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Assessment of the energy potential of agricultural biomass residues in Turkey

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ABSTRACT

Agricultural biomass residue based energy generation is one of the major focus areas of renewable energy in different countries around the world. A large quantity of biomass residue is generated from agricultural crop production. However, the biomass residues are the distributed resources with variation in spatio-temporal availability and its characteristics which their energy potential depends on. Biomass residues are emerged after harvesting of main crops as stalks, straw, stems and leaves, husks, cobs and etc. In this study, agricultural biomass residues energy potential was explored for Turkey using conducted studies of agricultural biomass residues characteristics in several countries located at different geographic regions. Data on characteristics of agricultural biomass residues were used from 16 European Union countries, as well as in India, Cameroon, China, Pakistan, Nigeria, Uganda and Turkey. Some residue characteristics such as residue product ratios, moisture levels, and lower heating calorific values of dry matter were taken into account. Furthermore, a mathematical model was defined for the calculation of the energy potential of Turkey's agricultural biomass residues. Theoretical biomass amount and theoretical energy potential, as well as available energy potential values of agricultural biomass residues were determined. The total amounts of biomass residues obtained from arable field crops and horticultural crops in Turkey were estimated as 59,432 kilotonne and 15,652 kilotonne respectively. The theoretical energy potential of these all agricultural biomass residues were calculated as 908,119 TJ and 90,354 TJ, respectively. The available energy potentials from agricultural biomass residues were calculated as 298,955 TJ for arable agricultural field crops and 65,491 TJ for horticultural crops.

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1. Introduction

Biomass is a renewable alternative source that is found all over the world. Biomass resources cover agricultural crops, plant residues, forest resources, special energy plants. Biomass are obtained as residues in the whole process agricultural production. Many residues have been obtained from the arable field crops and horticultural crops during the production of crops and fruits in agriculture. Energy policies and planning ensuring food security in the world should be supported in local, national and global scale biomass utilization for energy.

Countries across the globe have considered and directed state policies toward economic utilization of biomass for meeting their energy demands [1]. The International Energy Agency (IEA) estimates that world energy consumption will increase by 48% from the period of 2012–2040 [1]. In this context; Kyoto Protocol [2], the EU directive [3,4], such as international and national agreements and European 20:20:20 [5] and the US Recovery and Reinvestment Act [6] as well as political decisions that promote the use of renewable energy resources play a role as a compelling factor in the implementation of supporting policies. Besides the potential of biomass as one of the renewable energy sources to replace fossil fuels, there have been many studies on the determination of the biomass potential due to greenhouse gas emissions stabilizing properties and policies are developed up on this [7–9].

Biomass residues are directly linked with crop yield during agricultural crop production. The more the crop production, the more the residues of crop since the residues make up a certain percentage of the crop. The biomass residues mentioned here are residues which remains after the main crop harvesting in agriculture by cutting and pruning of stem, straw, stalk, leaf, branches, etc. The biomass energy potential can be calculated if these parameters are known. Crop yield and biomass residues, as well as their

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agronomic development, is also dependent on environmental factors such as climate and soil [10]. Many studies have been carried out on the potential of biomass resources at the world [11–13]. These studies to calculate agricultural biomass residues and their potential, which explored different results, have been published in the literature in the last 20 years. For example, findings from previous studies in Canada, showed that sustainable extraction rates of agricultural residues could vary from 44 to 64% [18]. Estimation of the residue to product ratio should be as much as specific as possible according to studied area. However, since these data are rarely available at global and local scale. This research has covered many specific studied areas for agricultural residues around the World to reflect more agricultural and climatic conditions. Furthermore, a new approach to mathematical model was also defined and used to calculate the biomass energy potential for agricultural biomass residues in Turkey.

In the first part of the study, studies on agricultural biomass residues were examined from different countries of the world. In these studies, important structural and physical properties of different type of crops for obtaining biomass residues energy were determined. These properties were residue-crop ratio, residue moisture and residue energy value. Based on these average values, it was possible to determine which agricultural crops has the higher biomass residues and energy potential. In the second part of the study, theoretically, the available energy potential values were calculated for Turkey utilizing average values, such as biomass residue moisture, residue product ratio and energy value from different countries at local and global scale. In particular, agricultural crops that yields higher biomass and hence energy potential were explored. It is important to know biomass sources potential in order to develop renewable energy policies and make planning based on biomass residues potential. In this study, a variety of regional and global bioenergy sources and their local implementation differences were reflected in the calculations. Knowing the areas where crops are intensively cultivated and their residue types, residue properties as well as energy capacities will be important in terms of the right choice of locations for possible renewable biomass power plants to be installed and sustainability of energy supplies.

2. Materials and methods

2.1. Characterization of agricultural biomass residues

The quantities and characteristics of the agricultural crop residues resulting from crop production vary depending on many factors. Local climatic conditions, differences in agricultural practices (such as cutting height during harvest), crop type and production values of crop should be taken into account [10,13,14]. Thus, properties of agricultural crops and amounts grown in different regions may be different. In this study, studies related to agricultural biomass residues in the world's different regions were analyzed. Data related to agricultural residues that was measured and used in 16 studies made in European Union (EU), Turkey (TR), India (IN), Cameroon (CM), China (CN), Pakistan (PK), Greece (GR), Nigeria (NG) and Uganda (UG) were also evaluated. Ratio of product residue (RPR), the degree of residue moisture (M) and lower heating values of dry matter of residue (LHV) were considered in determining the agricultural crop biomass energy potential due to agricultural production [14]. These values were given in Table 1.

In Table 1, agricultural arable field crops in the first column, residue types resulting from these field crops after harvest in the second column, and ratio of production residues, moisture and lower heating values of these crops for different countries were given in other columns, respectively. According to analysis of Table 1, the most prominent feature was the big differences in the amount of residues among countries. For example, residue straw in wheat production ranges between 0.50 and 1.75. The ratio of wheat straw for European Union countries was given as 0.5, 0.9, 1.0, and 1.66 respectively. These values were different for TR with 1.0, 1.5 for IN, 1.2 for CM, 1.37 for CN and 1.75 for PK. Wheat straw moisture values in these different countries were close to each other and changed between 10 and 15%. However, the lower heating values of wheat straw was varied between 13.9 and 19.5 MJ/kg; these values were 13.9 MJ/kg for PK, 15.6 MJ/kg for CM, 17.9 MJ/kg for TR and 17.5–19.5 MJ/kg for EU countries, respectively.

As shown in Table 1, some agricultural crops, such as corn, sunflower, cotton, maize and soybean have more production residues respectively. Although it varied by country to country; residual ratios also varied between 0.7 and 2.5 in corn, 0.7–3.5 in sunflower, 1.1–3.5 in cotton, 1.4–3.0 in millet and 0.76–3.50 in soybean.

Residual properties of horticultural plants obtained from conducted studies in EU, TR, GR, CM and UG were given in Table 2. Prunings residues generated in production of the cultivated horticultural crops constituted the majority of the residues. Overall residue ratio of pruning residues ranged between 0.2 and 0.5 and moisture level ranged between 35 and 45%. Their lower heating values were estimated around 17–20 MJ/kg respectively. Horticultural plants that has the highest rate of pruning residues were found to be in olives (1:14 to 1:25) and nuts (3.34), respectively.

2.2. Study area, data sources, data preperation

Turkey between 36 and 42° northern latitude and 26–45° east meridians, being part of the majority of the Asian continent, and located in the small part of the European continent, covers 783.562 km^2 area [31]. Turkey is located between temperate and subtropical zone and is a country dominated by Mediterranean, Black Sea and continental climate type. Turkey's climate shows different properties depending on the geographical location and landforms. More temperate climate is seen in the coastal areas with the impact of see. Summers hot and dry, winters are mild and rainy, vegetation are shrubs under the Mediterranean climate in the Aegean and Mediterranean coasts. Precipitation is seen in all seasons and natural vegetation is forest in Blacksea climate. Turkey's midlands, Central Anatolia, East Anatolia and Southeast Anatolia regions, has a continental climate [32].

Turkey's total agricultural area is 23.95 million hectares for 2015. Of the total area of cultivated land, 15.74 million hectares of cereals and other plants, 4.11 million hectares of fallow land, 808 thousand hectares of vegetable gardens area, 3.28 million ha of fruit and spice crops area and 4.6 thousand ha ornamental field constitutes respectively [33]. Production quantities in 2015 are increased by 10.2% in grains and other crops, by 3.9% in fruits and by 3.4% in vegetables compared to the previous year. Production quantities were recorded approximately 65.5 million tons in grains and other crops, 29.6 million tons in fruits and 17.8 million tonnes in vegetables in 2015 [34]. Turkey produced 64% of the world hazelnut production, 26.7% of the world fig production, 23% of world quince production, 21.5% of the world cherry production, 19% of the world apricot production and 13% of the world cherry production according to 2013 data [34]. Turkey's population is 78,741,053 according to data of 2015 [35]. Employed number in the agricultural sector decreased from 46% to 24.7% from 1990 until today. One out of every four people in Turkey are employed in the agricultural sector [36]. GDP (Gross Domestic Product) were 8.1%, 27.7% and 64.2% in agriculture, industry, service sector respectively according to 2015 data [37]. According to TurkStat 2015 data (Turkish Statistic Institute), Turkey's per capita GDP value

Table 1
Agricultural arable field crops residue properties in different countries.

Agricultural crops	Residue types	Ratio of Product Residue (RPR)	Country [Reference]	Moisture (M) (%)	Country [Reference]	Lower Heating Values (LHV) (MJ/kg)	Country [Reference]
Wheat	Straws	0.50–1.75	UE- [14]; TR- [15,16]; IN- [10]; CM- [17,18]; CN- [19–21]; PK- [22,23]; CN- [24]; TR- [11]	10–15	UE- [14], CM- [18]; CN- [24]; GR- [25]	13.9–19.5	PK- [22,23]; CM- [18]; UE- [14]; TR- [15,16]; TR- [11]; GR- [25]
Barley	Straws	1.08–1.36	UE- [14]; TR- [11]	11–15	UE- [14]; GR- [25]	17.5–19.5	UE- [14]; GR- [25]; TR- [11]
Avena	Straw	0.34–0.39	UE- [14]	9–14	UE- [14]	17.5–19.5	UE- [14]; GR- [25]
Rye	Straw	0.99	TR- [11]	15	TR- [11]	17.4	TR- [11]
Maize (Corn)	Stalks-cobs	0.70–2.50	UE- [14]; TR- [15,16]; IN- [10]; CN- [15]	40–65	UE- [14]	13.8–17.6	UE- [14]; TR- [15,16]
	Stalks	1.50–2.25	CM- [17,18]; CN- [19–21]; UG- [26]; TR- [11]; NG- [27]	15–17	CM- [18]; UG- [26]; CN- [24]	15.5–18.5	CM- [18]; NG- [27]; PK- [22,23]; UG- [26]; GR-https://www.google.com/ [25]; TR- [11]
	Cobs	0.27–0.86	NG- [27]; PK- [22,23]; TR- [11]	7–9	UG- [26]; GR- [25]; CN- [24]	12.6–18.4	NG- [27]; PK- [22,23]; UG- [26]; GR- [25]; TR- [11];
Rapeseed	Stalks	1.60–1.80	UE- [14]; IN- [10]	45	UE- [14]	17.1	TR- [28]
Sunflower	Stems and Leaves	0.70–3.50	UE- [14]; IN- [10]; TR- [11]; TR- [15,16]	14–40	UE- [14]; GR- [25]	13.2–17.9	TR- [15,16]; TR- [11]; UE- [16]; GR- [25]
Cotton	Stalks	1.10–3.50	TR- [11]; UG- [26]; PK- [22,23]; CN- [19,20,24]; IN- [13]; TR- [15,16]	6–12	GR- [25]; UG- [26]; CN- [24]	14.6–18.2	PK- [22,23]; TR- [15,16]; UG- [26]; GR- [25]; TR- [11]
Sugar beet	Leaves	0.12–0.14	TR- [15,16]	75	GR- [25]	15.5–17.7	TR- [15,16]; GR- [25]
Sugarcane	Top and leaves	0.10–0.30	IN- [13]; CN- [24]; CN- [19–21]; PK- [22,23]; UG- [26]	50–63	UG- [26]; CN- [24]	15.8	PK- [22,23]; UG- [26]
	Bagasse	0.10–0.30	CN- [24]; IN- [13]; PK- [22,23]; UG- [26]; CM- [17,18]	50–75	UG- [26]; CN- [24]; CM- [18]	8.6–15.4	PK- [22,23]; CM- [18]; UG- [26]
Rice (Paddy)	Straws	0.45–1.75	UG- [26]; CN- [19,20,24]; IN- [13]; TR- [11]; CM- [17,18]; NG- [27]; PK- [22,23]	10–25	UG- [26]; CM- [18]; GR- [25]; CN- [24]	8.8–16.0	UG- [26]; GR- [25]; PK- [22,23]; CM- [18]; NG- [27]
	Husks	0.20–0.27	UG- [26]; NG- [27]; TR- [11]; PK- [22,23]; IN- [13]; CN- [24]	10–13	CN- [24]; UG- [26]	12.9–19.9	TR- [11]; UG- [26]; PK- [22,23]; NG- [27]
Millets	straw	1.40–3.00	UG- [26]; PK- [22,23]; IN- [13]; NG- [27]; CM- [17,18]	15	CM- [18] 12-UG [26]	12.5–15.5	PK- [22,23]; UG- [26]; CM- [18]; NG- [27]
Soybean	Straw	0.76–3.50	TR- [11]; IN- [13]; CN- [24]; UG- [26]; PK- [22,23]	15	UG- [26]; CN- [24]	14.9–19.4	PK- [22,23]; UG- [26]; TR- [11]
Sorghum	Stalks	1.40–2.62	UG- [26]; IN- [13]; NG- [27]; CM- [17,18]	15	UG- [26]; CM- [18]	13.0–17.0	UG- [26]; NG- [27]; CM- [18]
Groundnut	Shells	0.20–0.52	IN- [13]; NG- [27]; PK- [22,23]; TR- [11]	8	UG- [26]	11.2–16.9	UG- [26]; NG- [27]; PK- [22,23]
	Straws-haulms	2.10–2.30	UG- [26]; NG- [27]; IN- [13]	15	UG- [26]	14.4–15.2	NG- [27]; PK- [22,23]
Chickpea	Straws	1.30	IN- [13]		–	–	–
Beans	Stems and Leaves	1.40–1.50	UG- [26]; CN- [19–21]	5	UG- [26]	14.7	UG- [26]
Hemp	Stems and Leaves	2.50	CN- [19–21]; CN- [24]				
Sesame	Trash	2.0.	UG- [26]	6	UG- [26]	15.5	UG- [26]
Cassava	Stalk	0.06	NG- [27]			13.4	NG- [27]
	Peels	0.25	NG- [27]			10.6	NG- [27]
	Stems and peels	0.40	UG- [26]	20	UG- [26]	13.1	UG- [26]
Yam	Peelings	0.25	NG- [27]			10.6	NG- [27]
Sweet potato	Vines and peels	0.40	UG- [26]	20	UG- [26]	16.0	UG- [26]
Tobacco	Stems	2.27	TR- [11]	85	GR- [25]	16.1	GR- [25]; TR- [11]
Tubers		0.50	CN- [24]	–	–	–	–

calculated as 9.261 USD and realized as 0.761 Human Development Index for the same year [38] (Table 3). Rapid population growth, energy consumption is increasing rapidly due to urbanization and industrialization in Turkey. Turkey 120 Mtoe primary energy supply was provided from 31% natural gas and 28% oil, 18% of imported coal, 11% of lignite, 4% of hydroelectric power, 4% of wood and other renewable sources [39,40] (Fig. 1).

As shown in Table 3, a large portion of Turkey energy requirements has met through imports and dependency on foreign sources that continues to increase every year. Turkey provides around 88% of the energy consumption from the fossil energy sources. Turkey has sufficient resources and potential in terms of renewable energy sources such as solar, wind, geothermal, hydro and biomass [13]. Biomass residues derived from forestry, agricultural and animal resources as a source of energy, household and urban waste is spread to all regions in Turkey. Turkey due to a wide variety of species in terms of biomass energy resources has great potential [43]. Annual crop biomass residues, horticultural plant residues are in the first place amongs the biomass resources. Agricultural crop statistics was the main data source for calculating agricultural biomass residue potential of Turkey [33].

Table 2
The properties of horticultural crop residues for different countries.

Horticultural crops	Residue types	Ratio of Product Residue (RPR)	Country [Reference]	Moisture (M) (%)	Country [Reference]	Lower Heating Values (LHV) (MJ/kg)	Country [Reference]
Stone fruit (Peach)	Prunings	0.30–0.50	UE- [14]	35–45	UE- [14]; GR- [25]	18.0–18.4	UE- [14]; GR- [25]
Pome fruit (Pear)	Prunings	0.14–0.30	UE- [14]	35–40	UE- [14]; GR- [25]	18–18.4	UE- [14]; GR- [25]
Almond	Prunings	0.60–0.61	UE- [14]; TR- [11]	35–40	UE- [14]; GR- [25]	18–18.4	UE- [14]; GR- [25]; TR- [11]
	Shells	0.55	TR- [11]	–	–	19.38	TR- [11]
Pistachio	Prunings	0.40–0.48	UE- [14]; TR- [11]	35	UE- [14]	18–19	UE- [14]; TR- [11]
	Shells	0.33	TR- [11]	–	–	19.26	TR- [11]
Fig22	Prunings	0.21	UE- [14]	55	UE- [14]	18–18.4	UE- [14]
Core 23	Prunings	1.57–2.00	UE- [14]	35	UE- [14]	18–18.4	UE- [14]
Orange	Prunings	0.20–0.50	TR- [11]; UE- [14]	35–45	UE- [14]; GR- [25]	17.6–18.5	TR- [11]; GR- [25]
Clementine	Prunings	0.27–0.50	UE- [14]	35–45	UE- [14]		
Mandarin	Prunings	0.17–0.40	TR- [11]; UE- [14]	35–45	UE- [14]; GR- [25]	17.6	TR- [11]; GR- [25]
Grapefruit	Prunings	0.11	TR- [11]			17.6	TR- [11]
Lemon	Prunings	0.19–0.40	TR- [11]; UE- [14]	35–45	UE- [14]; GR- [25]	17.6	TR- [11]; GR- [25]
Bergamot 24	Prunings	0.39–0.50	UE- [14]	35–45	UE- [14]	–	–
Vineyards	Prunings	0.39–0.45	UE- [14]	40–50	GR- [25]; UE- [14]	16.8–19.2	GR- [25]; UE- [14]
Olive	Prunings	1.14–1.25	UE- [14]	35–45	UE- [14]	18.1–18.8	TR- [11]; UE- [14]
	Pomace	0.55	TR- [11]	40–65	TR- [29]	20.69	TR- [11]
Walnut	Shells	0.66	TR- [11]	–	–	20.18	TR- [11]
	Prunings	0.44		–	–	19.0	
Hazelnut	Shells	0.87	TR- [11]	13	TR- [30]	19.3	TR- [11]
	Prunings	3.34		40	TR- [11]	19.0	
Coconut	Shells	0.60	CM- [15,18]	10	CM- [18]	10.6	CM- [18]
Apricot	Prunings	0.19	TR- [11]	40	GR- [25]	19.3–20.8	TR- [11]; GR- [25]
	Core	0.33	TR- [11]	–	–	–	–
Banana	Stalk and peels	2.00	UG- [26]	85	UG- [26]	13.1	UG- [26]
Cocoa	Pods, husk	1.00	CM- [17,18]	15	CM- [17,18]	15.5	CM- [17,18]
Coffee	Husk	1.00–2.10	UG- [26]; CM- [17,18]	15	CM- [18]; UG- [26]	12.6–15.9	CM- [18]; UG- [26]
Apple	Prunings	–	–	40	GR- [25]	17.8	GR- [25]
Cherry	Prunings	–	–	40	GR- [25]	21.7	GR- [25]
Sour cherry	Core	0.35	TR- [11]	–	–	21.8	TR- [11]
	Prunings	0.19		–	–	19.0	

2.3. Selection of agricultural crops for biomass residues

Annual production capacity of 70,000 tons in arable field crop and more than 75,000 tons of horticultural crops were selected. The total 30 different plants in two categories were taken into account to evaluate the biomass capacity in Turkey. These are given below;

(i) Arable field crops:

Wheat, Sugar beet, Barley, Maize, Cotton, Sunflower, Rice, Rye, Avena, Beans, Soybean, Groundnut, Rapeseed, Tobacco.

(ii) Horticultural plants:

Grapes, Apples, Oranges, Olive, Mandarin, Lemon, Apricot, Hazelnut, Peach, Cherry, Pear, Fig, Banana, Grapefruit, Pistachio, Almond.

Data collected on a global scale were analyzed by taking into account crop production patterns in different countries and selected crop residue types (straw, stalk, husk, stem-leaf, pruning etc.), with their relative moisture content as well as residue-production-ratio and their lower calorific values. Average values that were calculated based on minimum and maximum values of physical properties for agricultural originated arable and horticultural field crop residues were given in Tables 1 and 2. Amount of crop product (CP), residual moisture content (M), ratio of product residue (RPR), lower heating value (LHV), and availability ratios (A) were used in the mathematical model which were given in Table 4 and Table 5.

The available biomass energy potential from agricultural production in Turkey was calculated in three stages and flow diagram is shown in Fig. 2.

2.4. Theoretical biomass potential calculation

Theoretical Biomass Potential (TBP) shows the total annual production of biomass that obtained from agricultural residues. The value of TBP varies depending on plant's annual production amounts and residue production ratio (RPR) and moisture content (M). Theoretical biomass potential of plant residues can be calculated by the following equation using the data on Tables 4 and 5:

$$TBP = \sum_{i=1}^{n} CP(i) \times RPR(i) \times \left[\frac{100 - M(i)}{100}\right] \quad (1)$$

Where, CP (i) as the amount of product produced per year as tons RPR (i) residues - production ratio and M (i) indicates the relative moisture content in percentage terms. TBP (as i.th) is used in residue amount calculation obtained from dried plant. RPR = 2, shows 2 tons of residue can be obtained from every 1 tons of plant

Table 3
Socio-economic and energy indices and emissions of greenhouse gas in Turkey.

Parameters	Unit	Value	Ref. year	Reference
Social indices				
Population	Million	78.74	2015	[35]
Population growth rate	%	1.34	2015	[35]
GDP	Billion USD	718.22	2015	[41]
Agriculture sector	%	8.1	2015	[37]
Industrial sector	%	27.7	2015	[37]
Service sector	%	64.2	2015	[37]
GDP real growth rate	%	4	2015	[35]
GDP Per capita (PPP)	USD	9261	2015	[41]
Human development index	–	0.761	2015	[38]
Poverty rate	% of total population	1.6	2014	[41]
Energy indices				
Energy production	Mtoe	32.35	2013	[39]
Total primary energy supply (TPES)	Mtoe	116.49	2013	[39]
TPES/population	toe/capita	1.54	2013	[39]
Net energy imports	Mtoe	86.67	2013	[39]
Total electricity (power) generation	TWh	252	2014	[42]
Coal power	%	30.2	2014	[42]
Natural gas power	%	47.9	2014	[42]
Hydro power	%	16.1	2014	[42]
Renewable energy and wastes power	%	4.9	2014	[42]
Liquid fuel power	%	0.9	2014	[42]
Greenhouse gas emissions				
Carbon dioxide emissions (emissions from fuel combustion only)	Mt of CO_2	283.84	2013	[39]
Carbon dioxide emissions/TPES	t CO_2/toe	2.44	2014	[39]
Carbon dioxide emissions/population	t CO_2/capita	3.75	2014	[39]

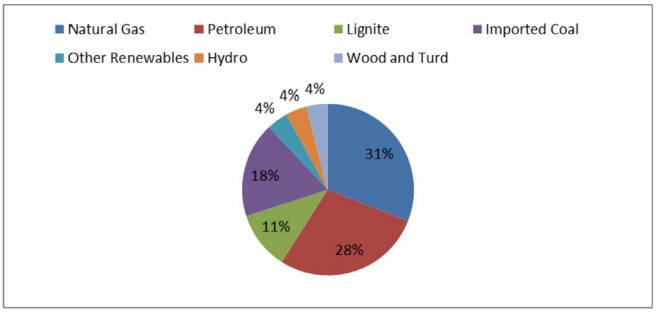


Fig. 1. Turkey's primary energy supply changes according to the resources.

[44]. Residue biomass amounts changes from region to region depending on agricultural practices and alternative usage of residues. For example, when the rice is cut by about 5 cm above the ground while RPR become 1.75; if it is cut from wrong place which is more than 5 cm during harvest, RPR could be reduced by up to 0.452. Agricultural crop biomass potential can be solved in detail defining the geographic boundaries in equation (1) [44].

2.5. Theoretical energy potential calculation

The following equation indicated below was used to calculate the theoretical energy potential (TEP) of dry biomass:

$$TEP = \sum_{i=1}^{n} TBP(i) \times LHV(i) \quad (2)$$

where, LHV (i) th plant that shows the lower heating value of plant as MJ/kg.

2.6. Available energy potential calculation

The equation indicated below was used to calculate the available energy potential (AEP) of arable field and horticultural crop residues:

$$AEP = \sum_{i=1}^{n} TEP(i) \times A(i) \quad (3)$$

A(i) is the available residue ratio as percentage in this equation.

Theoretical biomass energy potential were calculated in many literature in similar ways (10, 11, 14, 26, 27, 44).

3. Results and discussion

The theoretical biomass potential, theoretical energy potential and available energy potential of agricultural biomass residues were calculated in arable and horticultural field in 2015 in Turkey.

3.1. Field crops biomass and energy potential

In this year, 59.432 kilotonne of agricultural crop was recorded in field cultivation. More details concerning the production of agricultural crops produced in Turkey in 2015 and residues obtained were given in Table 6 and Fig. 3. This product of the total theoretical potential of biomass can now be obtained as dry substance (TBP) which was calculated to be 54.036 kilotonne. Wheat, maize and barley ranked in the first three place with 22,218, 13,463 and 8491 kilotonne of dry biomass residue from field production, respectively. Wheat straw, maize and barley stalks were of great importance among the arable field type residues in Turkey. Theoretical potential of this field based residues was estimated approximately 700,000 TJ, and the available energy potential was about 180,000 TJ. The theoretical energy potential of all residue was found to be 908,119 TJ (TEP- 21,690 ktoe) and available energy potential was determined as 298,955 TJ (AEP -7.140 ktoe), respectively.

As shown in Table 6 and Fig. 3, the limit values of the biomass characteristics were taken into account and the minimum and maximum potential values were determined along with the

Table 4
Selected field crops production, residue types, moisture, residue-product ratio, the lower heating value, availability rates.

Agricultural crops (i)	Amount of Crops Product (CP)[a] (kilotonne)	Residue types	Moisture (M)[b](%)		Ratio of Product Residue (RPR)[b]		Lower Heating Value (LHV)[b](MJ/kg)		Availability (A)[c] (%)
			Range	Avg.	Range	Avg	Range	Avg.	
Wheat	22,600	Straws	10–15	13	0.50–1.75	1.13	13.9–19.5	16.7	15
Sugarbeet	16,462	Leaves	75	75	0.12–0.14	0.13	15.5–17.7	16.6	15
Barley	8000	Straws	11–15	13	1.08–1.36	1.22	17.5–19.5	18.5	15
Maize	6400	Stalks	15–17	16	1.50–2.25	1.88	15.5–18.5	17.0	60
		Cobs	7–9	8	0.27–0.86	0.57	12.6–18.4	15.5	60
Cotton	2050	Stalks	6–12	9	1.10–3.50	2.30	14.6–18.2	16.4	60
Sunflower	1681	Stems- Leaves	14–40	27	0.70–3.50	2.10	13.2–17.9	15.6	60
Rice	920	Straws	10–25	18	0.45–1.75	1.10	8.8–16.0	12.4	60
		Husks	10–13	12	0.20–0.27	0.24	12.9–19.9	16.4	80
Rye	330	Straws	15	15	0.99	0.99	17.4	17.4	15
Avena	250	Straws	9–14	12	0.34–0.39	0.37	17.5–19.5	18.5	15
Beans	235	Stems- Leaves	5	5	1.40–1.50	1.45	14.7	14.7	15
Soybean	161	Straws	15	15	0.76–3.50	2.13	14.9–19.4	17.2	60
Groundnut	148	Shells	8	8	0.20–0.52	0.36	11.2–16.9	14.1	80
		Straws-haulms	15	15	2.10–2.30	2.20	14.4–15.2	14.8	80
Rapeseed	120	Stalks	45	45	1.60–1.80	1.70	17.1	17.1	15
Tobacco	75	Stems	85	85	2.27	2.27	16.1	16.1	60
TOTAL	**59,432**	-		-		-		-	-

[a] Arable field crops production quantities produced annually [33].
[b] Numerical data is calculated as the average of the lower and upper values given in Table 1.
[c] Availability rates are taken from the source numbered [11].

Table 5
Selected horticultural crops production, residue types, moisture, residue-product ratio, the lower calorific value, availability rates.

Agricultural crops (i)	Amount of Crops Product (CP)[a] (kilotonne)	Residue types	Moisture (M)[b](%)		Ratio of Product Residue (RPR)[b]		Lower Heating Value (LHV)[b](MJ/kg)		Availability (A)[c] (%)
			Range	Avg.	Range	Avg.	Range	Avg.	
Grapes	3650	Prunings	40–50	45	0.39–0.45	0.42	16.8–19.2	18.0	80
Apples	2570	Prunings	40	40	0.19	0.19	17.8	17.8	80
Oranges	1816	Prunings	35–45	40	0.20–0.50	0.35	17.6–18.5	18.1	80
Olive	1700	Prunings	35–45	40	1.14–1.25	1.20	18.1–18.8	18.5	50
Mandarin	1156	Prunings	35–45	40	0.17–0.40	0.29	17.6	17.6	80
Lemon	750	Prunings	35–45	40	0.19–0.40	0.30	17.6	17.6	80
Apricot	680	Prunings	40	40	0.19	0.19	19.3–20.8	20.0	80
Hazelnut	646	Prunings	40	40	3.34	3.34	19.0	19.0	80
Peach	642	Prunings	35–45	40	0.30–0.50	0.40	18.0–18.4	18.2	80
Cherry	535	Prunings	40	40	0.19	0.19	21.7	21.7	80
Pear	463	Prunings	35–40	38	0.14–0.30	0.22	18–18.4	18.2	80
Fig	300	Prunings	55	55	0.21	0.21	18–18.4	18.2	80
Banana	270	Stalk-peels	85	85	2.00	2.00	13.1	13.1	80
Grapefruit	250	Prunings	40	40	0.11	0.11	17.6	17.6	80
Pistachio	144	Prunings	35	35	0.40–0.48	0.44	18.0–19.0	18.5	80
Almond	80	Prunings	35–40	38	0.60–0.61	0.60	18–18.4	18.2	80
TOTAL	**15,652**	-		-		-		-	-

[a] Horticultural crops production quantities produced annually [33].
[b] Numerical data is calculated as the average of the lower and upper values given in Table 1.
[c] Availability rates are taken from the source numbered [11].

average potentials while the theoretical energy potentials was calculated. The biomass residue properties of crops (moisture, ratio of product residue and residual energy value) were shown the differences among the countries as shown in Tables 1 and 4. Therefore, the values obtained in energy potential calculations of agricultural crops can vary within wide range of limits. Moreover, besides the geography where the plants are located, the characteristics such as the yield value of the crop and the harvesting method also affect the amount of residues obtained from the crop. For example, when calculating the energy potential of the wheat straw, the energy value of 133,510 TJ was calculated when the moisture, ratio of product residue and energy values of the straw were taken as minimum. When the average and maximum values of the same characteristics were taken into consideration, 371,041 TJ and 694,103 TJ energy potential results can be obtained, respectively.

Agricultural biomass residues can be considered for largely grazing animals, animal feeding, using under the animal for bed, burning pruning residues and in the form of manure mixed with straw of animal waste for energy. Moreover, especially field residues are left in the harvest for organic materials to meet the requirements of the soil, it can also be used to improve the water-holding capacity and erosion control. Because of the reasons mentioned above, the ability to use agricultural residues for energy purposes is remaining low in Turkey.

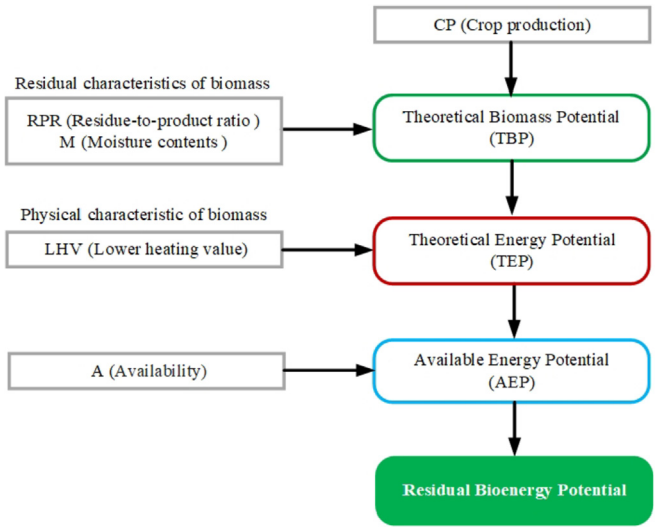


Fig. 2. Flow diagram for determining the energy potential calculation of agricultural residues.

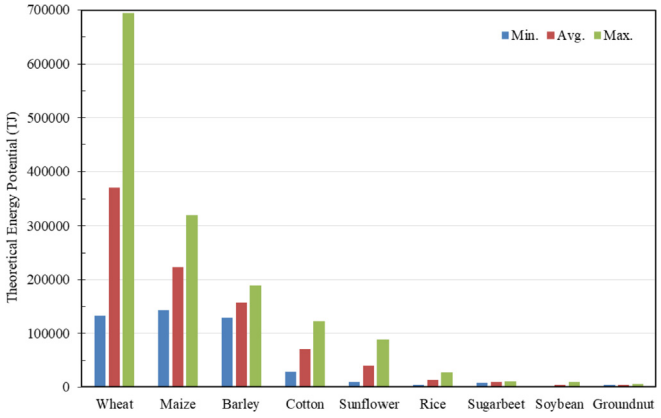


Fig. 3. Comparision of the calculated TEP for individual types of arable field crop biomass.

3.2. Horticultural crops biomass and energy potential

15.652 kilotonne of crop was produced in horticultural farming in 2015 in Turkey. Horticultural plants produced in Turkey in 2015 and the details of their prunings values were given in Table 7 and Fig. 4. The total theoretical potential of biomass that can be obtained as dry material (TBP) was calculated as 4.986 kilotonne. The first three ranking horticultural plants as dry biomass were listed as Hazelnut (1295 kilotonne), Olive (1224 kilotonne) and Grapes (843 kilotonne) respectively. The theoretical energy potential of all orchard pruning residues was about 90.354 TJ (TEP- 2158 ktoe) and available energy potential was determined as 65,491 TJ (AEP – 1564 ktoe). Amongs the Turkey fruit pruning residues, hazelnut, olive and grapes were of paramount importance respectively. The theoretical potential of this residues was estimated about 62,000 TJ, while the available potential was about 43,000 TJ.

3.3. Total agricultural biomass and energy potential

As it can be seen in Table 7 and Fig. 4, the limit values of the biomass properties were taken into consideration and the minimum and maximum potential values were determined besides the average potentials while the theoretical energy potentials were calculated. Biomass residue properties (moisture, ratio of product residue and residual energy value) were shown differences from country to country as seen in Tables 2 and 6. Therefore, the values obtained in energy potential calculations of crops can vary within wide range of limits. Moreover, besides the geography where the plants are located, the characteristics such as the yield value of the crop and the harvesting method also affect the amount of residues obtained from the crop. For example, the energy potential of 19,293 TJ was calculated when the moisture, ratio of crop residue ratio and energy values were taken as minimum while calculating the energy potential of the residues obtained by pruning of the olive tree. When the average and maximum values of the same characteristics were taken into consideration, 22,644 TJ and 25,968 TJ energy potentials can be realized, respectively.

Fig. 5, summarizes the total of the theoretical energy potential

Table 6
Features and energy potential of the agricultural biomass residues generated in field production in Turkey.

Agricultural crops (i)	Amount of Crops product (CP)[a] (kilotonne)	Residue types	Theoretical Biomass Potential (TBP) (kilotonne dry mass)			Theoretical Energy Potential (TEP) (TJ)			Available Energy Potential (AEP) (TJ)		
			Min.	Avg.	Max.	Min.	Avg	Max.	Min.	Avg.	Max.
Wheat	22,600	Straws	9605	22,218	35,595	133,51	371,041	694,103	20,026	55,656	104,115
Sugarbeet	16,462	Leaves	494	535	576	7655	8881	10,198	1148	1332	1530
Barley	8000	Straws	7344	8491	9683	128,520	157,087	188,822	19,278	23,563	28,323
Maize (Corn)	6400	Stalks	7968	10,107	12,240	123,504	171,817	226,440	74,102	103,090	135,864
		Cobs	1572	3356	5119	19,813	52,020	94,184	11,888	31,212	56,510
Cotton	2050	Stalks	1984	4290	6745	28,966	70,367	122,750	17,380	42,220	73,650
Sunflower	1681	Stems- Leaves	706	2577	4942	9319	40,201	88,464	5591	24,121	53,078
Rice	920	Straws	311	830	1449	2737	10,290	23,184	1642	6174	13,910
		Husks	160	194	224	2065	3187	4448	1652	2549	3558
Rye	330	Straws	278	278	278	4832	4832	4832	725	725	725
Avena	250	Straws	73	81	89	1279	1506	1730	192	226	260
Beans	235	Stems- Leaves	313	324	335	4594	4759	4923	689	714	738
Soybean	161	Straws	104	291	479	1550	5014	9292	930	3008	5575
Groundnut	148	Shells	27	49	71	305	691	1197	244	553	958
		Straws-haulms	264	277	289	3804	4096	4398	3043	3277	3518
Rapeseed	120	Stalks	106	112	119	1806	1919	2031	271	288	305
Tobacco	75	Stems	26	26	26	411	411	411	247	247	247
TOTAL	**59,432**	**-**	**31,335**	**54,036**	**78,259**	**474,670**	**908,119**	**1,481,41**	**159,05**	**298,955**	**482,864**

[a] Arable field crops production quantities produced annually [33].

Table 7
The features and energy potential of the residues generated in the horticultural farming in Turkey.

Agricultural crops (i)	Amount of Crops Product (CP)[a] (kilotonne)	Residue types	Theoretical Biomass Potential (TBP) (kilotonne dry mass)			Theoretical Energy Potential (TEP) (TJ)			Available Energy Potential (AEP) (TJ)		
			Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Grapes	3650	Prunings	712	843	986	11,957	15,177	18,922	9566	12,141	15,137
Apples	2570	Prunings	293	293	293	5215	5215	5215	4172	4172	4172
Oranges	1816	Prunings	200	381	590	3516	6903	10,919	2813	5522	8735
Olive	1700	Prunings	1066	1224	1381	19,293	22,644	25,968	9646	11,322	12,984
Mandarin	1156	Prunings	108	194	301	1902	3418	5290	1522	2735	4232
Lemon	750	Prunings	78	135	195	1379	2376	3432	1103	1901	2745
Apricot	680	Prunings	78	78	78	1496	1550	1612	1197	1240	1290
Hazelnut	646	Prunings	1295	1295	1295	24,597	24,597	24,597	19,678	19,678	19,678
Peach	642	Prunings	106	154	209	1907	2804	3839	1525	2243	3071
Cherry	535	Prunings	61	128	61	1323	1323	1323	1059	2229	1059
Pear	463	Prunings	39	64	90	700	1168	1661	560	934	1329
Fig	300	Prunings	28	28	28	510	516	521	408	413	417
Banana	270	Stalk-peels	81	81	81	1061	1061	1061	849	849	849
Grapefruit	250	Prunings	17	17	17	290	290	290	232	232	232
Pistachio	144	Prunings	37	41	45	674	762	854	539	610	683
Almond	80	Prunings	29	30	32	518	550	584	415	440	467
TOTAL	**15,652**	**-**	**4228**	**4986**	**5682**	**76,338**	**90,354**	**106,088**	**55,284**	**65,491**	**77,080**

[a] Horticultural crops production quantities produced annually [33].

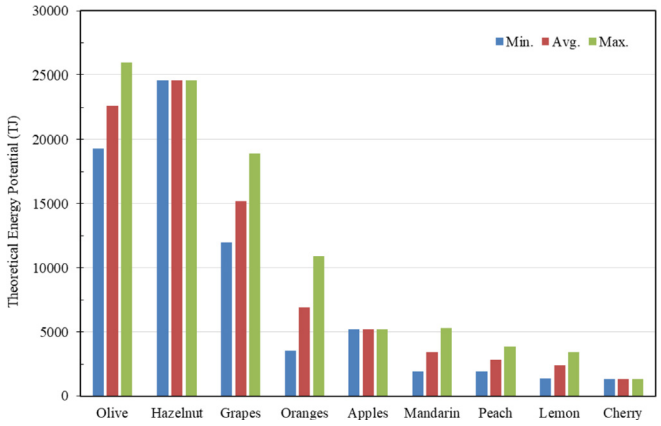


Fig. 4. Comparision of the calculated TEP for indivhttps://www.google.com/idual types of horticultural crop biomass.

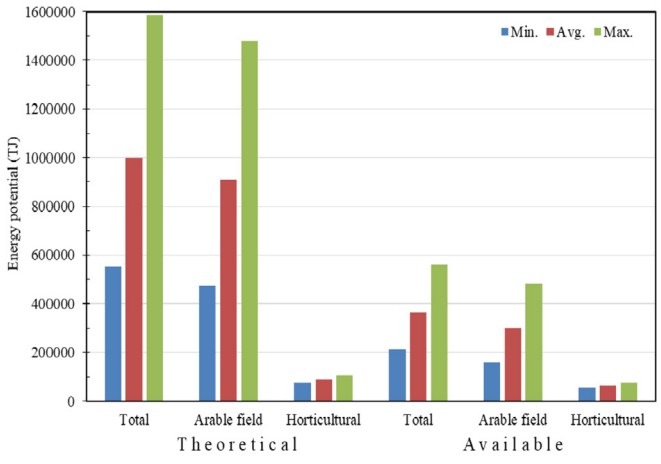


Fig. 5. Total TEP and AEP of agricultural (arable field and horticultural) biomass residues.

and available energy potential values resulting from residues in the field and horticulture crop cultivation in Turkey. Again, the potential values were given in terms of the minimum and maximum values, as well as the mean values of the residual properties. The total energy potential of biomass residues derived from Turkey's arable and horticultural farming has a minimum of 551,005 TJ, an average of 998,473 TJ and a maximum of 1,587,495 TJ. The total available energy potential values of agricultural crop residues in Turkey were estimated as 214,332 TJ, 364,446 TJ and 559,944 TJ, respectively.

The available energy potential calculated for field and horticultural product residues was notified as 228,000 TJ and 75,000 TJ respectively by Ozturk and Başçetinçelik in 2002–2003 by year of production in Turkey based on the data in a study [11]. The total biomass energy potential of Turkey is about 33 million tons of oil equivalents (Mtoe). The amount of usable biomass potential of Turkey is approximately 17 Mtoe [45]. Available energy potential was determined as 49 PJ obtained from animal wastes conducted in a study by Onurbaş Avcıoğlu and Türker based on data for production year of 2009 in Turkey [46].

4. Conclusions

The diversity of agricultural crop types is quite high in Turkey due to its climatic conditions and agricultural crop production. In both field production residues as well as the large quantity of fruit production residues are generated. The amount of the residues in the cultivation of field was calculated as 54,036 kilotonne dry mass in arable field crops and 4.986 kilotonne dry mass in horticultural crops. Theoretical energy potential of these biomass residues was estimated about 908.119 TJ (21,690 ktoe) from arable field crops and 90.354 TJ (2158 ktoe) from horticultural crops, respectively. Agricultural crops with leaving higher residues in the field were ranked as; wheat straw, corn stalks and barley stalks, and hazelnut, olive and grapes pruning residues, respectively. The available energy potential of agricultural residues for field crops was estimated around 298,955 TJ (7140 ktoe), and for horticultural crop farming was about 65,491 TJ (1564 ktoe).

Agricultural residue management is extremely important in energy production and utilization of biomass in terms of resolving the environmental problems as the alternative energy source.

There is significant value in terms of development of rural areas and agriculture sector though the contribution to electricity production of established biomass energy capacity but power generation is low in Turkey. Established capacity reached 237 MW in 2013 with 22% compound annual growth rate between 2002 and 2013 years based on biomass resources in electricity generation in Turkey. Biomass installed capacity grew by 49% compared to 2012 [48,49]. As of June 2016, total installed capacity of 70 biogas, biomass, waste heat and pyrolytic oil energy power plants is 385 MW. The total electrical installed capacity rate is 0.5%. Biomass power plants generate 1862 GWh/ year electricity [50].

Continuity and sustainability of biomass residues especially in regions where wheat, corn, barley, nuts, olive and grape growing is important for the selection and establishment of biomass power plants. According to residual bioenergy potentials, the sustainable energy production can be achieved in the strategical locations with right political decisions. Energy can be obtained by pellet or briquette technology for wheat, barley straw, nuts, olives and grape pruning residues with low moisture content. The maize residues with high moisture content and the pulp produced after olive processing are also valuable biomass residues for biogas production. Besides biomass energy conversion methods, composite materials with biomass utilization technologies, manure, compost production, construction materials, chip board, the production of bioproducts such as bioplastics is concerned. It is possible to obtain both higher added value biological products and energy with little residue in biorefinery system. There are agricultural residues potential which will be input to bioproducts in Turkey. However, organizational and financial challenges encountered in agricultural residue collection and transportation, weak public awareness of the utilization of residues, there are a limited number of companies due to the lack of government policies and regulations despite numerous academic studies that are conducted [47]. Unfortunately, agricultural biomass residues are largely used for animal feed or burned directly for basic thermal heating in Turkey. The regulatory and investment potential of biomass energy sources need to be improved in order to ensure both economical and environmental sustainability for Turkey which imports most of the energy needs.

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