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Research Article

Determination of Agricultural-Based Biomass Energy Potential as a Sustainable Clean Energy Source: The Case of Muş Province (2020-2024)

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Abstract: This study aims to calculate the biomass energy potential that can be theoretically obtained from agricultural products for the Muş province between 2020-2024. In this context, calculations were made by taking into account the legumes, industrial plants, cereals, forage crops, oilseeds, and tubers grown in the region. The analyses are based on five-year data (2020–2024) obtained from the Plant Production Statistics Database of the Turkish Statistical Institute. Accordingly, the average biomass energy potentials were calculated in megawatts (MW). According to the results, the product groups with the highest biomass energy potential were grains and forage crops. When evaluated on a district basis, the Central district has the highest share (33,02%) and the Hasköy district has the lowest share (2,44%) in terms of 5-year average biomass energy potential. Considering all available biomass sources in Muş province, the estimated annual energy potential was determined to be 27.145 MW in 2020, 29.288 MW in 2021, 33.863 MW in 2022, 37.361 MW in 2023, and 40.608 MW in 2024. These findings show that Muş province has significant potential on both national and global scales in terms of sustainable and environmentally friendly biomass energy that can be produced from agricultural crops.

Keywords: agricultural crops; biomass; clean energy; Muş; sustainability.

Araştırma Makalesi

Sürdürülebilir Temiz Enerji Kaynağı Olarak Tarımsal Kökenli Biyokütle Enerji Potansiyelinin Belirlenmesi: Muş İli Örneği (2020-2024)

Özet: Bu çalışmada, Muş ili için 2020-2024 yılları arasında tarım ürünlerinden teorik olarak elde edilebilecek biyokütle enerji potansiyelinin hesaplanması amaçlanmıştır. Bu kapsamda, bölgede yetiştirilen baklagiller, endüstriyel bitkiler, tahıllar, yem bitkileri, yağlı tohumlar ve yumru bitkiler dikkate alınarak hesaplamalar yapılmıştır. Analizler, Türkiye İstatistik Kurumu'nun Bitkisel Üretim İstatistikleri Veri Tabanı'ndan temin edilen 2020–2024 dönemine ait beş yıllık verilere dayanmaktadır. Bu doğrultuda ortalama biyokütle enerji potansiyelleri megawatt (MW) cinsinden hesaplanmıştır. Sonuçlara göre, biyokütle enerji potansiyeli en yüksek ürün grupları tahıllar ve yem bitkileri olmuştur. İlçeler bazında değerlendirildiğinde, 5 yıllık ortalama biyokütle enerji potansiyeli bakımından en yüksek paya Merkez ilçe (%33,02), en düşük paya ise Hasköy ilçesi (%2,44) sahiptir. Muş ilinde mevcut tüm biyokütle kaynakları

değerlendirildiğinde, elde edilebilecek yıllık enerji potansiyelinin 2020 yılında 27.145 MW, 2021 yılında 29.288 MW, 2022 yılında 33.863 MW, 2023 yılında 37.361 MW ve 2024 yılında 40.608 MW olduğu tespit edilmiştir. Bu bulgular, Muş ilinin tarımsal ürünlerden üretilebilecek sürdürülebilir ve çevre dostu biyokütle enerjisi açısından hem ulusal hem de küresel ölçekte kayda değer bir potansiyele sahip olduğunu göstermektedir.

Anahtar Kelimeler: biyokütle; Muş; sürdürülebilirlik; tarım ürünleri; temiz enerji**.**

1. Introduction

Energy, one of the most important indicators of economic and social development, has become a priority for all countries in the world since the early 1970s [1]. In recent years, global population growth, modernization and rapid development of industrialization have significantly increased energy demand. Although fossil fuels such as coal and oil dominate the energy market today, they come with environmental costs such as greenhouse gas emissions, global warming, and ozone layer depletion. Although approximately 80% of energy consumption worldwide is based on fossil fuels, excessive use of these resources leads to their depletion, and combustion processes harm the environment by increasing the emission of greenhouse gases such as carbon dioxide (CO_2), carbon monoxide (CO) and sulfur dioxide (SO_2). It is predicted that energy consumption, especially in the transportation sector, will increase by 60% by 2030. In addition, excessive use of fossil fuels brings with it many environmental and social problems such as energy security risks, fluctuations in crude oil prices, and damage to biodiversity. The search for renewable and carbon-neutral energy sources has accelerated to combat global climate change. [2]. Therefore, the need to develop new, accessible, environmentally safe, sustainable, and ecologically sound energy sources has become more urgent than ever [3].

Renewable energy is derived from naturally replenishing resources such as sun, wind, water, geothermal heat, and biomass and, unlike fossil fuels, is inexhaustible. It is generally environmentally friendly with a low carbon footprint, improves air quality, and provides sustainable energy solutions. It also reduces fossil fuel dependency, supports economic growth, and provides energy security. Prominent technologies include solar panels, wind turbines, hydroelectric power plants, organic matter-burning biomass power plants, geothermal power plants, tidal/wave systems, and hydrogen fuel cells [4]. Among these, biomass has become an important energy source and the fourth largest energy source worldwide, and as a result, studies on the use of biomass to meet the energy needs around the world have intensified in recent years [5]

Biomass is a renewable alternative that is widely available in nature and used for sustainable energy production. Biomass, derived from plant and organic matter, has a wide range of sources including agricultural crops, plant residues, forest wastes, and specially grown energy crops [6]. Biomass is produced by green plants converting sunlight into plant material through photosynthesis and includes all terrestrial and aquatic vegetation as well as all organic waste. A biomass resource can be thought of as organic matter in which the energy of sunlight is stored in chemical bonds. When the bonds between adjacent carbon, hydrogen, and oxygen molecules are broken through digestion, combustion, or decomposition, these substances release their stored chemical energy [7].

Biomass energy refers to any type of heat energy obtained from biological sources other than fossil fuels. This energy source can be provided not only from terrestrial ecosystems but also from ocean and freshwater habitats [8]. Among renewable energy sources (solar, geothermal, wind, tidal, bioenergy, etc.), biomass is the only renewable carbon source that can be converted into energy, solid/liquid/gaseous fuels, and chemicals by thermochemical (combustion, pyrolysis, gasification, hydrothermal liquefaction, etc.) and biological (anaerobic digestion, fermentation, etc.) conversion methods [9].

In today's world where climate change concerns are increasing, fossil fuel reserves are rapidly depleting and the need for green energy is becoming increasingly urgent, biomass stands out as a strong alternative for energy production. Biomass plays a critical role in nature's carbon cycle; CO_2 released into the atmosphere during the combustion process of biomass is reabsorbed by plants and other organic matter. This natural cycle creates a closed-loop carbon system that separates biomass from fossil fuels, significantly reducing net carbon emissions. Thanks to its environmentally friendly structure, wide range of resources, and accessibility, biomass is becoming an increasingly preferred renewable energy source. In contrast to the limited nature of fossil fuels, biomass offers a sustainable and renewable energy reserve. A wide range of feedstocks, from forestry waste to specially grown energy crops, can be easily adapted to different geographic regions and local farming systems. This flexibility makes biomass a powerful solution that both increases energy security and reduces dependence on fossil fuels [10].

The United Nations Sustainable Development Goals (SDGs) provide a comprehensive plan to promote sustainability and a cleaner future. The SDGs' pillars include universal access to energy, environmental responsibility, and climate action. SDG 7 (Goal 7) aims to ensure that everyone has access to affordable, reliable, modern, and environmentally friendly energy. In this context, biomass energy, as a clean and renewable energy source, offers an important solution, especially in regions where traditional energy infrastructure is inadequate [11, 12]. In addition, the efficient use of biomass energy is essential to achieve many of the SDGs, including those related to clean energy, zero hunger, industry, innovation, infrastructure, responsible production and consumption, and climate action. The efficient and sustainable use of biomass energy plays a key role in achieving the environmental, social, and economic objectives outlined in the United Nations' 2030 Agenda for Sustainable Development, particularly those related to clean energy, climate action, and responsible resource use [13].

In Türkiye, 86% of the energy demand is met by fossil resources and 73% is imported. Energy consumption in Türkiye is increasing much faster than its production, making Türkiye a rapidly growing energy importer. At the same time, agriculture is one of the main activities in Türkiye and represents a large part of the national income. Due to the climatic conditions and agricultural production in Türkiye, the diversity of agricultural products is quite high. Both agricultural production residues and large amounts of horticultural production residues are produced. Biomass can meet a significant part of the energy demand in Türkiye, as it is abundant. If local energy resources such as biomass are used adequately and efficiently, external dependence on energy will be significantly reduced and energy imports to the country can be eliminated [1]. In this study, annual average dry biomass amounts and corresponding theoretical biomass energy potentials were calculated based on agricultural crops planted in the districts of Muş province between 2020 and 2024.

2. Material ve Method

Muş province is located in the Upper Murat-Van section of the Eastern Anatolia Region. It was established on the plain between Çar Creek and Korni Creek. Muş province consists of 6 districts, including Bulanık, Hasköy, Korkut, Malazgirt, Varto, and Center. Muş is bordered by Ağrı to the east, Bingöl to the west, Erzurum to the north, Diyarbakır and Batman to the southwest, and Bitlis to the south. Its total area is 8196 km^2 and covers approximately 1,1% of Turkey's surface area. The geographical location of Muş is given in Fig. 1.

Muş is generally under the influence of the harsh and continental climate of the Eastern Anatolia Region. Steppe plants, meadow grasses, and oak forests constitute the vegetation types of Muş province, which is located within the influence zone of the continental climate. Agriculture and animal husbandry are the main sectors of the provincial economy. The total land of the province consists of 41,2% agricultural land, 38,8% meadow, 9,2% forest land, 8,3% pasture, and 2,5% land unsuitable for agriculture [14]. Irrigated agriculture is primarily practiced in the lands around the bed of the Murat River and Karasu, which flow in the Muş Plain in the central district. Later on, irrigated agriculture was practiced in Bulanık and Malazgirt districts where the waters of the Murat River could be reached, and in the Hasköy district where Karasu passes through. Apart from these lands, there are lands where

irrigated agriculture is practiced in a fragmented manner where there are no large lands where irrigated agriculture is practiced [15]. Cereals (wheat-barley) are cultivated on 84% of the total cultivated agricultural land, forage crops (alfalfa) on 10%, industrial crops (sugar beet, tobacco, sunflower) on 3%, and vegetables, fruits, and legumes on the remaining 3% [16].

Figure 1. Geographical location and districts of Muş province.

The data used to determine the biomass energy potential in Muş province were obtained from the Turkish Statistical Institute (TUIK). The data were obtained by following the path shown in Fig. 2.

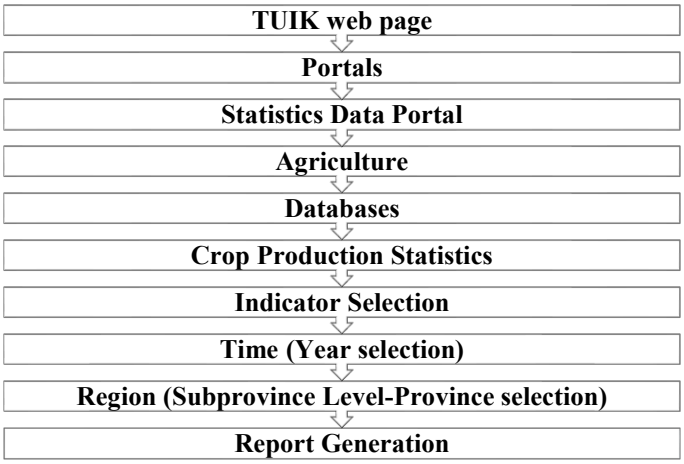

Figure 2. Schematic of obtaining data for the study.

In this study, in order to determine the biomass energy potential of Muş province, the areas covered by field crops cultivated between 2020-2024 were taken in hectares, and average dry biomass amounts and average biomass energy potentials were calculated for each district. Legumes, industrial crops, cereals, forage crops, oilseeds, and tuber crops are considered field crops. The calculations are based on average values reported in the literature, indicating that approximately 25-30 tons of dry agricultural biomass can be obtained per hectare annually, with a calorific value ranging between 3800-4300 kcal/kg,

depending on the crop type and environmental conditions. 1 kcal is taken as 1.10^{-7} TOE (tons of oil equivalent) and 1 TOE is taken as 11,63 MW and calculations were made using the following formulas (Eqs. 2.1-2.8) [17-19].

$$B_1 = 25 \times A \quad (2.1)$$

$$B_2 = 30 \times A \quad (2.2)$$

$$B_{ort} = (B_1 + B_2)/2 \quad (2.3)$$

$$C_1 = B_{ort} \times 3800 \quad (2.4)$$

$$C_2 = B_{ort} \times 4300 \quad (2.5)$$

$$C_{ort} = (C_1 + C_2)/2 \quad (2.6)$$

$$D_{ort} = C_{ort} \times 10^{-7} \quad (2.7)$$

$$E_{ort} = D_{ort} \times 11{,}63 \quad (2.8)$$

Where; A: Area (ha), B_1: Minimum dry biomass amount (tons), B_2: Maximum dry biomass amount (tons), B_{ort}: Average dry biomass amount (tons), C_1: Minimum dry biomass heating value (kcal), C_2: Maximum dry biomass heating value (kcal), C_{ort}: Average dry biomass heating value (kcal), D_{ort}: Average dry biomass energy amount (TOE), E_{ort}: Average dry biomass energy amount (MW).

3. Results and Discussion

Muş, which is located in the TRB2 Region covering the provinces of Van, Muş, Bitlis, and Hakkari, has a total agricultural land area of 3.241.124 decares according to TUIK data for 2024. Of this area, 3.135.099 decares are cultivated agricultural land and 22.535 decares are fallow. The total agricultural land in Muş corresponds to approximately 1,35% of the total agricultural land in Turkey. When the distribution of agricultural areas of Muş province by districts is examined, there are 963.700 decares in the central district, 899.905 decares in Malazgirt, 647.889 decares in Bulanık, 336.500 decares in Varto, 335.707 decares in Korkut and 57.423 decares in Hasköy [20].

3.1. Cereals

The main cereal crops grown in Muş province are rye, wheat, barley, corn, triticale, and oats. The average dry biomass amounts in tons that can be obtained from cereals in the center and districts of Muş province between 2020-2024 are given in Table 1 (Eq. 2.3), and the average biomass energy amounts determined in MW are given in Fig. 3 (Eq. 2.8). From Table 1, it is seen that the average dry biomass in Muş province in terms of cereals is 3.748.382 tons in 2020 and 5.023.015 tons in 2024, and the average dry biomass amount increases by approximately 34% in five years. It was determined that the highest average dry biomass amount in the districts was 2.264.754 tons in Malazgirt district in 2024 and the lowest was 41.525 tons in Varto district in 2024. There may be differences in the average amount of dry biomass that can be obtained from cereal crops on a district basis. This may be due to the difference in the size of the cultivated agricultural area between the districts. If the sum of the average dry biomass amounts that can be obtained from cereal crops between 2020 and 2024 are ranked from largest to smallest for the districts, they are Malazgirt, Central, Bulanık, Korkut, Varto and Hasköy, respectively.

Table 1. Average amounts of dry biomass from cereal crops in Muş province (tons)

	Bulanık	**Hasköy**	**Korkut**	**Malazgirt**	**Central**	**Varto**	***Total***
2020	1.027.925	57.351	173.223	1.285.955	1.065.633	138.295	3.748.382

	Bulanık	Hasköy	Korkut	Malazgirt	Central	Varto	*Total*
2021	928.373	75.625	393.759	1.453.295	1.118.659	191.634	4.161.344
2022	930.974	46.604	355.988	1.519.051	1.363.590	189.989	4.406.196
2023	1.146.910	62.769	258.088	1.856.250	1.507.847	232.375	5.064.238
2024	1.195.543	62.769	219.918	2.264.754	1.238.507	41.525	5.023.015

Considering Fig. 3, when evaluated in terms of the average biomass energy potential that can be obtained from cereal crops between 2020-2024 for Muş province, Malazgirt district has the highest total biomass energy potential with approximately 39.468 MW. In 2020, the average biomass energy potential of Malazgirt district was calculated as 6.057 MW, 6.845 MW in 2021, 7.155 MW in 2022, 8.743 MW in 2023, and 10.667 MW in 2024. The district with the lowest total biomass energy potential is Hasköy district with approximately 1.437 MW. The average biomass energy potential in the Hasköy district was calculated as 270 MW in 2020, 356 MW in 2021, 220 MW in 2022, and 296 MW in 2023 and 2024. The total average biomass energy potential in the central district is 29.647 MW, 24.633 MW in Bulanık, 6.599 MW in Korkut, and 3.739 MW in Varto. The average biomass energy potential that can be obtained from cereal crops in Muş province is calculated as 17.655 MW in 2020, 19.601 MW in 2021, 20.754 MW in 2022, 23.853 MW in 2023 and 23.659 MW in 2024.

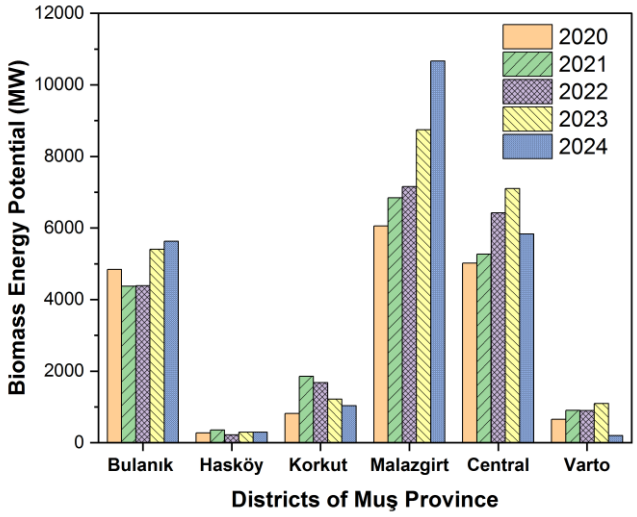

Figure 3. The average biomass energy potential from cereal crops in Muş province

3.2. Legumes

Chickpeas, beans, and lentils, which are legume crops, are grown in Muş province. The average dry biomass amounts that can be obtained from legumes in Muş province between 2020 and 2024 are given in Table 2 (Eq. 2.3) and the average biomass energy potentials that can be obtained are given in Fig. 4 (Eq. 2.8). When Table 2 is evaluated, it is determined that the average dry biomass from legume crops in Muş province is 83.597 tons in 2020, 89.774 tons in 2021, 92.043 tons in 2022, 121.545 tons in 2023, and 11.052 tons in 2024. There can be differences in the average amount of dry biomass from legumes over the years. While there was a linear increase in the average dry biomass amounts from 2020 to 2023 in the province, there was a significant decrease of approximately 87% in 2024. If the sum of the average

dry biomass amounts from legumes between 2020-2024 are listed from largest to smallest according to the districts, they are Central, Malazgirt, Bulanık, Korkut, Varto, and Hasköy, respectively.

Table 2. Average amount of dry biomass from legumes in Muş province (tons)

	Bulanık	**Hasköy**	**Korkut**	**Malazgirt**	**Central**	**Varto**	***Total***
2020	5.137	1.944	1.540	11.363	61.361	2.252	83.597
2021	5.027	2.338	2.461	12.350	65.447	2.151	89.774
2022	869	756	2.338	2.874	84.051	1.155	92.043
2023	2.789	1.042	4.538	1.183	110.688	1.306	121.545
2024	2.585	1.042	2.409	525	4188	303	11.052

The five-year change in the energy potential of the average dry biomass obtained in the districts is shown in Fig. 4 for each district. When the averages of the highest biomass energy potential from legumes between 2020-2024 are examined; the highest value was determined as 521.4 MW in the Central district in 2023 and the lowest value was determined as 1,4 MW in Varto in 2024. In 2020, the biomass energy potential was calculated as 24,2 MW for Bulanık, 9,2 MW for Hasköy, 7,3 MW for Korkut, 53,5 MW for Malazgirt, 289 MW for Central, and 10,6 MW for Varto. In 2024, biomass energy potential is calculated as 12,2 MW in Bulanık, 4,9 MW in Hasköy, 11,3 MW in Korkut, 2,5 MW in Malazgirt, 19,7 MW in Central, and 1,4 MW in Varto. By 2024, the amount of biomass energy that can be obtained in all districts has decreased significantly and it is also seen that approximately 82% of the five-year average biomass energy potential from legumes for Muş province can be met from the Central district.

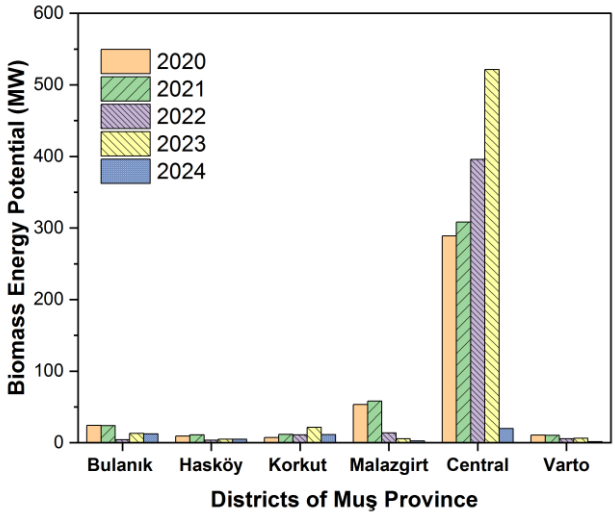

Figure 4. The average biomass energy potential from legumes in Muş province

3.3. Forage Crops

Vetch (Hungarian), vetch (other), alfalfa, sainfoin, corn for silage, forage peas, and meadow grass (green grass) are grown as forage crops in Muş. The average amount of dry biomass from forage crops in Muş province is given in Table 3 (Eq. 2.3), and the average biomass energy potentials are given in

Fig. 5 (Eq. 2.8). When Table 3 is examined, it was determined that 1.670.848 tons of dry biomass were generated from fodder crops in Muş province in 2020, 1.664.894 tons in 2021, 2.382.001 tons in 2022, 2.289.639 tons in 2023, and 3.127.784 tons in 2024. When forage crops are evaluated by years, it is seen that there is an increase in 2024, although there is a decrease in 2021 and 2023. If the sums of the average dry biomass amounts from forage crops between 2020-2024 are ranked from largest to smallest, they are Central, Varto, Korkut, Bulanık, Malazgirt, and Hasköy, respectively.

Table 3. Average amount of dry biomass from forage crops in Muş province (tons)

	Bulanık	**Hasköy**	**Korkut**	**Malazgirt**	**Central**	**Varto**	***Total***
2020	164.986	159.225	188.650	141.488	757.697	258.803	1.670.848
2021	158.043	113.988	213.397	180.188	747.203	25.2076	1.664.894
2022	250.225	129.635	371.168	133.235	1.025.717	472.021	2.382.001
2023	469.579	60.258	385.688	135.638	637.079	601.398	2.289.639
2024	508.780	60.258	672.579	138.589	925.471	822.107	3.127.784

According to Fig. 5, when the average biomass energy potential that can be obtained from forage crops in Muş province in the five-year period between 2020 and 2024 is evaluated, it is seen that the district with the highest total biomass energy potential is the Central district, with approximately 19.279 MW. In 2020, the average biomass energy potential of the Central district was calculated as 3.569 MW, 3.519 MW in 2021, 4.831 MW in 2022, 3.001 MW in 2023, and 4.359 MW in 2024. The district with the lowest total average biomass energy potential is Hasköy district, with 2.465 MW. The total average biomass energy potential in other districts is 11.375 MW for Varto, 8.627 MW for Korkut, 7.308 MW for Bulanık, and 3.434 MW for Malazgirt, respectively. The average biomass energy potentials from forage crops in Muş province are calculated as 7.870 MW in 2020, 7.842 MW in 2021, 11.219 MW in 2022, 10.785 MW in 2023, and 14.732 MW in 2024.

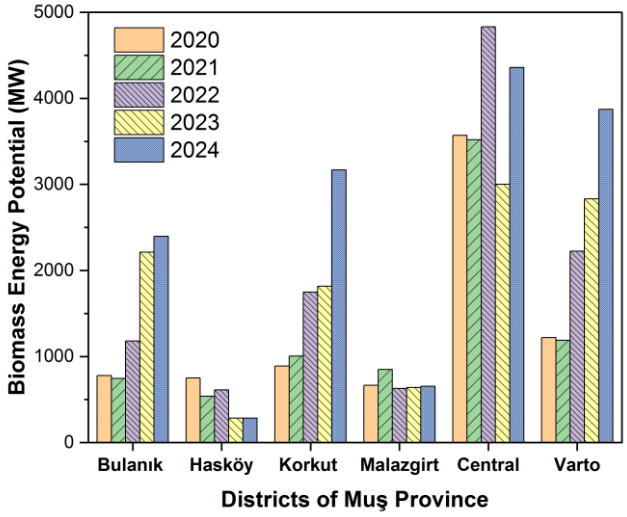

Figure 5. The average biomass energy potential of forage crops in Muş province

3.4. Industrial Plants

Sugar beet and tobacco are grown as industrial plants in Muş province. Sugar beet is not cultivated only in the Varto district, and tobacco is cultivated only in the Central district. The average dry biomass amounts from industrial crops in the central and districts of Muş province between 2020-2024 are given in Table 4 (Eq. 2.3), and the average biomass energy amounts that can be obtained are given in Fig. 6 (Eq. 2.8). As can be seen from Table 4, in Hasköy and Korkut districts, no planting was done in 2023, and replanting was done in 2024. In the Varto district, no industrial crops were planted between 2020 and 2024. When the total amount of average dry biomass in terms of industrial plants in Muş province was evaluated by years, it was determined that 358.669 tons of average dry biomass was formed in 2024, and this value increased by approximately 76% compared to 2020 but decreased by approximately 9% compared to the previous year. In addition, the highest average amount of dry biomass in cultivated areas was found in the Central district in 2023, while the lowest amount was found in the Korkut district in 2021. If the sum of the average dry biomass amounts from industrial plants between 2020-2024 is ranked from largest to smallest for the cultivated districts, they are Central, Malazgirt, Bulanık, Korkut, and Hasköy, respectively.

Table 4. The average amount of dry biomass from industrial plants in Muş province (tons)

	Bulanık	**Hasköy**	**Korkut**	**Malazgirt**	**Central**	**Varto**	***Total***
2020	33.481	4.538	10.516	50.133	86.504	0	185.171
2021	33.550	11.932	3.671	63.443	104.643	0	217.239
2022	27.588	4.964	11.303	63.800	81.887	0	189.541
2023	58.163	0	0	90.750	209.756	0	358.669
2024	49.830	13.277	17.518	61.050	185.081	0	326.755

When Fig. 6 is evaluated, it is seen that industrial plant production is realized in Bulanık, Hasköy, Korkut, Malazgirt, and Central districts in terms of industrial plants. There is no industrial plant production in the Varto district. In addition, there was no industrial plant production in the Hasköy and Korkut districts in 2023. Therefore, there is no average biomass energy potential for the districts and years with no cultivation. The highest total average biomass energy amount was calculated as 3.246 MW in the Central district. In 2020, the average biomass energy potential of the Central district was calculated as 407 MW, 493 MW in 2021, 386 MW in 2022, 988 MW in 2023, and 872 MW in 2024. The district with the lowest total biomass energy potential is Hasköy district, with 163 MW. The average biomass energy potential in the Hasköy district was calculated as 21 MW in 2020, 56 MW in 2021, 23 MW in 2022, and 63 MW in 2024. In other districts, the total biomass energy potentials are as follows: Bulanık 954 MW, Korkut 203 MW, and Malazgirt 1.550 MW. The average biomass energy potential that can be obtained from industrial plants in Muş province is calculated as 872 MW in 2020, 1.023 MW in 2021, 893 MW in 2022, 1.689 MW in 2023, and 1.539 MW in 2024.

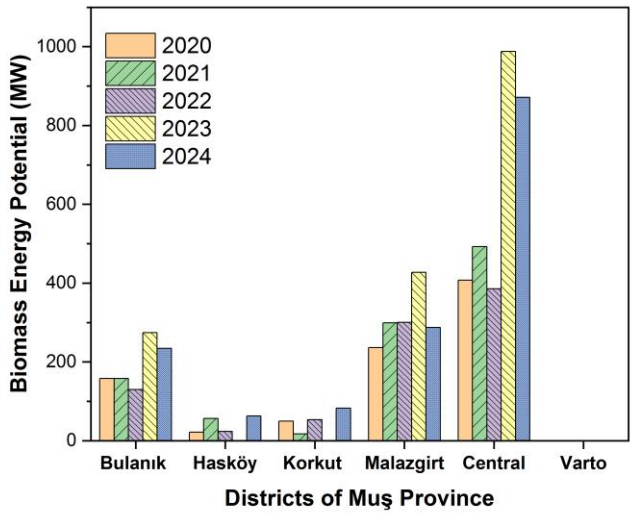

Figure 6. The average biomass energy potential from industrial plants in Muş province.

3.5. Oilseeds

Sunflower and safflower are grown in Muş province as oilseed crops. The average amount of dry biomass from oilseed crops in Muş is given in Table 5 (Eq. 2.3), and the average biomass energy potentials are given in Fig. 7 (Eq. 2.8). As can be seen from Table 5, some districts in Muş province do not cultivate oilseed crops. These districts include the Hasköy, Korkut, and Varto districts. Among the districts where oilseed crops are cultivated, both sunflower and safflower are produced in the Central district, while only sunflower is produced in the Bulanık and Malazgirt districts. In terms of oilseed crops, it was determined that the average dry biomass in Muş province was 71.437 tons in 2020, increased by approximately 13% to 80.751 tons in 2021, increased by approximately 47% in 2022 compared to the previous year to 118.726 tons, decreased by approximately 18% to 96.899 tons in 2023 compared to the previous year, and increased by approximately 31% to 126.800 tons in 2024 compared to the previous year. If the total of the average dry biomass amounts from oilseed crops between 2020-2024 is ranked from largest to smallest for the districts where production is made, it is Central, Malazgirt, and Bulanık, respectively.

Table 5. The average amount of dry biomass from oilseeds in Muş province (tons)

	Bulanık	**Hasköy**	**Korkut**	**Malazgirt**	**Central**	**Varto**	***Total***
2020	2.428	0	0	2.571	66.437	0	71.437
2021	1.711	0	0	2.695	76.346	0	80.751
2022	17.177	0	0	10.799	90.750	0	118.726
2023	25.300	0	0	2.830	68.769	0	96.899
2024	22.055	0	0	2.860	101.885	0	126.800

Fig. 7 shows that oilseed crops are not cultivated in some districts in Muş province. Since oilseed crops are cultivated in the Central, Malazgirt, and Bulanık districts, the average biomass energy potential between 2020-2024 was calculated only for these districts. The Central district has the highest average

biomass energy potential among these districts. While the average biomass energy potential in Central shows a linear increase between 2020 and 2022 (312,9 MW for 2020, 359,6 MW for 2021, and 427,4 MW for 2022), it decreased by approximately 24% in 2023 to 323,9 MW compared to the previous year and increased to 479,9 MW in 2024. In total, about 1.904 MW of biomass energy was provided in the center between 2020 and 2024, while about 323 MW of biomass energy was provided in Bulanık and 102,5 MW in Malazgirt. It is seen that approximately 82% of the five-year average biomass energy potential that can be obtained from oilseeds for Muş province can be provided from the Central district.

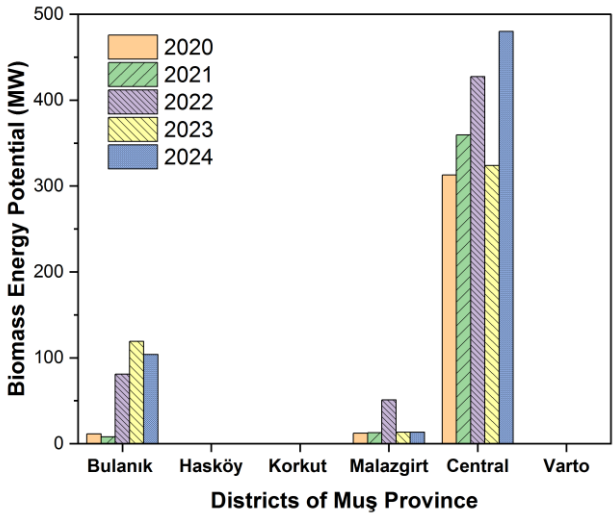

Figure 7. The average biomass energy potential from oilseeds in Muş province

3.6. Tuberous Plants

In Muş province, only potatoes are cultivated in the tuber crops class. The average amount of dry biomass from tuber crops in Muş is given in Table 6 (Eq. 2.3), and the average biomass energy potentials that can be obtained are given in Fig. 8 (Eq. 2.8). When the data in Table 6 are examined, only the Bulanık, Central, and Korkut districts of Muş province produced tuberous plants. In the Korkut district, while very little production was made between 2020-2023, no production was made in 2024. In Bulanık district, the average dry biomass amount decreased by approximately 97% in 5 years. The highest average dry biomass amount was calculated in 2024 in the Central district. In addition, the highest average dry biomass amount in terms of tuberous plants is also in the Central district.

Table 6. The average amount of dry biomass from tuberous plants in Muş province (tons)

	Bulanık	**Hasköy**	**Korkut**	**Malazgirt**	**Central**	**Varto**	***Total***
2020	2145	0	14	0	1403	0	3561
2021	2013	0	8	0	1966	0	3988
2022	74	0	6	0	825	0	905
2023	69	0	44	0	963	0	1075
2024	61	0	0	0	5984	0	6045

According to Fig. 8, when the average biomass energy potential from tuberous plants in Muş province between 2020 and 2024 is evaluated, the district with the highest total biomass energy potential is the Central district, with 52,47 MW. In 2020, the average biomass energy potential of the Central district was calculated as 6,61 MW, 9,26 MW in 2021, 3,89 MW in 2022, 4,53 MW in 2023, and 28,19 MW in 2024. The district with the lowest total biomass energy potential is Korkut district, with 0,34 MW. The total biomass energy potential in Bulanık is 20,54 MW. The average biomass energy potential from tuber crops in Muş province is calculated as 16,77 MW in 2020, 18,78 MW in 2021, 4,26 MW in 2022, 5,06 MW in 2023, and 28,19 MW in 2024.

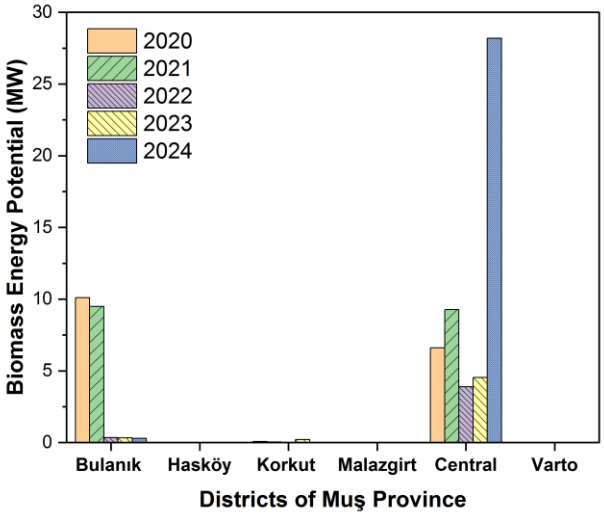

Figure 8. The average biomass energy potential from tuberous plants in Muş province

4. Conclusions

There are six districts in Muş province, including the Central district and five districts. In the study, 5-year average dry biomass amounts and average biomass energy potentials were calculated separately for each district between 2020-2024. Cereals, legumes, industrial plants, oilseeds, forage crops, and tuberous plants were taken as the basis in the calculations. In the calculations made using the data between 2020-2024, the total biomass energy potential of Muş province by year is given in Table 7 (Eq. 2.8). It is seen from Table 7 that the five-year total biomass energy potential is listed as cereals > forage crops > industrial plants > oilseeds > legumes > tuberous plants on the basis of agricultural products. Due to the high cereal planting and production in Muş province, where agriculture and animal husbandry are carried out, the amount of dry biomass and biomass energy potential produced by cereal products are also high.

The total biomass energy potential from field products for the districts of Muş province between 2020-2024 is given in Table 8 (Eq. 2.8). The biomass energy potential more or less varies depending on whether the agricultural areas are fully planted or not, due to the nature of the method used in this study. As seen in Table 8, the agricultural products that are planted the most and therefore produce the most biomass energy for all districts are cereals (62,7%) and forage crops (31,2%). The districts with the highest and lowest 5-year average biomass energy potential are Central (33,02%) and Hasköy (2,44%), respectively. When the biomass energy potentials that can be obtained from all products between 2020 and 2024 are evaluated on a district basis, it has been determined that 33.317 MW of energy can be obtained for Bulanık, 4.099 MW for Hasköy, 15.491 MW for Korkut, 44.688 MW for Malazgirt, 55.563 MW for Central, and 15.107 MW for Varto.

In this study, it was determined that there is an average of 35.723.911 tons of 5-year total biomass potential based on the areas where cereals, legumes, forage crops, industrial plants, oilseeds, and tuberous plants were planted in Muş province between 2020-2024, and the average energy potential corresponding to this dry biomass is approximately 170.000 MW.

When these findings are evaluated within the national context, they are consistent with similar studies conducted for other provinces. For instance, in Elazığ, the theoretical biomass energy potential from field crops between 2000 and 2010 was calculated as 158.948MW, with cereals contributing the largest share at 132.083 MW [21]. In Iğdır, the agricultural biomass energy potential for the 2009–2013 period was found to be 639.000 TOE, representing about 0,3% of Turkey's total biomass energy potential [18]. Likewise, in Kars, a study reported that the total annual biomass production was approximately 1,56 million tons, which could potentially yield 361.488 MWh of electricity [22].

In conclusion, the findings of this study demonstrate that Muş province has a highly promising agricultural biomass energy potential compared to similar regions. The province's substantial cereal cultivation and animal husbandry activities position it as a strategically important region for contributing to both regional development and the national renewable energy strategy.

Table 7. Total biomass energy potential from field products in Muş province between 2020-2024

	Biomass Energy Potential (MW)					
	2020	2021	2022	2023	2024	***Total***
Cereals	17.655,44	19.600,55	20.753,84	23.853,32	23.659,16	*105.522,31*
Forage Crops	7.869,94	7.841,90	11.219,58	10.784,54	14.732,33	*52.448,30*
Industrial Plants	872,18	1.023,23	892,77	1.689,38	1.539,07	*6.016,63*
Oilseeds	336,48	380,35	559,22	456,41	597,25	*2.329,70*
Legumes	393,76	422,85	433,53	572,49	52,06	*1.874,69*
Tuberous Plants	16,77	18,78	4,26	5,06	28,47	*73,35*
Total	*27.144,58*	*29.287,66*	*33.863,20*	*37.361,21*	*40.608,33*	**168.264,98**

Table 8. Total biomass energy potential from field products in Muş province between 2020-2024 on a district basis

	Biomass Energy Potential (MW)						
	Bulanık	**Hasköy**	**Korkut**	**Malazgirt**	**Central**	**Varto**	***Total***
Cereals	24.632,79	1.437,15	6.598,80	39.467,78	29.646,79	3.739	*105.522,31*
Legumes	77,28	33,55	62,58	133,27	1.534,26	33,76	*1.874,69*
Forage Crops	7.308,33	2.465,12	8.626,55	3.434,35	19.279,43	11.334,52	*52.448,30*
Industrial Plants	954,33	163,49	202,57	1.550,46	3.145,77	0	*6.016,63*
Oilseeds	323,45	0	0	102,47	1903,78	0	*2.329,70*
Tuberous Plants	20,54	0	0,34	0	52,47	0	*73,35*
Total	*33.316,72*	*4.099,31*	*15.490,83*	*44.688,34*	*55.562,50*	*15.107,28*	**168.264,98**

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Conflict of Interest

The author reports no conflict of interest relevant to this article.

Research and Publication Ethics Statement

The author declared that they complied with the scientific, ethical and citation rules of the *International Journal of Pure and Applied Sciences* throughout the entire process of the study.

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