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Research Article

Agricultural Residues in Turkey: Energy Potential and Evaluation of Existing Biomass Power Plants

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Abstract: Biomass energy gains importance constantly in order to increase energy security, diversity and develop the rural economy. Most of the existing biomass energy power plants in Turkey use solid waste, it is extremely important to encourage the use of agricultural residues in these facilities. In this study, agricultural residues were examined under two headings: primary residues (PR) are the residues left in the field after harvest (corn stalk, wheat straw, etc.), and secondary residues (SR) are the residues after the products are processed in the factory (almond shell, corn cob, etc.) When calculating the amount of agricultural residues, special uses such as soil protection, animal feeding, heating purposes are taken into account. The most cultivated products across 81 provinces in Turkey are listed and the residues are concentrated on products with high calorific value. The amount of primary and secondary residues belonging to these agricultural products was extracted and mapped based on provinces. Then the energy potential of these residues was calculated. The total amount of PR and SR produced in Turkey is 39 412 683 tonnes and 6 803 787 tonnes. By assuming the total efficiency of the power plant as 30% and the capacity factor of the biomass power plant as 0.65, the power to be obtained from only PRs will be 2 438.5 MW and from only SR will be 830 MW in the total of 81 provinces. Based on AHP method, cost is the most important criterion in the selection of pretreatment before transportation.

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Türkiye'deki Tarımsal Atıklar: Enerji Potansiyeli ve Mevcut Biyokütle Santrallerinin Değerlendirilmesi

Makale Bilgileri

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Öz: Biyokütle enerjisi; enerji güvenliğini, çeşitliliğini artırmak ve kırsal ekonomiyi geliştirmek için devamlı önem kazanmaktadır. Türkiye'deki mevcut biyokütle enerji tesislerinin daha fazla atık kullandığı bilinmesine rağmen, bu tesislerde tarımsal artıkların kullanımının teşvik edilmesi son derece önemlidir. Bu çalışmada tarımsal atıklar iki başlık altında incelenmiştir: birincil atıklar (BA), hasat sonrası tarlada kalan atıklardır (mısır sapı, buğday samanı, vb.), ikincil atıklar (İA) ise ürünlerin fabrikada işlenmesinden sonra kalan atıklardır (badem kabuğu, mısır koçanı, vb.). Tarımsal kalıntı miktarı hesaplanırken toprağın korunması, hayvanların beslenmesi, ısınma amaçlı gibi özel kullanımlar dikkate

Anahtar Kelimeler

Tarımsal artıklar/atıklar,
Biyokütle Santrali,
Biyokütle ön işlem,
Enerji potansiyeli,
Tedarik zinciri

alınır. Türkiye'de 81 ilde en çok ekilen ürünler listelenmiş ve kalori değeri yüksek ürünlerin atıkları üzerinde yoğunlaşılmıştır. Bu tarım ürünlerine ait birincil ve ikincil atık miktarları iller bazında ayıklanmış ve haritalanmıştır. Daha sonra bu atıkların enerji potansiyeli hesaplanmıştır. Türkiye'de üretilen toplam BA ve İA miktarı yıllık 39 412 683 ton ve 6 803 787 tondur. Santralin toplam verimi %30 ve biyokütle santralinin kapasite faktörünün 0.65 olduğu varsayıldığında, toplam 81 ilde sadece BA'dan yılda 2 438,5 MW ve sadece İA'dan yılda 830 MW güç elde edilecektir. AHP yöntemine göre, nakliye öncesi ön işlem seçiminde maliyet en önemli kriterdir.

1. Introduction

Energy has been one of the basic inputs for economic and social development throughout human history. The increase in population, the development of technology, and rapid urbanization increase the demand for energy day by day. It is known that a large part of this demand is met by fossil fuels. But fossil resources are finite. In addition, carbon dioxide, which is formed as a result of the burning of fossil fuels, is one of the most important greenhouse gases that cause climate change. It is a necessity to give up fossil resources in the fight against climate change. Renewable energy should be used more and more to meet the energy demand, and it will also contribute to the energy security of countries (Cergibozan, 2022). Renewable energy resources are sustainable resources that can renew themselves in a human lifetime. Renewable energy includes solar energy, wind energy, hydro energy, biomass energy, geothermal energy, tidal energy, ocean thermal energy, and wave energy (Murele et al., 2020).

The place of biomass is different among renewable energy sources. Biomass can be used directly for heat and power generation, or it can be processed into fuel, bio-based material, or chemicals. Biomass is defined as organic materials that can be renewed in less than a 100-year period, including plant wastes/residues, animal waste/residues, food industry wastes, energy forestry, energy plants, and urban wastes (Ioannidou et al., 2020).

The use of biomass in energy production strengthens the rural economy, increases energy security, and minimizes the environmental impact of energy production. For Turkey, the total energy potential that will contribute to the economy is estimated as 16.92 Mtoe (Ozturk et al., 2017). Due to its relatively low calorific value, high moisture content, and low bulk density, the need to use large amounts of biomass to produce the desired energy is among the most important challenges. The supply and logistics of sufficient biomass are also a challenge. Because the amount and content of most biomass are affected by time, season, and climatic conditions (Werther et al., 2000).

Among the biomass resources, agricultural biomass requires a special supply chain management due to seasonal availability (Rentizelas et al., 2009). A typical agricultural biomass supply chain may involve a combination of the following processes: field preparation, cultivation, harvesting, storage, field/forestry transport, road transport, and biomass use at the power station (Nunes et al., 2020). The low density of biomass further increases the cost of the collection, processing, transportation, and storage stages of the supply chain. But when the supply chain is set up correctly, energy from biomass can be cheaper than others. However, for biomass integration into an available energy supply chain to be beneficial, the energy materials used must be from the local source (Murele et al., 2020). The reason for that is delivery times are more predictable when biomass materials are sourced locally. It also results in a shorter supply chain, with lower costs and greenhouse gas emissions (Murele et al., 2020).

Agricultural biomass types are generally characterized by seasonal availability. The period in which these biomass types are available is very limited and is determined by the harvest season of the product, weather conditions, and the need for re-planting of the fields. Since most of the biomass energy applications up to the present have been related to the use of single biomass, there is a need for storage of huge amounts of biomass over a significant time if the operation of the power plant is desired throughout the year. Dry matter loss and degradation of biomass are the main risks of storage, and this problem can be eliminated with proper storage (Nunes et al., 2020).

Although pretreatment is not mandatory, it plays an important role in the supply chain. Biomass has several disadvantages during storage, transportation, and combustion because of the low density, low heating value, high moisture content, or high volatile matter. Besides, pretreatment of biomass extends the durability period of this biomass (Murele et al., 2020).

In recent years, Turkey has been promoting biomass energy to increase energy security and ensure energy diversity. It is seen that the use of solid wastes, sewage sludge, agro-industrial wastes, and animal manure in existing biomass power plants is common. However, Turkey also generates a large amount of agricultural residue due to its geographical location and agricultural production. It is seen that these wastes are concentrated in different provinces of Turkey.

In the present study, the amount and distribution of agricultural residues in Turkey on the basis of provinces and the energy potential of these residues were calculated. It was also examined whether the existing biomass power plants benefit from this potential. Moreover, the analytical hierarchy process method was used for deciding the most preferred pretreatment method to ease the transport and storage of agricultural residues.

2. Material and Methods

2.1. Collection of data

In the present study, agricultural residues were categorized as primary residues (PR) and secondary residues (SR). PR is the crop residue that is collected from the field directly after harvest. Stalk, stover, and straw of the crops are examples of this kind. SR is the crop residue which is obtained during the processing of the crop. Husks, shells, etc., can be included in this category. The PR data has been collected by the Ministry of Energy and Natural Resources (MoE) in Turkey and the Turkish Statistical Institute for the years 2019-2020. Both organizations publish the yearly data based on province. However, the data for SR has never been recorded by any of the organizations. Therefore, SR data was calculated by multiplying the crop production rate with the percent of husk or shell found in the crop. Fuel properties in terms of proximate analysis and heating value of each PR and SR were collected from different papers. Existing biomass power plants in Turkey (both licensed and unlicensed), their capacities, and the type of feedstock that they are using were all collected from MoE.

2.2. Methodology

The present study consists of three parts. In which provinces and what quantity of PR and SR were produced in Turkey were investigated first. For calculating the energy potential, a lower heating value (LHV) was multiplied with the annual amount of residue of each crop listed under either PF or FS. Then, the existing biomass power plants in Turkey and what kind of biomass is used in these plants were investigated. In the third stage, the proximity of the provinces with high PR and SR potential to the existing power plants and whether the biomass potential reaches the nearest power plant were investigated. Analytic Hierarchy Process method was applied to rank the criteria (cost of pretreatment, enhancement in heating value, requirement of size reduction, transport easiness, density enhancement, storage easiness) that affect the selection of pretreatment method by their importance. The formulation of the AHP method is extensively explained by Brunelli (2015).

3. Results

3.1. Energy potential of PR and SR in Turkey

Cornstalk, wheat straw, sunflower stalk, cotton stalk, rye straw, barley straw, and oat straw constitute the majority of PR. The distribution of PR produced in Turkey by provinces is shown in the map chart in Figure 1. The total amount of PR produced in Turkey is 39 412 683 tonnes. Among the provinces, Konya is the province with the highest PR production (4 875 500 tonnes). The second province that contributes the most to PR production is Şanlıurfa (2 518 368 tonnes). Adana comes after these provinces (with 2 331 890 tonnes) that contribute to total production.

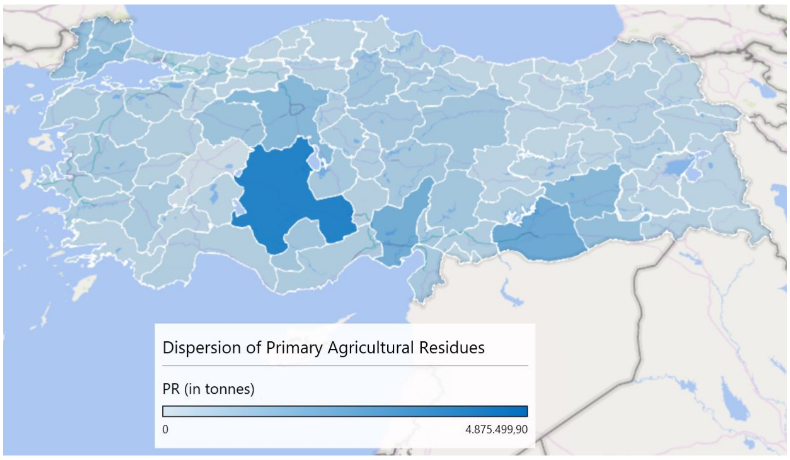

Figure 1. Distribution of PR produced in Turkey by provinces.

Almond shell, corn cob, hazelnut shell, olive husk, peanut shell, sunflower husk, walnut shell, and wheat husk are the major constituents of SR in Turkey. SR, which is less in amount compared to PR, is produced more in industrially developed provinces. The distribution of SR produced in Turkey by provinces is shown in the map chart in Figure 2. Konya is the province that contributes the SR production most (729 724 tonnes). Almond shell is mainly produced in Mersin (11 313 tonnes). Corn cob and wheat husk are mainly produced in Konya (165 681 tonnes of corn cob and 407 587 tonnes of wheat husk). Ordu, which meets the majority of hazelnut production in Turkey, is also a leader in hazelnut shell production (144 318 tonnes). Since most of the olive production in Turkey is in the Aegean and southern Marmara regions, it is seen that the processing of olives is also in this region. Manisa is the province with the highest amount of olive husk (41 859 tonnes). Adana, which has a great contribution to agricultural production, is also ahead in peanut shell production (39 534 tonnes). Sunflower husk is majorly produced in Tekirdag (173 751 tonnes). Walnut shell has the lowest contribution to total SR in Turkey, which is mainly produced in Kahramanmaraş (8 412 tonnes).

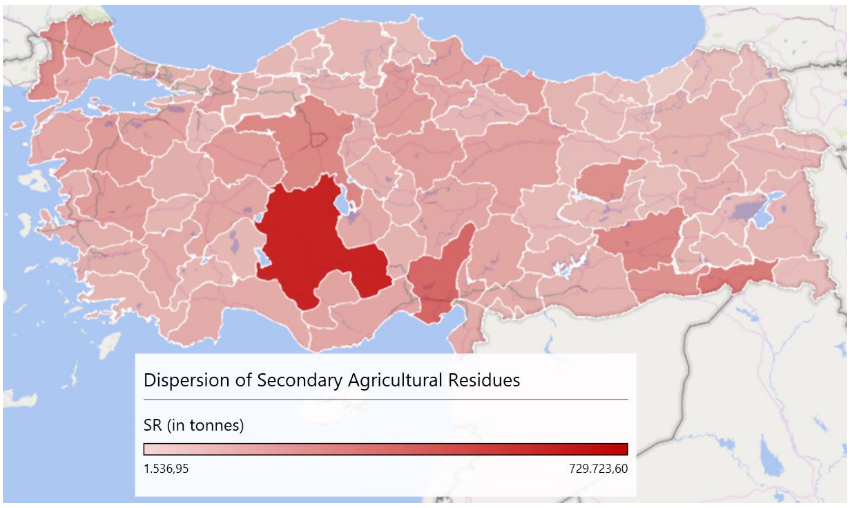

Figure 2. Distribution of PR produced in Turkey by provinces.

Energy, which is released via combustion (Q) of any agricultural residue listed under PR, is calculated by using the amount of annual agricultural residue (R, in kg/year), lower heating value (LHV, in MJ/kg) of the corresponding biomass, moisture content (MC) of the corresponding biomass and the availability of the agricultural residue (A) (Polat, 2020) as shown in equation 1,

$$Q\left(\frac{Mj}{year}\right) = R \times (1 - MC) \times A \times LHV \tag{1}$$

The energy released by the combustion of SR can also be calculated by using equation 1. Since the annual amount of SR is not listed or recorded, R for SR is calculated by multiplying the annual agricultural production amount (P) with residue ratio (S), as seen in equation 2. P data for corn, wheat, sunflower, walnut, hazelnut, almond, and peanut are all listed on the website of the Turkish Statistical Institute. The residue ratio is the husk or shell ratio of the agricultural product. For corn cob, S is 15% (Patsios et al., 2016), for sunflower husk, it is 50% (Perea-Moreno et al., 2018), for olive husk, S is 13.5% (Khdair & Abu-Rumman, 2020), and for wheat husk, it is 20% (Santos et al., 2019). For the other shells, S is 80% for thick shells and 40% for leaf-like shells (Fornés Comas et al., 2019).

$$R = P \times S \tag{2}$$

The proximate analysis of each PR and SR are given in Table 1 and Table 2.

Table 1. Proximate analysis for common primary residues

	HHV Mj/kg	VM, %	Ash, %	FC, %	BD, kg/m^3	References
Corn Stalk	16.82	74.79	6.47	19.06	57.50	(Avcıoğlu et al., 2019), (Fornés Comas et al., 2019), (García et al., 2014), (Jiang et al., 2019), (Poudel & Oh, 2014), (Zhou et al., 2019)
Wheat Straw	19.09	72.92	9.78	17.15	79.50	(Aqsha et al., 2014), (Avcıoğlu et al., 2019), (Bai et al., 2017), (Bajwa et al., 2018), (Biswas et al., 2017), (Danish et al., 2015), (García et al., 2014), (Havrysh et al., 2021), (Jiang et al., 2019), (Moayedi et al., 2019), (Montero et al., 2016), (Nhuchhen & Abdul Salam, 2012), (Patsios et al., 2016), (Qian et al., 2017), (Ríos-Badrán et al., 2020)
Sunflower Stalks	18.85	85.27	7.81	9.79	112.00	(Jiang et al., 2019), (Morato et al., 2019), (Nhuchhen & Abdul Salam, 2012)
Cotton Stalk	17.05	71.99	10.72	21.93	200.00	(Avcıoğlu et al., 2019), (Bajwa et al., 2018), (Danish et al., 2015), (Nhuchhen & Abdul Salam, 2012), (Tang et al., 2015)
Rye Straw	18.79	83.02	2.92	15.01	0.00	(Avcıoğlu et al., 2019), (García et al., 2014), (Havrysh et al., 2021), (Wang et al., 2016)
Barley Straw	16.69	74.87	5.99	11.67	66.45	(Aqsha et al., 2014), (Avcıoğlu et al., 2019), (García et al., 2014), (Havrysh et al., 2021), (Jiang et al., 2019), (Patsios et al., 2016), (Qian et al., 2017)
Oat Straw	18.52	77.20	8.41	15.43	91.00	(Aqsha et al., 2014), (Bajwa et al., 2018), (Havrysh et al., 2021), (Patsios et al., 2016), (Qian et al., 2017), (Yang et al., 2016)

HHV : Higher Heating Value.
VM : Volatile Matter Content.
FC : Fixed Carbon Content.
BD : Bulk Density.

The energy potential of PRs produced in 81 provinces is 5 283 MW. On the basis of provinces, it is noteworthy that the energy potential of PRs in Konya, Şanlıurfa, and Adana is quite high. The energy content of the PRs that can be collected from Konya alone is 690 MW. This province with great potential is followed by Şanlıurfa (455 MW), Adana (447 MW) and Tekirdağ (268 MW). The energy content of the PRs to be collected from these provinces is 35% of the total potential. Looking at the overall 81 provinces, it is seen that the energy potential of primary agricultural residues produced in 16 provinces is over 100 MW. Of course, 100% of this potential is not converted into electrical energy. If we accept the total efficiency of the power plant as 30% and the capacity factor of the biomass power plant as 0.65, the power to be obtained from only PRs in the total of 81 provinces will be 2 438.5 MW. With the same assumptions, 16 provinces (Konya, Şanlıurfa, Adana, Tekirdağ, Diyarbakır, Mardin, Edirne, Kırklareli, Ankara, Karaman, Osmaniye, Hatay, Manisa, Eskişehir, Aydın and Kahramanmaraş) hold 67% of the total energy potential. The power plants to be established in these provinces will be between 318 MW (Konya) and 47 MW (Kahramanmaraş). After Konya, there comes Şanlıurfa, Adana and Tekirdağ with 210 MW, 207 MW and 124 MW, respectively.

Table 2. Proximate analysis for common secondary residues

	HHV Mj/kg	VM, %	Ash, %	FC, %	BD, kg/m^3	References
Hazelnut Shell	19.21	73.00	2.22	23.64	560.00	(Acar & Ayanoglu, 2012), (Avcıoğlu et al., 2019), (Bajwa et al., 2018), (Bilgiç, 2014), (Demirbas, 2016), (Estiati et al., 2016), (García et al., 2014), (Moayedi et al., 2019), (Nhuchhen & Abdul Salam, 2012), (Qian et al., 2017), (Zhao et al., 2020)
Walnut Shell	20.26	69.24	3.35	27.42	No data available	(Acar & Ayanoglu, 2012), (Avcıoğlu et al., 2019), (Estiati et al., 2016), (García et al., 2014), (Moayedi et al., 2019), (Nhuchhen & Abdul Salam, 2012), (Qian et al., 2017)
Olive Husk	18.56	71.45	11.45	25.75	No data available	(Acar & Ayanoglu, 2012), (Demirbas, 2016), (Moayedi et al., 2019), (Nhuchhen & Abdul Salam, 2012), (Patsios et al., 2016), (Qian et al., 2017)
Almond Shell	18.94	79.40	2.94	20.55	No data available	(Avcıoğlu et al., 2019), (Danish et al., 2015), (García et al., 2014), (Moayedi et al., 2019), (Nhuchhen & Abdul Salam, 2012), (Qian et al., 2017)
Peanut Shell	19.97	71.97	6.04	21.79	No data available	(Avcıoğlu et al., 2019), (Estiati et al., 2016), (Mohammed et al., 2016), (Nhuchhen & Abdul Salam, 2012)
Corn Cob	16.00	81.75	1.85	11.31	155.00	(Avcıoğlu et al., 2019), (Biswas et al., 2017), (Danish et al., 2015), (Thanarak, 2012), (Yao et al., 2017)
Sunflower Shell	18.00	76.20	3.05	19.80	95.00	(Acar & Ayanoglu, 2012), (Jiang et al., 2019)
Wheat Husk	17.80	71.40	2.30	19.30	549.00	(Montero et al., 2016), (Santos et al., 2019)

Table 3. Availability, LHV, and MC values for primary residues in Turkey

Product	A (%)	LHV Mj/kg	Moisture %
Barley Straw	15	17.25	8.85
Corn Stalk	60	13.25	11.73
Cotton Stalk	60	16.40	9.56
Oat Straw	15	16.55	7.39
Rye Straw	15	16.55	10.45
Sunflower Stalks	60	16.00	9.20
Wheat Straw	15	16.62	12.65

Table 4. Availability, LHV, and MC values for secondary residues in Turkey

Product	A (%)	LHV Mj/kg	Moisture %
Almond Shell	80	19.38	6.30
Corn Cob	60	14.01	20.44
Hazelnut Shell	80	19.15	7.64
Olive Husk	50	20.69	9.34
Peanut Shell	80	14.05	8.17
Sunflower Husk	60	16.5	8.77
Walnut Shell	80	20.18	20.58
Wheat Husk	15	14.5	6.50

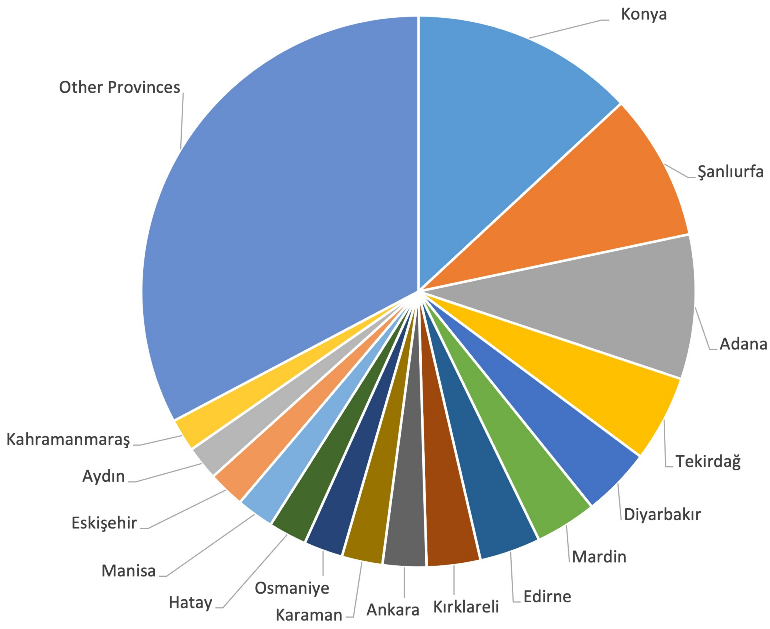

Figure 3. Distribution of the energy potential of PR by provinces.

The figure shows the energy potential distribution of SR on the basis of provinces. The total energy potential of SR across 81 provinces is 1 797.6MW. Approximately 58% of this potential is provided by 17 provinces. Since Adana and Konya are pioneers in SR production, the amount of energy that can be obtained in these provinces is also high. While the energy potential of SRs in Adana is 180MW, it is 168 MW in Konya. These two provinces are followed by Tekirdağ (79 MW) and Ordu (66 MW). It should not be forgotten that, as stated before, we cannot convert all of the chemical energy released by the combustion of biomass into electrical energy and that the biomass power plant cannot operate at maximum capacity. Assuming that the biomass power plant operates at 30% efficiency and the capacity factor is 0.65, the total power that can be obtained from the SR will be 830 MW.

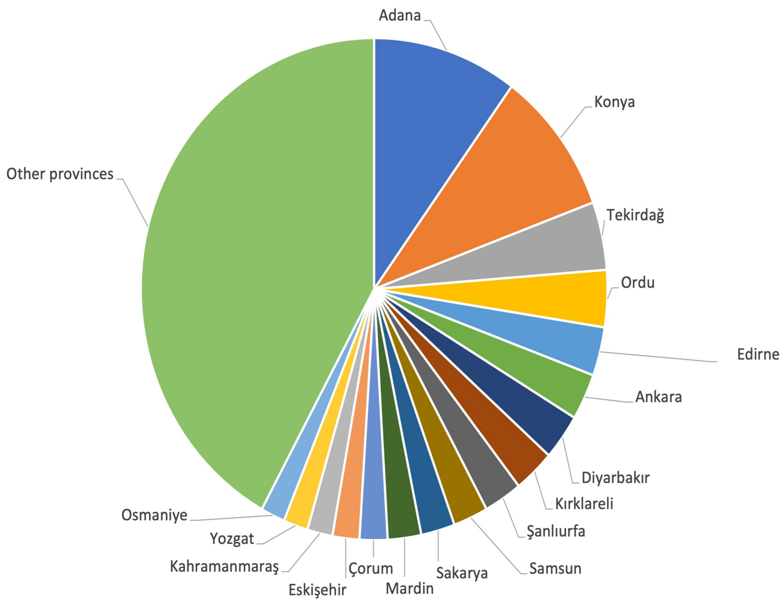

Figure 4. Distribution of the energy potential of SR by provinces.

3.2. Biomass power plants in Turkey

Combustion of biomass is the most common thermochemical conversion technology to produce power, heat, or combined heat and power. In contrast to coal-fired power production, energy from biomass-fired power plants is generally considered “carbon neutral”. The reason for thinking in this way is that the carbon taken from the atmosphere during the growth of biomass is given to the environment at the end of energy production. However, information such as the type of biomass, its life span, the technology chosen, how and at what distance the biomass comes to the power plant are important in deciding whether the biomass energy is carbon-neutral or not. Life cycle assessment is a helpful tool for assessing the environmental effects and impacts of total biomass energy production (Paletto et al., 2019). The biomass energy power plant (BEPP) produces electricity by firing biomass, including agricultural residues/wastes, forestry residues/wastes, and solid waste. Biomass is burned in a boiler to produce high-pressure steam. This steam flows over the turbine blades. The rotation of the turbine drives the generator, which produces electricity(Gebreegziabher et al., 2014). Although a very well-known technology, the biggest disadvantage is the efficiency, which is 10-30% on average.

In Turkey, some regulations were made within the scope of the Regulation on Unlicensed Electricity Production in the Electricity Market (Official Gazette No. 28783 on October 2, 2013) in order to expand small businesses based on renewable energy sources and to encourage small-scale investments. If electricity is to be produced below a certain installed capacity, there is no obligation to obtain a license and establish a company. Thus, consumers will primarily meet their own needs with small-scale investments, and the surplus electricity will be sold to the existing electricity grid. The unlicensed biomass power plant must be under 5MW, as stated in the Electricity Market Article no 6446 (*ETKB*, 2021).

As of the end of December 2020, the installed power based on biomass energy in Turkey is 1 485 MW, and its share in total electricity generation is 1.8%. There are more than 350 BEPPs, which use different biomass sources as fuel. Solid waste, sludge, agricultural waste, animal manure, and biowastes are common feedstocks. The present study focuses on the BEPPs, which use agricultural residues as fuel. Table 5 shows the installed capacity of some BEPPs (licensed and unlicensed) that use agricultural wastes/residues. The cities which are more industrialized, seem to have BEPPs with high installed capacity. Ankara (28.32 MW), Samsun (27 MW), and Mardin (12 MW) are among the examples.

In Fig. 5 and Fig. 6, the distribution of PR and SR by provinces and the existing biomass power plants are given on the same map. As can be seen from these maps, the number of BEPPs using agricultural wastes is low in regions with high PR potential. It is evident that the current energy potential of the PR is not utilized where the PR is produced. There is a need for production facilities to utilize the current potential of PR, especially in provinces such as Konya and Şanlıurfa, where PR is highly produced. Similarly, the potential of SRs cannot be said to be evaluated in existing BEPPs. It is necessary to establish power generation facilities in or near the provinces where PR and SRs with high energy potential are produced excessively.

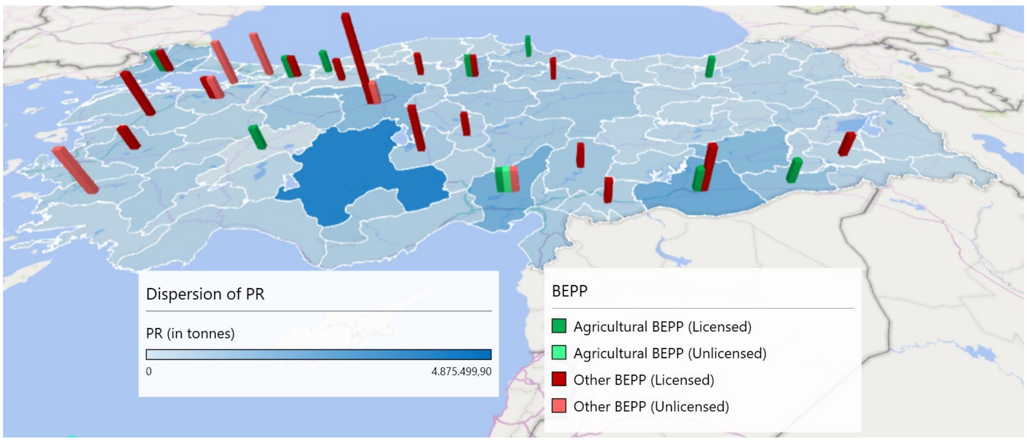

Figure 5. The distribution of PR by provinces and the existing biomass power plants.

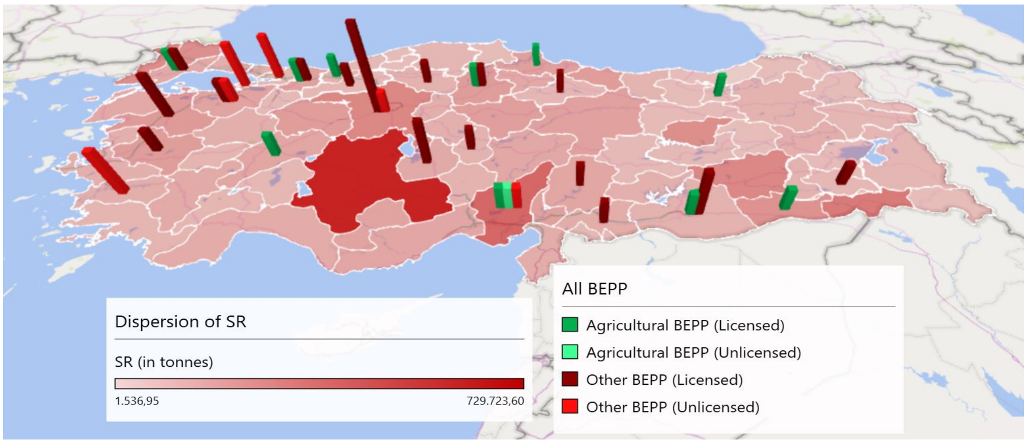

Figure 6. The distribution of SR by provinces and the existing biomass power plants.

Table 5. Installed capacity of some BEPPs that use agricultural wastes/residues

Fuel Type	Facility Name	City	Installed Power (MW)
Corn and Cotton Straw, Citrus waste	Fby BEPP Yuregir	Adana	9.3
Agricultural Residue/Waste	Eber BEPP	Afyonkarahisar	27
Beet Greens, Animal Manure	Aksaray Yapılcan BEPP	Aksaray	1.2
Beet Greens, Animal Manure	Yapılcanlar2 BEPP	Aksaray	1.067
Organic Waste	De Solar 7 BEPP	Ankara	3.201
Solid Waste	Sincan Çadırtepe BEPP	Ankara	28.32
Biowaste	Astosan BEPP	Balıkesir	1.054
Biowaste	Edincik BEPP	Balıkesir	2.134
Hazelnut Shell, Sunflower stalk, Corn Straw, Wood Flour	Bayburt BEPP	Bayburt	1.56
Hazelnut Shell, Sunflower Straw, Corn Straw, And Wood Flour	Çorum-Mecitözü BEPP	Çorum	5
Forest Residue, Hazelnut Shell, Tea Waste and Rice Husk	Düzce BEPP	Düzce	12
Biowastes	Salihli BEPP	Manisa	10
Cotton and Corn Residue	Mavibayrak Doğu BEPP	Mardin	12
Biowaste	Mevlüt Coşkun BEPP	Nevşehir	2
Biowaste	Karma 1 BEPP	Sakarya	1.487
Agricultural and Forest Residue	Samsun- Çarşamba BEPP	Samsun	27
Plant Residue	Biopir Piroliz BEPP	Şanlıurfa	3.192
Biowaste	Siirt BEPP	Siirt	1.413
Sludge	Modern BEPP	Tekirdag	6
Biowaste	Cemak BEPP	Tokat	6.15

It is seen that an effective biomass supply chain should be established in order for existing and future BEPPs to make maximum use of agricultural wastes. Because the potential of PR and SR has spread throughout Turkey, only in provinces such as Konya, Adana, Şanlıurfa, the potential is higher than in other provinces. Especially in regions such as Eastern Anatolia, Eastern Black Sea, and Southeastern Anatolia, the biomass energy potential is distributed. In this case, the storage and transport of biomass will be extremely important. This is mainly due to the seasonality of crop residues. In order not to face feedstock shortages or surplus, there should be good planning regarding the storage and transport of biomass. The low bulk density and high moisture content of biomass are major disadvantages in transport and storage. Pretreating the biomass after harvest is the best option to ease storage and transportation.

Different pretreatments can be applied to densify, dry, and increase the heating value of the biomass. Pretreatment can be either physical (such as baling, loafing, drying, pelleting, and briquetting) or thermochemical (such as torrefaction hydrothermal treatment). Drying is the cheapest and easiest pretreatment. Due to the high moisture content of biomass, drying is the most important pretreatment before any thermochemical conversion process. Drying is intended only for easy and risk-free storage (Akkuş, 2018). Pelleting and briquetting don't change the content of biomass, but those processes ease the transport and storage by compressing the biomass at high pressure. Torrefaction (also called low temperature pyrolysis) is heating the biomass under an inert environment. The main purpose of this process is to obtain a high quality fuel by increasing the heating value while removing the moisture.

There is a reality that biomass -especially the agricultural residues- is a very cheap source. Applying any of the pretreatment increases the cost. To be competitive, the overall cost of the biomass feedstock should below, which means that the cost of the pretreatment is one of the key criteria in deciding the pretreatment option.

3.3. Analytic hierarchy process

In the present study, Analytic Hierarchy Process (AHP) method was applied to rank the criteria (cost of pretreatment, enhancement in heating value, requirement of size reduction, transport easiness, density enhancement, storage easiness) that affect the selection of pretreatment method by their importance. A questionnaire was prepared in google forms platform and shared with experts (scholars, energy professionals, and energy systems engineers). They are asked to make a pairwise comparison based on their preference ranging from 1 to 9 (1:equal importance, 3: moderate importance, 5: strong importance, 7: very strong importance, 9: extreme importance. 2, 4, 6, and 8: interpolated values) (Ioannou et al., 2018). Scientific papers (30 different papers which were all related to biomass treatment methods) were also evaluated for their preference. The consistency ratio was found as 0.053, which showed that experts' decisions were consistent.

Based on the principal eigenvector of the decision matrix (principal eigen value is 6.333), the resulting weights are given in Table 6. Based on pairwise comparisons, the most important criterion is the cost of pretreatment with 33.6% importance (+/- 11.4 %), which means that the cost of pretreatment is the most important criterion in selecting biomass pretreatment method. Transport easiness takes second place with 27.2% importance (+/- 10.7 %). The third important criterion with 13.4% importance is density enhancement (+/- 4.7 %). Enhancement in heating value and storage easiness have equal importance (11.2%) (+/-3.3% and +/-3.2%, respectively). The least important criterion is a requirement of size reduction (3.5%, +/- 1.6 %).

Table 6. Decision matrix

	Cost of Pretreatment	Enhancement in Heating Value	Requirement of Size Reduction	Transport Easiness	Density Enhancement	Storage Easiness
Cost of Pre-Treatment	1	3	5	2	3	3
Enhancementin Heating Value	0.33	1	5	0.5	0.5	1
Requirement of Size Reduction	0.2	0.2	1	0.167	0.2	0.2
Transport Easiness	0.5	2	6	1	3	4
Density Enhancement	0.333	2	5	0.333	1	1
Storage Easiness	0.333	1	5	0.25	1	1

The results show that investors don't want to pay too much money on pretreatment. If any pretreatment should be done, this should be for making the transport easy. This was an expected result since the agricultural residue itself is a cheap feedstock. Any additional cost will increase the cost of energy production. Selecting a pretreatment that enhances the density is the most important criterion after transport easiness. Baling, loafing, pelleting are the most preferred methods to enhance the bulk density. Enhancing the heating value by using pretreatment (such as torrefaction and hydrothermal drying) is not seen as an important criterion in deciding the pretreatment method. This is expected due to the reason that those methods apply heat, which increases the cost of total energy production. By considering AHP results, the most efficient methods to ease the transport and storage are baling, loafing, pelleting, or briquetting without size reduction.

4. Conclusion

Due to the fact that agricultural areas are large, agricultural products are diverse, and the climate is suitable for agriculture, the amount of waste and residues left over from agricultural activities in Turkey is high. A large amount of these wastes and residues have high energy content. The total amount of PR and SR produced in Turkey is 39 412 683 tonnes and 6 803 787 tonnes, respectively. By assuming the total efficiency of the power plant as 30% and the capacity factor of the biomass power plant as 0.65, the power to be obtained from only PRs in the total of 81 provinces will be 2 438.5 MW, the same for SR will be 830 MW. Konya, Şanlıurfa, Adana, Tekirdağ, Diyarbakır, and Mardin are the provinces that investors should think of installing biomass energy power based on PR and SR. Considering that the installed power based on biomass energy in Turkey by the end of 2020 is 1485 MW, the installed power will triple when only the potentials of the existing PR and SR are used. This will increase the share of biomass power in total electricity generation above 5%.

In power generation from agricultural biomass, it is necessary to pretreat the biomass in order to transport the biomass from agricultural fields to the power station and to store it safely. Although there are many pretreatment methods, the AHP method has shown that cost is the most important criterion in the selection of pretreatment. Investors will prefer the least costly pretreatment method that makes transportation easier. Therefore, pretreatments such as baling, pressing, and pelleting can be recommended for agricultural biomass.

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