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Analyzing the most eligible site selection for biomass energy facilities through weighted overlay analysis: case of Balikesir (Turkey) province

Weighted owerlay analizi ile biyokütle enerjisi tesisleri için en uygun yer seçimi analizinin yapılması: Balıkesir (Türkiye) ili örneği

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Keywords: Biomass energy, geographic information systems, landscape planning, renewable energy sources, sustainable planning, weighted overlay analysis

Anahtar sözcükler: Biyokütle enerjisi, coğrafi bilgi sistemleri, peyzaj planlama, yenilenebilir enerji kaynakları, sürdürülebilir planlama, weighted overlay analizi

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ABSTRACT

Objective: This study aims to analyze the eligible site selection for biomass energy facilities in Balıkesir province, which is ranked as one of the important provinces of Turkey from the perspective of agriculture and livestock activities.

Material and Methods: Within the framework of the study, the most eligible areas for biomass energy facilities in the province were determined by Weighted Overlay Analysis with the use of Geographic Information Systems.

Results: In results of the study, it was revealed that the most eligible areas for biomass energy facilities in the province were the districts of Karesi, Susurluk and Savaştepe, respectively, while the districts of Ayvalık, Edremit and Erdek districts located in the coastal part of the province were not suitable.

Conclusion: This study is expected to shed light on all the planning studies undertaken within the scope of the sustainable management of the city and the protection of ecology.

ÖZ

Amaç: Bu çalışmada, Türkiye'nin tarım ve hayvancılık faaliyetleri açısından önemli illeri arasında yer alan Balıkesir ilinde biyokütle enerjisi tesisleri için uygun yer seçimi analizinin yapılması amaçlanmıştır.

Materyal ve Yöntem: Çalışma kapsamında, Coğrafi Bilgi Sistemleri'nden faydalanarak Weighted Overlay Analizi (WOA) ile ildeki biyokütle enerji tesisleri için en uygun alanlar belirlenmiştir.

Araştırma Bulguları: Çalışma sonucunda ilde biyokütle enerji tesisleri için en uygun alanlar sırasıyla Karesi, Susurluk ve Savaştepe ilçeleri iken, ilin kıyı kesiminde yer alan Ayvalık, Edremit ve Erdek ilçelerinin ise uygun olmadığı ortaya çıkmıştır.

Sonuç: Yapılan bu çalışmanın kentin sürdürülebilir alan yönetiminde ve ekolojinin korunması kapsamında yürütülen tüm planlama çalışmalarına ışık tutması öngörülmektedir.

INTRODUCTION

Throughout history, energy has been and remains an important concept in connection with science, human life, technology, industry, ecology and all ecosystem components. The effects of urbanization, industrialization, overpopulation, expansion of transportation networks and development of technology have led to an increase in energy needs (Seik, 1997; Buntaine & Pizer, 2015; Özcan et al., 2017; Akyıldız, 2020). "The International Energy Agency (IEA) estimates that developed countries will account for 93% of the increase in energy demand between 2010 and 2035, and the cost of this will amount to $30 trillion" (Özcan et al., 2017).

Available energy resources on a global scale are classified by considering the criteria of exhaustibility or renewability at the end of use. Coal, oil, natural gas and fossil fuels are among the non-renewable energy sources; on the other hand, solar, wind, geothermal, hydraulic, biomass, wave and hydrogen energy are classified as renewable energy sources (Anonymous, 2007; Panwar et al., 2011; Kaya, 2014; Owusu & Asumadu, 2016). The use of fossil fuels increases the importance of renewable energy sources in many countries due to the depletion of fossil fuel reserves all over the world, as well as leading to important negativities such as irreversible environmental problems, foreign-source dependency on fuel and increased import expenses. In addition, the damages to the ecosystem are much lower compared to non-renewable energy sources (Hager, 1992; Anonymous, 2014, Masnadi et al., 2015; Tokar, 2015; Anonymous, 2016a; Burke & Stephens, 2018; Doğan & Uludağ, 2018; Karcı & Birişçi, 2020).

Biomass energy is among the important renewable energy sources in minimizing the damages to the ecosystem, preserving the ecology and ensuring sustainability at the stage of meeting the increasing energy needs on a global scale. Since plant growing will last as long as the sun exists, biomass is an inexhaustible energy source. It is considered as an appropriate and important energy source as it can be grown everywhere and helps socio-economic developments, especially for rural areas. The energy generated from biomass is called biomass energy. It is possible to discuss biomass energy in two groups including conventional and modern. The first consists of fuel wood obtained from conventional forests and plant and animal wastes used as fuel, and the second, that is, modern biomass energy, is described as energy forestry and forest-tree industry wastes, vegetable wastes in the agricultural sector, urban wastes, and agro-industrial wastes. Bioenergy is a general term comprising solid, liquid and gaseous fuels of biological origin. Energy in the form of heat and power (i.e. electricity), which can be transported or used stationary, can be named bioenergy (Toklu, 2017).

The use rates of biomass energy among total renewable energy sources are 96% in Africa, 65% in Asia, 59% in Europe and 59% in America. While the rate of biomass in renewable energy sources was 80.4% in 1990 around the world, this rate decreased to 78% in 2000 and to 67.5% in 2018 (Kaygusuz, 2020). Although the use rates of biomass energy have decreased over the years, it still holds a large share in the total renewable energy supply (Kumar et al., 2015; Anonymous, 2019a; İrfan et al., 2020).

In Turkey, the biomass waste potential is estimated to be approximately 8.6 MTEP and the biogas reserve that can be generated is estimated to be approximately 1.5-2 MTEP (Emeksiz & Fındık, 2021; Anonymous, 2021a). From the perspective of biomass production, Turkey has a very large raw material in terms of biomass energy due to water resources, availability of agricultural area, climatic conditions and favorable sun (İlleez, 2020; Emeksiz & Fındık, 2021). Table 1 shows the amounts of biomass energy generation in Turkey between 1995-2020.

Table 1. Biomass energy generation in Turkey between 1995-2020 (Anonymous, 2021a)

Çizelge 1. *Türkiye'de 1995-2020 yılları arası biyokütle enerji üretimi (Anonymous, 2021a)*

Years	1995	2000	2005	2010	2015	2020
Biomass energy production (GWh)	222	174	44	346	1263	3283

The subject of this study is to conduct eligible site selection analysis for biomass energy facilities in Balıkesir province, which is located within the borders of Turkey. In this context, we tried to determine the most eligible site for biomass energy facilities with Weighted Overlay Analysis (WOA) by using Geographic Information Systems.

An important step in proper site selection analysis is to identify the weight of each criterion influencing the eligibility. The fact that the factors influencing the eligibility have different levels of importance and that various and multiple criteria exist complicates the eligibility analysis (Saaty, 1980; Zhang et al., 2015; Karabacak, 2021).

Weighted Overlay tool is one of the methods of modeling eligibility. A new layer is obtained by weighting more than one raster layer according to each layer and within their own structure, and then overlapping them. This layer includes areas that meet and do not meet the criteria determined as a result of the assessment. The weighted overlay tool allows to apply several steps in the overall site selection analysis process within a single tool (Anonymous, 2016b; Rahman et al., 2021).

MATERIALS and METHODS

Balıkesir province, which has significant biomass energy potential in Turkey, was selected as the study area. Balıkesir province, geographically, the province is located between 39.20°- 40.30° North parallel and 26.30°- 28.30° East meridians in the western part of Turkey. The total population of the city is 1.226.575 and the total labor force consists of 837.517 people (Anonymous, 2021b). Figure 1 shows the map of the study area (Balıkesir province).

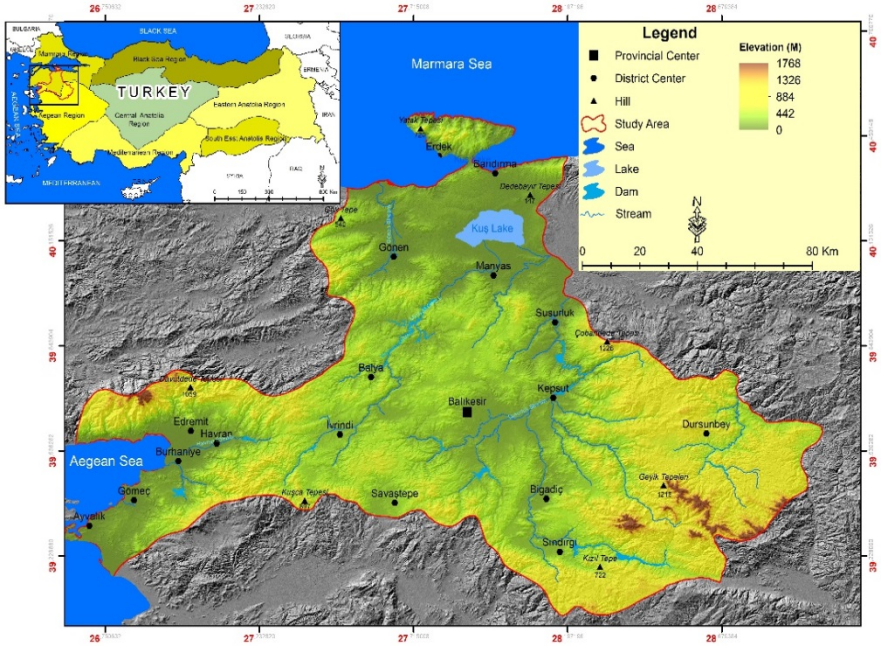

Figure 1. Location map of Balikesir province.

Şekil 1. *Balıkesir ili lokasyon haritası.*

Balıkesir has a semi-arid climate, cool in winters and warm in summers. The annual average temperature is 14.3°C. Balıkesir, which consists of 20 districts in total, has a coastal length of 290.5 km. Total surface area (including lakes) is 1,447.300 ha (hectares) and of these areas, 393.886 8 (ha) is used as agricultural land, 81.877 (ha) is used as meadow-pasture area, 649.115 (ha) is forest area and 322.422 (ha) is used as non-agricultural land (Anonymous, 2019b).

Balıkesir is an agricultural city thanks to its geographical structure and climatic conditions. Balıkesir, where fertile agricultural lands are widely available, has the opportunity to easily market the agricultural products thanks to its strategic position. When examining the distribution of investments, it is observed that the dominant sector in terms of economic size is agriculture and animal husbandry with 64%. Balıkesir, located in the Marmara Region where industrialization is very intense, hosts a significant part of intensive (industrial) milk and breeding enterprises (Kocabey, 2019). Table 2 depicts the assets of poultry, bovine and ovine animals in Balıkesir province in 2020.

Table 2. Assets of poultry, bovine and ovine animals in Balıkesir province in 2020 (Anonymous, 2021c)
Çizelge 2. *Balıkesir iline ait 2020 yılı kümes, büyükbaş ve küçükbaş hayvan varlığı (Anonymous, 2021c)*

Poultry			Bovine		Ovine	
broiler	chicken	turkey	cattle	water buffalo	sheep	goat
25.761.143	6.573.494	152.698	536.855	6.369	1.112.323	171.635

Balıkesir has a very rich potential in terms of animal, plant, forest products and wastes as well as industrial waste potential required for biomass energy generation. Plants such as wheat, paddy, maize, barley, rye, cotton, sugar beet, which have high calorie capacity in biomass energy investments, are among the field crops grown in Balıkesir province. Table 3 displays the important field crops grown in Balıkesir province for biomass generation in 2020.

Table 3. Important field crops grown in Balıkesir province for biomass generation in 2020 (Anonymous, 2021c)
Çizelge 3. *Balıkesir ilinde yetişen ve 2020 yılına ait biyogaz üretimi için önemli tarla bitkileri (Anonymous, 2021c)*

Field crops	Planted area (decare)	Production (ton)
Maize	304.168	1.522.866
Wheat	1.111.435	271.595
Paddy	152.920	118.620
Barley	128.027	39.248
Rye	86.143	27.752
Cotton	2.101	939
Sugar beet	2.375	13.000

It is quite important to build the facilities in appropriate sites in order to generate and maintain biomass energy, distribute the energy generated, and dispose of the waste without harming the environment (Woo et al., 2018; İrfan et al., 2020; Wang et al., 2020). In this study, eligible site selection analyzes were carried out for biomass energy facilities in Balıkesir province located within the borders of Turkey. We tried to determine the most eligible site for biomass energy plants with Weighted Overlay Analysis (WOA) by using Geographic Information Systems.

Although there are no definite rules on the appropriate site selection for biomass power plants, physical and human criteria can be formed by the decision maker upon the consideration of the activity efficiency and environmental effects.

Examining the researches on the selection of suitable sites for biomass power plants within the scope of the method of the study is one of the important steps for the researchers to decide on the parameters specific to the study areas. Ma et al. (2005) have determined the appropriate location for the biogas plant that is planned to be established in New York City in order to evaluate the animal wastes in the farms and turn them into energy. They carried out their analyzes on 11 parameters. These parameters; wetlands and lakes, critical environment areas, streams, airports, flood plain, slope gradient, roads, transmission lines, natural gas pipelines, power plants and substations, residential areas. Sultana & Kumar (2012) have carried out a study on the selection of suitable sites for biomass plants. The main parameters they determined within the scope of their studies; rural and urban areas, industrial and mining zones, airport and heliport, park and recreational areas, rivers, lakes and other waterbodies, wetlands, environmentally sensitive areas, roads, power plant and substation, transmission line, natural gas and oil pipelines, land surface gradient. Silva et al. (2014)

conducted a study to identify the most suitable sites for the placement of biogas plants using milk manure as a raw material, especially in the Entre-Douro-e-Minho Region in Portugal. The parameters determined within the scope of the study; national ecological reserves (NER) and protected areas, hydrographic network, roads and railway, slope, urban, industrial and commercial and infrastructure, built-up areas, electricity grid. Venier & Yabar (2017) were determined the potential areas for the selection of suitable sites for biogas plants by utilizing Geographical Information Systems in Buenos Aires, Argentina. In the selection of the appropriate location for the biogas plant, certain main parameters were determined at the point of environmental sensitivity and they carried out their analyzes on these parameters. The determined parameters are; urban areas, water bodies, transport stations, green, protected and inadequate areas. Table 4 shows the parameters and buffer zones used in site analyzes suitable for biomass energy plant in similar studies.

Table 4. Parameters and buffer zones used in site analysis for biomass energy plant in similar studies

Çizelge 4. *Benzer çalışmalarda biyokütle enerji tesisi için uygun yer analizlerinde kullanılan parametreler ve buffer zonları*

Determined parameters	Buffer zones	References
Wetlands and lakes	Outside 100 m buffer	Ma et al. 2005
Critical environment areas	Outside 500 m buffer	
Streams	Outside 100 m buffer	
Airports	Outside 500 m buffer	
Flood plain	Sites falling within 100-year flood plains are avoided	
Slope gradient	Areas with slopes larger than 15% are avoided	
Roads	Outside 30 m buffer	
Transmission lines	Outside 200 m buffer	
Natural gas pipelines	Outside 100 m buffer	
Power plants and substations	Outside 200 m buffer	
Residential areas	A distance of 2000 m from high-density residential areas or urban residences A distance of 1000 m from medium-density residential areas	
Rural and urban areas	A distance of 1 km from residential and urban areas	Sultana & Kumar, 2012
Industrial and mining zones	Outside 1 km buffer	
Airport and heliport	Outside 1 km buffer	
Park and recreational areas	Outside 500 m buffer	
Rivers, lakes and other waterbodies	Outside 200 m buffer	
Wetlands	Outside 200 m buffer	
Environmentally sensitive areas (flood plains, conservation areas, habitat sites)	Outside 500 m buffer	
Roads	Outside 30 m buffer	
Power plant and substation	Outside 100 m buffer	
Transmission line	Outside 100 m buffer	
Natural gas and oil pipelines	Outside 100 m buffer	
Land surface gradient	Areas with slopes larger than 15% are avoided	
National ecological reserves (NER) and Protected Areas	Areas classified as NER 2000 m are excluded from the analysis.	Silva et al. 2014
Hydrographic network	Outside 150 m buffer	
Roads and railway	Outside 70 m buffer	
Slopes		
Urban, industrial and commercial and infrastructure	Outside 200 m buffer	
Built-up areas	To exclude buildings	
Electricity grid	Outside 200 m (high voltage line)	
Minimum area	It must have an area of at least 1 ha for implementation of a biogas plant	
Adequate shape	Exclude polygons that verify the following condition	
Urban areas	Outside 1 km buffer	Venier & Yabar 2017
Water bodies	Outside 200 m buffer	
Transport stations	Outside 500 m buffer	
Green, protected and inadequate areas	Outside 200 m buffer	

In this study, the parameters of proximity to raw materials, fault lines, main roads, villages, rivers, sea, lakes and dams, land use and slope were identified and an eligible site analysis was carried out for the biomass energy facilities, which are planned to be built in Balıkesir province, by making use of the literature on the selection of the eligible sites. The significance levels of each parameter within the scope of the study were determined by the decision makers by referring to the literature studies. Figure 2 demonstrates the flow chart of the study method.

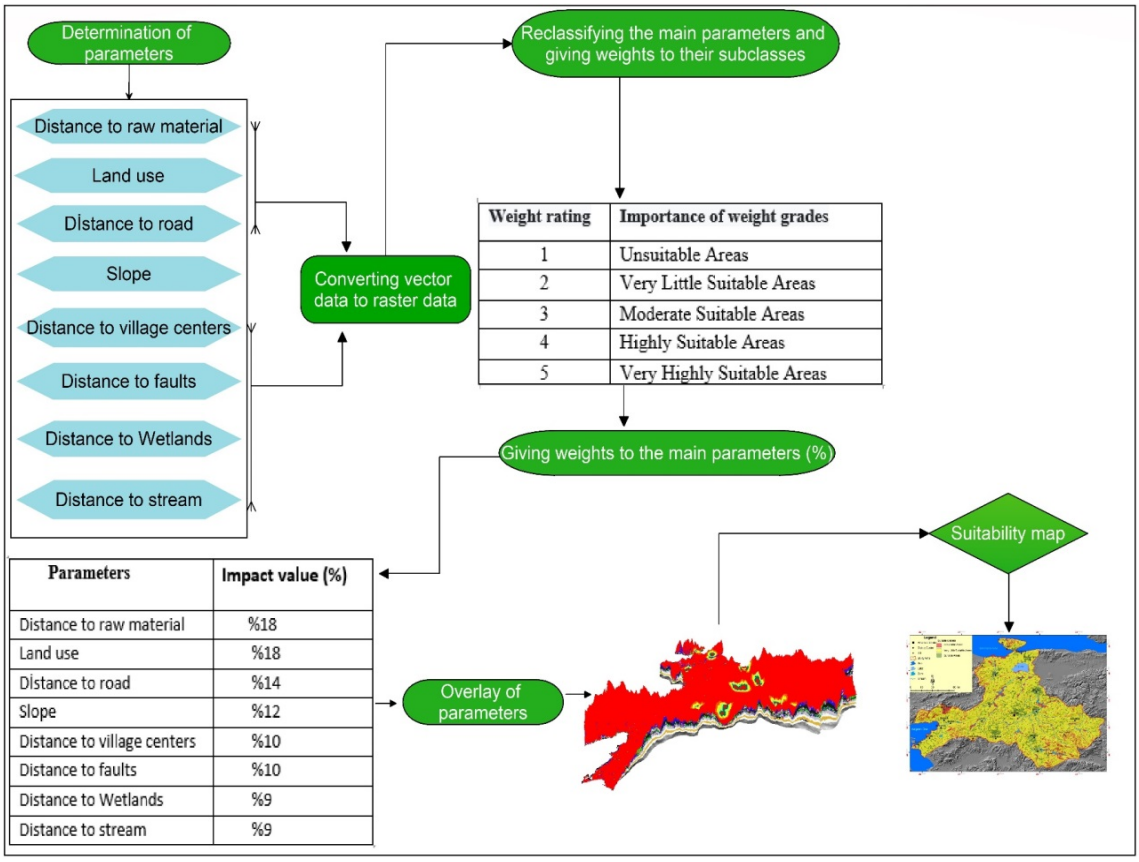

Figure 2. Flow chart of the study method.

Şekil 2. *Yöntem akış şeması.*

As part of the study, raw material data acquired from Balikesir Directorate of Provincial Agriculture and Forestry and prepared with the assistance of the Google Earth software were mapped in ArcGIS 10.3 platform. Fault line information taken from Balıkesir Mineral Research and Exploration Institute Directorate was used in the preparation of fault line map in ArcGIS 10.3 platform. The land use map, on the other hand, was prepared by classifying with remote sensing techniques using the Coordination of Information on the Environment (CORINE) land cover. High-resolution Dem data of Balıkesir province generated from USGS Earthexplorer program was converted into slope index map with ArcGIS software. Moreover, Google Earth and Geographic Information Systems were also used to build proximity maps to main roads, villages, streams, seas, lakes and dams. These obtained data were then re-weighted to the sub-parameters of the parameters using the reclassify toolbar in ArcGIS 10.3 platform. These parameters, which are subject to reassessment within their own structure, are then rated through the scale of importance with values ranging from 1 to 5. Table 5 shows the parameters determined for the eligible biomass plant in Balıkesir province and the main and sub-parameter weight ratings.

Table 5. Parameters determined for the eligible biomass plant, main and sub-parameter weight ratings

Çizelge 5. *Uygun biyogaz tesisi için belirlenen parametreler, ana ve alt parametre ağırlık dereceleri*

Parameters	Sub-parameter weight ratings	Main parameter weight ratings (%)
Raw material		
1000	5	
2000	4	
3000	3	18%
4000	2	
5000	1	
5000< +		
Land uses		
swamp	1	
vineyards and orchards	2	
low density vegetation	4	
mixed agricultural land	3	
dry farmland	2	18%
forests	1	
on the water surface	1	
irrigated agricultural field	2	
settlement area	1	
meadows and pastures	5	
Road proximity (m)		
250	5	
500	4	
750	3	14%
1000	2	
1000 < +	1	
Slope		
0-5.3	5	
5.3- 10.9	4	
10.9-17.1	3	12%
17.1-24.8	2	
24.8< +	1	
Proximity to villages (m)		
1000	1	
2000	5	10%
3000	4	
4000	3	
5000	1	
Fault line proximity (m)		
500	1	
1000	2	10%
1500	3	
2000	4	
2000 < +	5	
River proximity (m)		
250	1	
500	2	
750	3	9%
1000	4	
1000 and above	5	
Proximity to sea, lakes and dams (m)		
500	1	
1000	2	9%
1500	3	
2000	4	
2000 < +	5	

In the study, the necessity of analyzing many layers with different weight ratings at the same time was created thanks to the weighted overlay tool included in GIS. Through the rating system in the weighted overlay, it can be understood that the least eligibility criteria are met in the areas where the lowest rating is given and the highest eligibility criteria are met in the areas where the highest ratings are given.

RESULTS and DISCUSSION

Specified parameters for biomass energy facilities

Raw material proximity

All naturally occurring animal and plant-derived materials containing carbohydrate compounds as the main component are included in the scope of biomass raw material (Kapluhan, 2014). The amount and type of animal and plant raw materials used for the production of biomass energy is an important criterion for the biomass energy plant. Easy access to raw materials will minimize the energy spent during the transportation of raw materials and prevent various environmental and economic problems (Akther et al., 2019). In addition to its high agricultural potential, Balıkesir province is among the top 5 provinces in Turkey in terms of the number of all animal species and the production of animal products (Kocabey, 2019). Animal and vegetable raw material data obtained from Balikesir Directorate of Provincial Agriculture and Forestry and prepared by supporting with Google Earth program are among the main criteria determined for the appropriate biomass energy plant.

For the raw material proximity map, the locations of the hen, turkey, sheep and cattle farms, where the animal wastes used in biomass energy generation in Balıkesir were obtained, were identified on the map and buffer zones were determined at 1000 m intervals upon performing buffer analysis. This process was also carried out for the fields of maize silage, barley, wheat, paddy, rye, cotton sugar beet grown in Balıkesir (Figure 3).

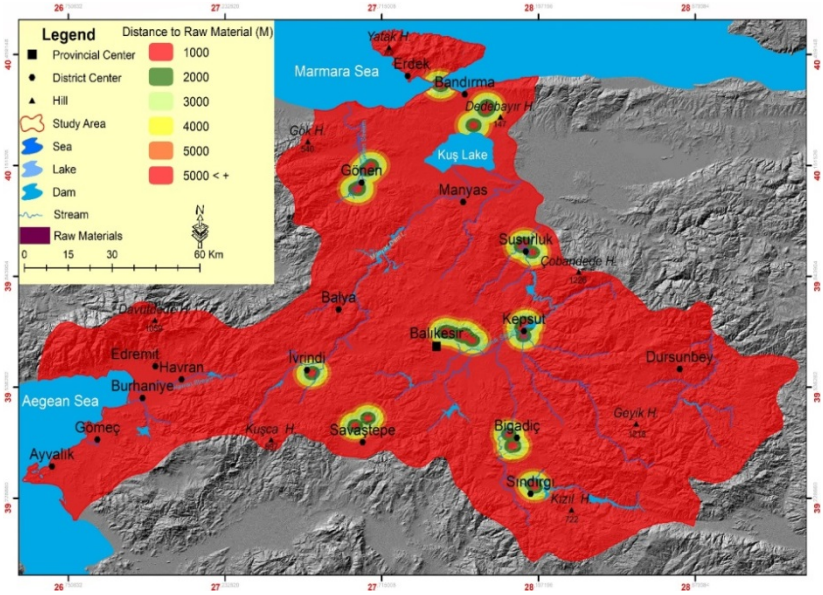

Figure 3. Raw material proximity map.

Şekil 3. *Hammaddeye yakınlık haritası.*

Land use

Land use map is one of the most important maps in the implementation of any site selection project. In the appropriate location analysis for the biomass energy plant, it is necessary to determine the land use classes in order to protect human health, not damage the cultural, natural, and near natural areas that need to be protected, and not deteriorate the soil structure suitable for agriculture, and to make a selection in a way that does not damage these areas. In addition, the fact that the facility to be constructed is away from the protected areas is also important in terms of sustainable area management (Khademalhoseiny et al., 2017).

The purpose of preparing the land use map is to identify the most eligible areas not posing a threat to the environment by designating the areas that need to be protected. 8 groups were determined in the classification of land uses. These groups include, vineyards and orchards, low-density vegetation, irrigated agricultural land, mixed farming land, dry agricultural land, forests, water surfaces, settlements, meadow and pasture lands (Figure 4).

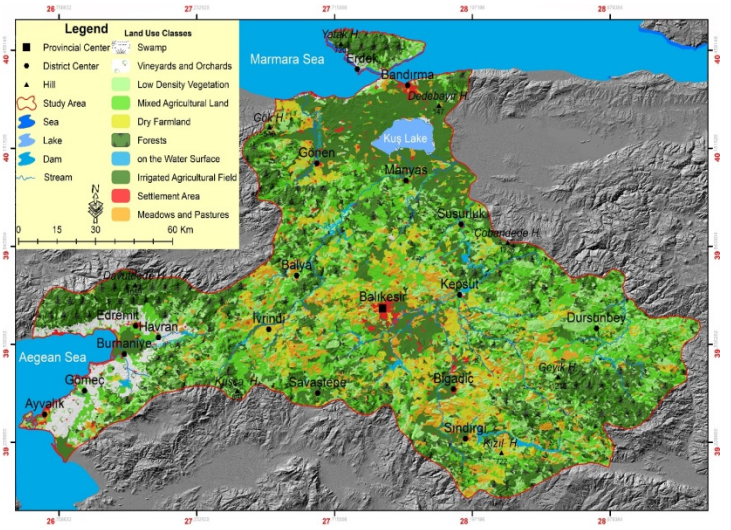

Figure 4. Land use map of Balıkesir province.

Şekil 4. *Balıkesir ilinin arazi kullanım haritası.*

Road proximity

One of the appropriate site selection criteria for biomass energy plants is proximity to main roads. From an economic point of view, it is very important for biomass power plants that the raw material can easily access the plants. At the same time, it is recommended to use old roads instead of making new roads to get rid of high construction costs (Nas et al., 2010).

For this reason, buffer analysis was performed on the main and by-roads of Balıkesir province and buffer zones were determined at 250 m intervals (Figure 5).

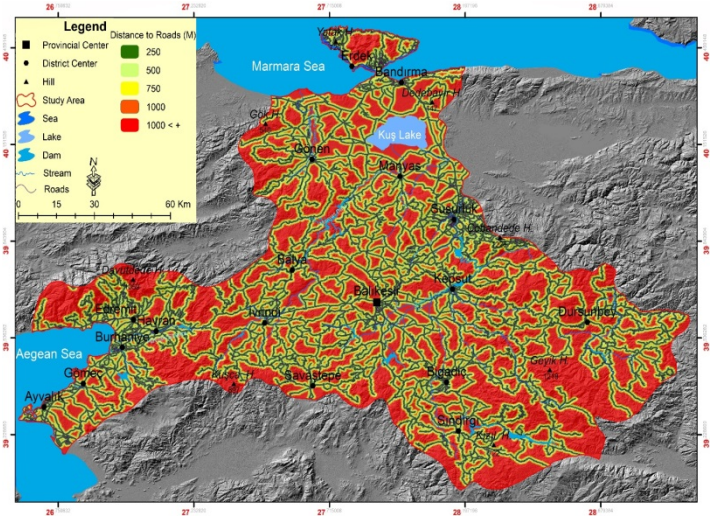

Figure 5. Road proximity map.

Şekil 5. *Yola yakınlık haritası.*

Slope

In the light of the interviews conducted with the officials of biomass power plants within the borders of Balıkesir province, it is revealed that the lands with high a degree of slope are not eligible for biomass power plants. It is predicted that the lands with high a degree of slope will endanger the operation and safety of the facilities in case of natural disasters that may occur, and that the pits and channels built for wastes will cause serious problems in such lands. According to the slope map prepared, slope grades of 0-5.3, 5.3-10.9, 10.9-17.1, 17.1-24.8, 24.8 and above were determined (Figure 6).

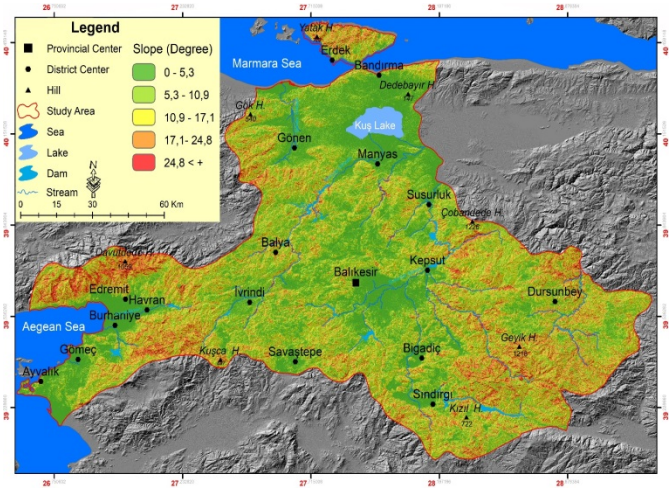

Figure 6. Slope map of Balikesir province.

Şekil 6. *Balıkesir ilinin eğim haritası.*

Proximity to villages

The livelihood of the people living in the villages in Balıkesir is mostly based on agriculture and livestock. During the interviews with the facilities, it was indicated that the transportation of plant and animal wastes to the facilities was undertaken by the villagers or the facilities depending on the waste amount. Although the establishment of the facilities in the lands close to the villages is eligible in terms of the logistics of the raw material, there may be problems in terms of environmental awareness. Therefore, buffer analysis was performed by determining a distance of at least 250 m to the village centers (Figure 7).

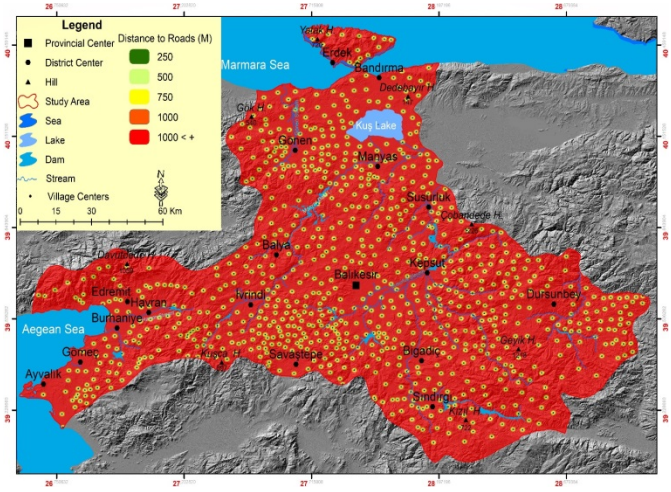

Figure 7. Map of proximity villages.

Şekil 7. *Köylere yakınlık haritası.*

Fault line proximity

Biogas mainly contains CH4 and CO2, small amounts of H2S and NH3, as well as trace amounts of H2, N2, CO, O2, aromatics, halogenated compounds (chlorides, fluorides, etc.) and silicones. It contains many chemical components in the first production of biogas. These components include 60%-70% methane (CH4), 30%-40% carbon dioxide (CO2), 1%-2% nitrogen (N2), ammonia (NH3) and hydrogen sulfide (H2S) with hydrogen (H2) depending on the sulfur concentration in the wastewater (Deviren et al., 2017). In the event of a possible disaster and neglect in biomass power plants, it is expected that methane gas in its content may pose serious hazards in the event of contact with oxygen (Juntarawijit, 2013; Anonymous, 2016c). If the biomass power plants are established in a land away from fault lines, this will reduce the possibility of being affected by a possible earthquake disaster. It is foreseen that the further the facilities to be constructed are from the fault lines, the safer they will be in terms of earthquake risk. For this reason, buffer analysis was performed for the map of proximity to the fault lines and zones were determined at 500 m intervals (Figure 8).

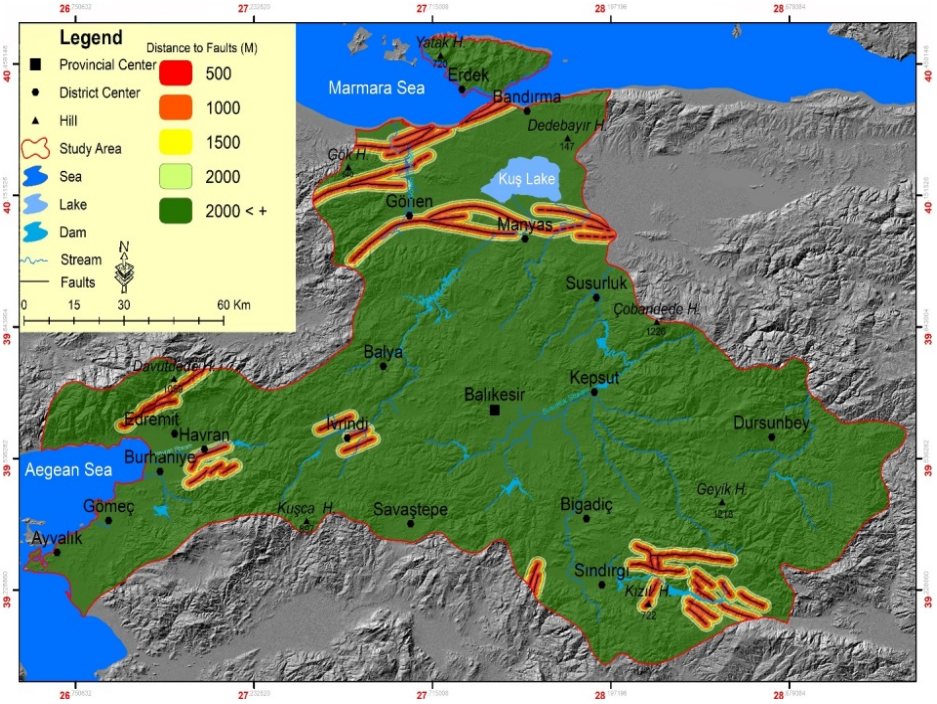

Figure 8. Map of proximity to fault lines.

Şekil 8. *Fay hatlarına yakınlık haritası.*

River proximity

The construction of biomass power plants at a distance from the river heads is quite important for the existing rivers in the province. Rivers in the immediate vicinity should not be adversely affected by biomass power plants. In addition, the facility should not be affected by floods and inundations that may occur in extreme rainfall (Akther et al., 2017). Akther et al. (2017) determined the proximity to the river between 0-500 m for the biogas plant that was planned to be established in their study. They emphasized that the reason they determined in this range was that there were not enough streams to be affected around the study areas. Balıkesir is highly rich in terms of the number of rivers. As can be seen in Figure 9, buffer analysis was performed on the rivers in the province and buffer zones were determined at 250 m intervals.

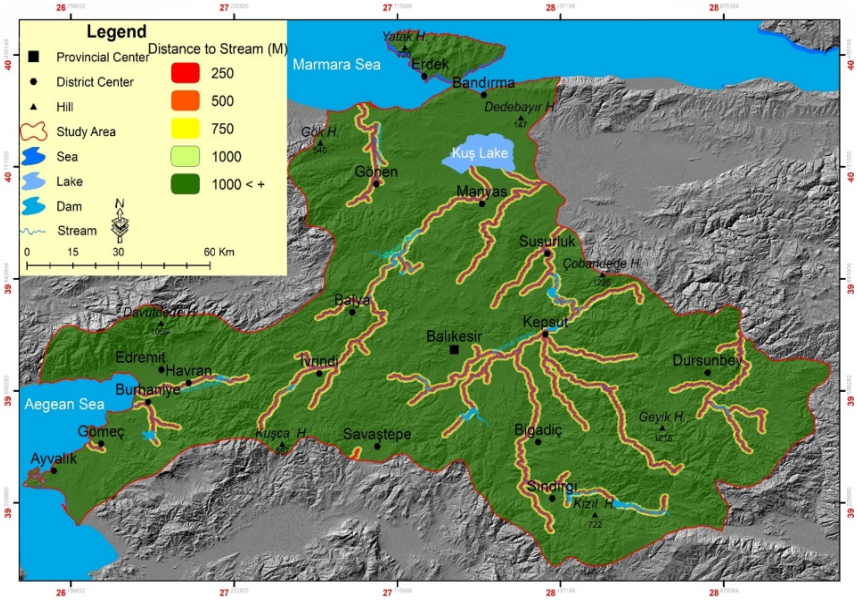

Figure 9. River proximity map.

Şekil 9. *Akarsuya yakınlık haritası.*

Proximity to sea, lakes and dams

The fact that biomass power plants are constructed far from the sea, lakes and dams as well as river heads is important for water surfaces and aquatic organisms. As seen in Figure 10 below, buffer analysis was performed on sea, lakes and dams in the province and buffer zones were determined at 500 m intervals. Lake Manyas Bird Paradise National Park in Balıkesir province is of great ecological importance. buffer zone range was started from 500 m with the effort of preventing settlements in the close vicinity of both the sea shores and Manyas Bird Paradise National Park.

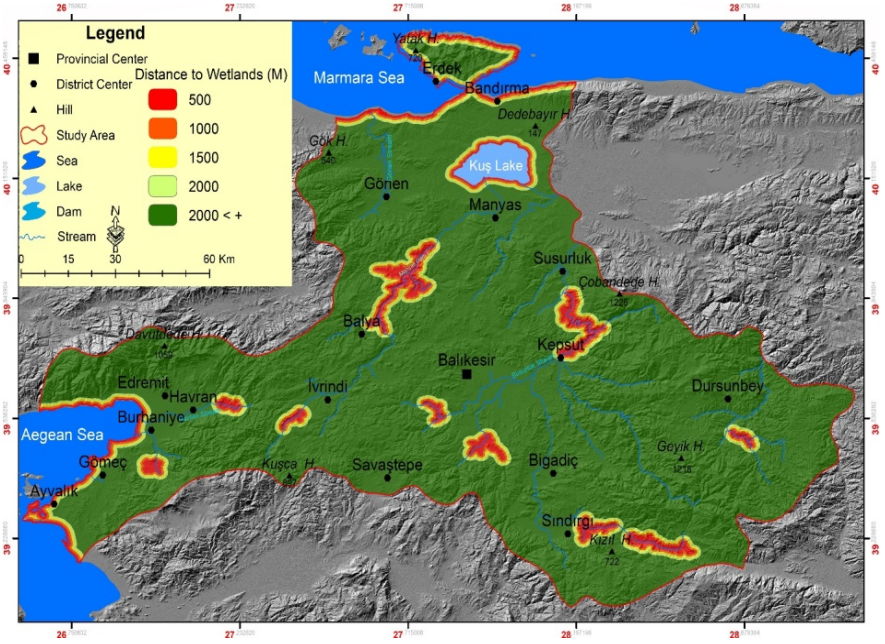

Figure 10. Map of proximity to sea, lake and dam.

Şekil 10. *Deniz, göl ve baraj yakınlık haritası.*

Determination of eligible areas for biomass energy facilities

The parameters identified in order to determine the most eligible biomass energy plant sites in Balıkesir province were rated between 1 and 5 and the eligibility maps of each parameter were prepared using the weighted overlay tool through GIS (Figure 11).

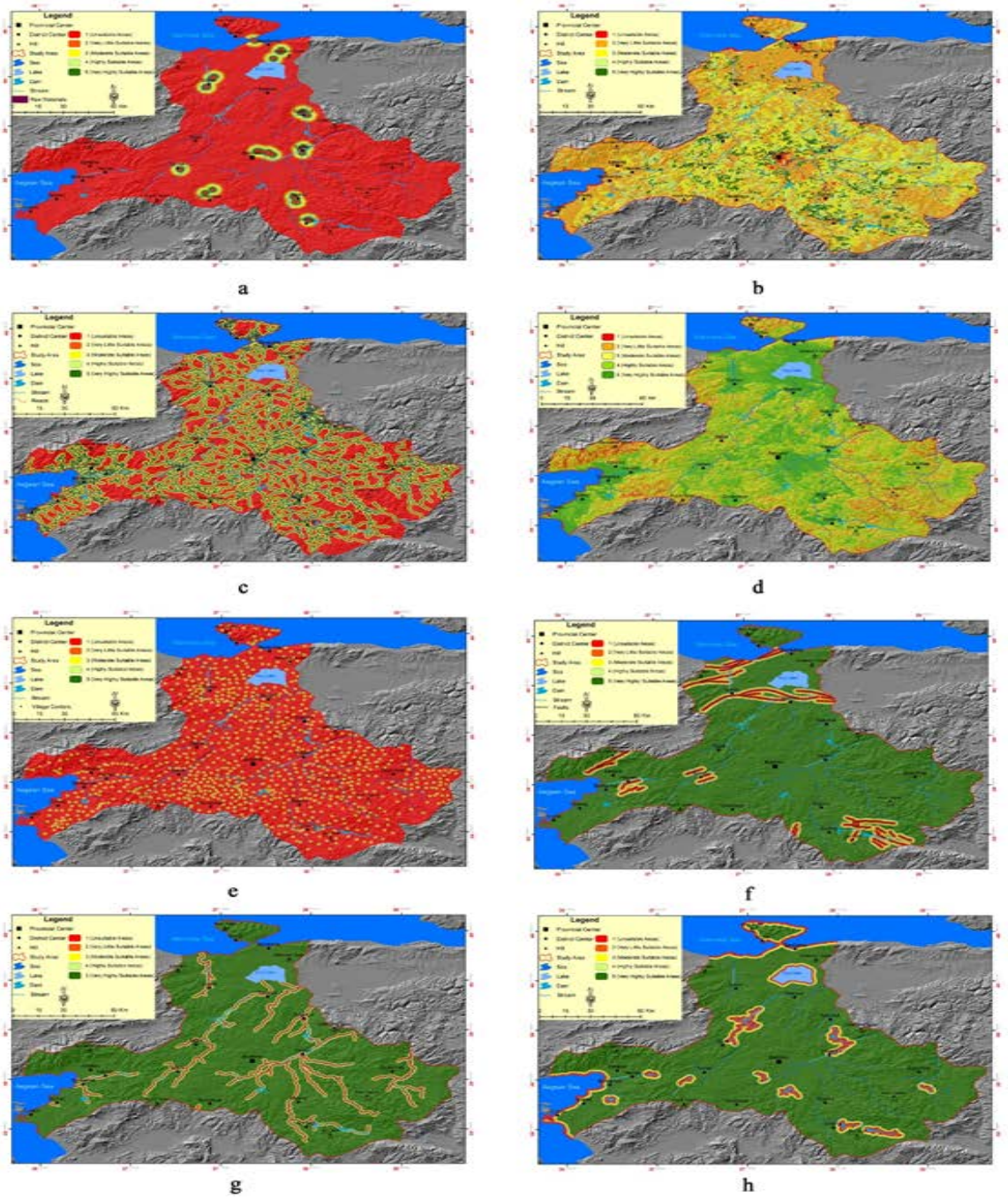

Figure 11. Raw material eligibility map b) land use eligibility map c) road proximity eligibility map d) slope eligibility map e) village proximity eligibility map f) fault line eligibility map g) river eligibility map h)sea, lake and dam eligibility map.

Şekil 11. *a) Hammadde uygunluk haritası b) arazi kullanım uygunluk haritası c) yola yakınlık uygunluk haritası d) eğim uygunluk haritası e) köylere yakınlık uygunluk haritası f) fay hattı uygunluk haritası g) akarsu uygunluk haritası h) deniz, göl ve baraj uygunluk haritası.*

As a result of overlaying the eligibility maps acquired according to the main and sub parameters, the eligible biomass plant map of Balıkesir province was revealed (Figure 12).

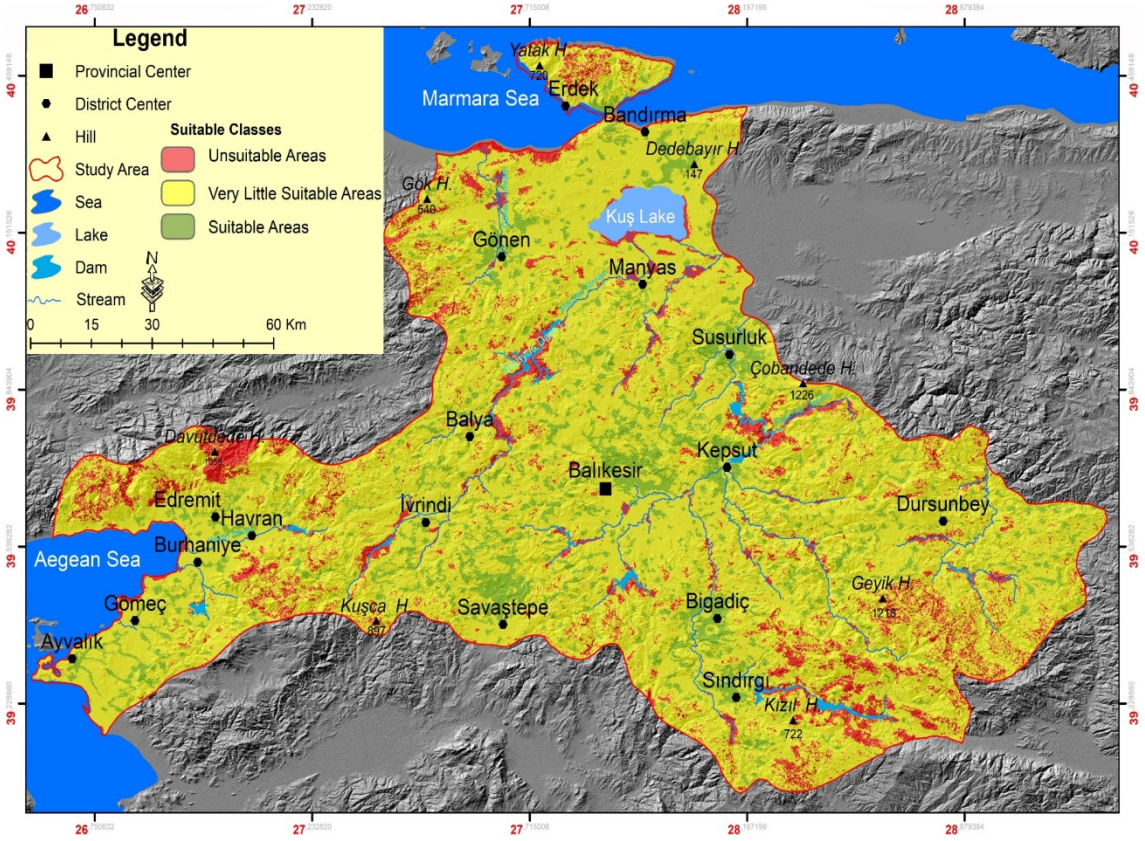

Figure 12. The resulting map of the eligible biomass plants in Balıkesir province.

Şekil 12. *Balıkesir iline ait uygun biyogaz tesisi sonuç haritası.*

When the resulting map acquired as a result of the study is analyzed, the most eligible areas for biomass facilities are found as Karesi, Susurluk, Savaştepe, Bigadiç, Kepsut, Bandırma, Gönen and Sındırgı districts, respectively. In addition, when the amount of suitable areas for biomass energy facilities within the provincial borders of Balıkesir is calculated, it has been revealed that a total area of 1703.92 km^2 is suitable for these facilities (Table 5).

Table 5. Calculation of areas of suitable classes for biomass energy facilities

Çizelge 5. *Biyokütle enerji tesisleri için uygun sınıflardaki alanların hesaplanması*

Suitable classes	Area (Kilometers)	Percentage (%)
Unsuitable Areas	1599.6	11.2 %
Very Little Suitable Areas	11008.347413	76.9 %
Suitable Areas	1703.92	11.9 %
Total	14311.9	100 %

CONCLUSION

Given the scientific studies conducted, there is a dominant notion that benefiting from bioenergy efficiently will make a significant contribution to energy demand on the global scale. Also, it may be possible for biomass energy to prevent the damages that may be caused in the ecological structure by

reducing greenhouse gas emissions, contrary to non-renewable energy sources. In addition to all these notions, factors such as supporting rural development efforts and providing economic opportunities to local people in areas, where biomass energy is available, are among the positive features of biomass energy. Balıkesir ranks among the important provinces of Turkey from the perspective of agricultural and livestock production capacity. The fertile soil potential, the presence of animal farms in rural areas and many other regions of the city and the interest of the local people in livestock production are the factors that enhance the biomass energy potential in Balıkesir.

In this study, we tried to determine the most eligible site for biomass energy facilities with Weighted Overlay Analysis (WOA) by using Geographic Information Systems in Balıkesir. In conclusion of the study; Karesi, Susurluk and Savaştepe districts were identified as the most eligible areas in the province, respectively. In addition, it was also determined that there are eligible areas for biomass energy facilities in the districts of Bigadiç, Kepsut, Bandırma, Gönen and Sındırgı. However, it is understood that Ayvalık, Edremit and Erdek districts located in the coastal part of the province are not eligible for biomass energy facilities. The reason for this situation is that Ayvalık, Edremit and Erdek districts are located on the seashore, that the tourism sector stands out more compared to agriculture and animal husbandry in the economic structure of these districts, and that there are many areas that need to be conserved in terms of natural and cultural aspects. It was also revealed that especially the areas of Mount Kaz National Park, which is located in Edremit district and is of great importance not only for Balıkesir province but also for Turkey, are ineligible for the establishment biomass energy facilities.

Consideration of the studies conducted on the eligible site selection for the construction of biomass energy facilities will gain significant benefits especially to those who generate and utilize this energy. These benefits are as follows:

- Minimizing the possible damages that biomass energy will cause to nature during the generation phases,
- Gaining maximum benefit from biomass energy,
- Ensuring the economic and environmental sustainability of the facilities,
- Prevention of possible damage to all areas that are conserved and need conservation in the provinces and districts where the facilities are established,
- Preventing the facilities from being damaged by possible disasters and not causing any harm to the environment after the disaster
- Protecting urban and rural ecosystems and meeting the energy demand in these systems.

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