The quantity of houses having been compensated electricity consumption.

	2020	2021	2022
Lowest return scenario (number of houses)	187	282	378
Highest return scenario (number of houses)	6972	6663	6545

3.4. Results

Using statistical data, GIS and artificial intelligence, the theoretical bioenergy potentials that could be obtained considering different scenarios, were calculated in this study. The areas suitable for agriculture but idle in practice were determined spatially and the increase in amount of energy could be obtained under different scenarios are presented in Table 20.

According to the results of these scenarios, it was determined that the highest bioenergy potential was found in rapeseed (canola), which was not yet grown in the application area, but could be cultivated easily in soils and climates where grains could grow. It was calculated that in addition to the existing potential, 7913,295, 7562,056 and 7428,700 toe/year energy could be obtained from agricultural residues of canola in the next three years if it was planted on 25% of the arable but unused land. As a result of sowing only wheat and barley on the same land, in addition to the existing potential, there is energy potential of 3133,396, 3069,296 and 3072,422 toe/year from agricultural residues, however, if all six cereals and other products were planted in equal amounts on the land, it has been calculated that 1891,899, 1848,827 and 1848,605 toe/year energy could be obtained. It was also determined that as a result of draining 50%, 75% and 100% of the marshes by three years and planting the selected grains in equal amounts in all dried areas, in addition to the existing potential, 212,229, 320,225 and 428,515 toe/year could be obtained.

In Turkey, the annual average electricity consumption of a family of four people has been reported as 1,135 toe (13200 KWh) [41]. Even in the scenario with the lowest theoretical energy potential, in addition to the existing potential, the total annual electricity demand of 187, 282 and 378 houses will be able to be met in a sustainable and clean manner. Besides, under the assumption that the

Table 22
Variation of three-year theoretical energy potential increase as a result of the utilization rate changes of unused lands.

Years	Utilization rate of idle land (%)	Scenario 1 (toe)	Utilization rate of idle land (%)	Scenario 2 (toe)	Utilization rate of idle land (%)	Scenario 3 (toe)	Utilization rate of idle land (%)	Scenario 4 (toe)
2020	30	2270,28	30	3760,07	30	233,45	30	9495,95
	20	1513,52	20	2506,72	20	191,01	20	6330,64
2021	30	2218,59	30	3683,15	55	341,57	30	9074,47
	20	1479,06	20	2455,44	45	298,88	20	6049,64
2022	30	2218,33	30	3686,91	100	428,51	30	8914,44
	20	1478,88	20	2457,94	95	407,09	20	5942,96

25% of the idle land has been used and canola is planted in the whole area, in addition to the existing potential, the total annual electricity demand of 6972, 6663 and 6545 houses will be met from agricultural residues in a sustainable and clean manner (please see Table 21).

Lastly, we analyze the theoretical bioenergy potential of various scenarios considering the changes in the utilization rate of idle land. As the unit of agricultural area has been taken as a basis, the 5% changes in the utilization rate have been examined for all scenarios. The possible outcomes of each change in terms of theoretical bioenergy potential are shown in Table 22.

It can be clearly seen that the variation of the utilization rate of unused land has an effect on theoretical energy potential of the application area. The 30% utilization rate of idle land for Scenario 4 has resulted in the highest theoretical bioenergy increase, roundly 9496, 9074, and 8914 toe for years 2020, 2021, and 2022. On the other hand, approximately 191, 299, and 407 toe theoretical bioenergy increase, which is the lowest, can be gathered if the 20%, the 45%, and the 95% yearly utilization rate of idle land if Scenario 3 has been selected.

As expected, possible bioenergy potential increase in Scenario 3 is the lowest among others since usable idle land in this scenario is less than any other scenario. Among three other scenarios, Scenario 4 has resulted in the highest bioenergy potential increase due to agricultural land, yield, and energy potential ratio of rapeseed.

4. Discussion and conclusions

The need for energy increases day by day, new energy sources, efficient conversion methods, and supply chain designs that enable more efficient transportation of energy resources are emerging. Similar to other countries, in our country, the use of biomass resources in energy production is rising and new conversion facilities are commissioned every year in order to provide cleaner energy production minimizing environmental damage.

In this study, the production amounts, yields and theoretical energy potentials of poultry and various cereal residues, which are considered to be used as raw materials in energy production, have been estimated using SVR, an artificial intelligence-based method. According to the production amounts of cereal and other crop products with high biomass potential grown in the application area seven agricultural crops (wheat, barley, rye, chickpea, sugar beets, and poppy) have been determined as biomass feedstock. Three-year forecasts of agricultural land, yield, and theoretical energy potential from residues have been calculated for all considered biomass feedstock. Then, spatial analysis has been carried out utilizing GIS and energy potentials of different scenarios have been evaluated using statistical data. Since the unit of agricultural area has been taken as a basis, idle agricultural land has been determined spatially. And annually, arable but idle agricultural land has been measured as 10206,566, 9915,566 and 9878,566 ha, respectively. Considering four different scenarios, what-if analyses have been conducted to foresee the possible outcomes of various biomass feedstock on theoretical energy potential. The scenario which includes the cultivation of rapeseed plants on 25% of the idle land and the utilization of its residues in bioenergy production have been found to yield the highest energy potential. The results also show that the total annual electricity demand of 6972, 6663 and 6545 houses could be met adopting this scenario. Lastly, sensitivity analysis has been performed to analyze variations on the theoretical bioenergy potential of various scenarios considering the changes in the utilization rate of idle land.

As a result of this study, the distribution and quantities of various biomass resources have been determined for the next three years and data have been obtained to make more consistent strategic decisions. Using SVR, which is widely considered as a robust forecasting method, satisfactory results have been gathered in relatively short computational time with precision. The integration of GIS with SVR not only is a novel approach for bioenergy potential forecasting but also has resulted in capturing and analyzing geological data with accuracy. With the adoption of different scenario approaches, uncertainties have been incorporated into the solution, and possible distributions and quantities of biomass resources have been determined using spatial approaches.

The proposed integrated method can be easily applied to various biomass resources, different regions of Turkey and can be used as a decision support system for long-term planning. In addition, the integrated solution approach can be combined with different methods that take into account uncertainty, such as simulation or system dynamics in further researches.

CRediT authorship contribution statement

Ahmet Alp Senocak: Methodology, Software, Validation, Formal analysis, Investigation, Writing - original draft. **Hacer Guner Goren:** Conceptualization, Methodology, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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