Mapping of energy potential through annual crop residues in Turkey

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Abstract: The objective of this study was to determine the annual crop residue potential in terms of types, quantities and mapping in Turkey. The calorific values of agricultural residues were determined by calorimeter according to ASTM D 5865 Standard Test Method for Coal and Coke 2002. In this study, the energy potential of annual crop residues was evaluated by ArcGIS™ which is a geographical information system program. The total amount of unused annual crop residues was approximately 15.24 Mt/a. It was found that the total calorific value of the field crop residues was around 268 PJ/a for the 2012 production period in Turkey. The major crops included in the ratio of the total calorific value were maize (45.81%), wheat (21.30%), sunflower (15.10%) and cotton (18.1%). The amount of CO_2 emitted into the atmosphere can be reduced by 30 Mt/a year through the use of agricultural residues.

Keywords: agricultural residue, exploitable energy potential, mapping, GIS, Turkey

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1 Introduction

Energy will play an important role in the world's future. Energy is central to economic development, and there is a clear correlation between energy consumption and living standards. Energy sources are split into three categories: fossil fuels, renewable sources and nuclear sources. Renewable alternatives have been considered as sources of die rent energies and have led to the development of various research programs[1].

Turkey's geographical location makes it a natural bridge between the energy-rich Middle East and Central Asian regions. Energy is one of the most important development priorities in Turkey. The rapid increase in domestic energy demand has forced Turkey to increase its dependence on foreign energy supplies[2].

Turkey's energy consumption has been growing much faster than its energy production, making Turkey an energy importer. The main indigenous energy resources of Turkey are lignite, hydro and biomass. Turkey's annual biomass energy potential is 32 Mtoe (Million tons of oil equivalents) and biomass potential is 117 Mt/a. The world's biomass production is approximately 985 Mt/a. Biomass meets 26% of primary energy consumption in non-OECD countries, while it accounts for only 3% of primary energy consumption in OECD countries[2]. More than 60% of energy consumption in the country is met by imports and the share of imports continues to grow each year. Therefore, it is critical to meet its energy demand by using domestic non-renewable resources (such as lignite, hard coal, oil and natural gas) and renewable resources[3].

According to investigated results of the potential of renewable energy resources in Turkey, biomass energy ranks second compared to the potential of solar energy. It is 7.9 Mtoe in terms of consumption and its proportion of the total energy consumption comes first by 13%[4].

Conventional biomass plays a considerable role in

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energy production in Turkey. Categorized among the classic biomass resources, wood is used as a major resource for direct cooking and heating in rural regions, but the use of modern biomass for energy production is a rather recent event. Turkey is an agricultural country; moreover, it has important forestry potential, especially in the Central Anatolia, Çukurova and Southern Anatolia regions. Agricultural waste is an important source of biomass due to its high potential[4].

Turkey has always been one of the major agricultural countries in the world. The importance of agriculture is increasing for biomass energy which is one of the major resources in Turkey. Biomass waste materials can be used in Turkey to provide centralized, medium- and large-scale production of process heat for electricity production. Electricity production from biomass has been found to be a promising method for the very near future in Turkey[5].

Fernandes and Costa have made a study using GIS database and statistical analysis for the potential of forest and agricultural residues in a region of Portugal (Marvão). In this study potential of forest and agriculture residues were determined as 2 634 t/a and 7 973 t/a, respectively. According to authors, that means an energy resource of approximately 106 000 GJ annually for Marvão[6].

In another study the potential of agro-industrial residues was determined for the generation of electricity in Spain. These potentials were calculated based on statistical data and then was integrated into a GIS. As a result of the study, the total installed power from agro-industrial residues was determined as 206 MW in Spain[7].

The energy contents of agricultural and forestry residues in Spain, and the potential for the generation of electricity from them were determined in another study made by Gómez et al. According to this study, the combined technical potential of agriculture and forestry residues is 118 PJ/a. The economic potential is 46.3 PJ/a (equivalent to 4.43% of net electric energy generated in Spain in 2008)[8].

The biomass potentials of Central and Eastern European countries under different scenarios were determined by van Dam et al. The scenarios in the study indicated the smallest and the highest biomass potentials are 2.0–5.7 EJ and 11.7 EJ (85% from energy crops, 12% from residues and 3% from surplus forest wood) respectively for all Central and Eastern European countries[9].

Xue at al.[10] developed a model which was built on a geographic information system (GIS) platform for estimate the total biomass of the land-cover forests, annual biomass from forest and agricultural residues, and in particular the production potential of biomass from hybrid poplars over marginal lands in the state of Connecticut, USA. The annual total amounts of biomass from crop and forest residues were calculated about 3 million t in this study. Converted to ethanol energy equivalent, the potential production of biomass from forest and agricultural residues was determined about 104 million L/a.

In another study used GIS by Parent et al.[11], the potential quantity of forest residue available for use in coal-fired power plants in the eastern United States was estimated. The total annual forest residue available to coal plants in the region was 29.4, 40.2 and 48.2 million dry tons. This study indicated that coal usage in the region could be reduced by 2.0%–3.4% and also this reduction could cause lower greenhouse gas emissions by 1.9%–3.1%, NOx emissions by 0.9%–1.5%, and SO_x emissions by 1.6%–2.6%.

Biomass energy includes agricultural residues, domestic waste, fuelwood, animal waste and other fuel derived from biological sources[12].

Agricultural residues are defined as a biomass by-product from the agricultural system and include straws, husks, shells, and stalks[13].

The main objective of the present study was to determine the exploitable real potential of annual crop residues in Turkey. Its major benefits are environmental and are related to the reduction of GHG (Greenhouse Gas) emissions (since crops are considered CO_2 neutral), conservation of natural resources and reduction of fossil fuel consumption. They are complemented by economic benefits (reduction of imported fuel consumption), regional development and investment increases. The estimation of agricultural biomass types, their

geographical distribution and energy content is important in case studies[14].

The most important difference between this study and previous ones is that this one was conducted separately for each province. When previous studies are examined, it is seen that no publication has been published with separate provincial data. Therefore, the separate data of crop production in each province are identified in this study. Most importantly, we determined the agricultural waste of real potential of Turkey's county districts. Thus, we think that the point will be important for all kinds of investments in the future.

2 Materials and methods

Turkey is a country which has a huge agricultural potential with 230.7 km^2 agricultural arable land. About 181.1 km^2 is cultivated and the remaining part is fallow land[4]. Annual crop residues are those that remain in the field after the crops are harvested. The main annual crops in Turkey are cereals, maize, cotton, sunflower and groundnut.

The quantities of residues from the annual crops cultivated in Turkey in tons of dry matter per year, were calculated and estimated using the production data of annual crops from surveys by local authorities of the Ministry of Agriculture and Rural Affairs, Turkish Statistical Institute and available literature for the year 2012[15]. The annual gross potential of agricultural residues was determined using the residue-to-product ratio (RPR). In order to determine the amount of residues produced, it is necessary to know the RPR. The RPR was determined by survey for each crop and each province. For example, the RPR was determined for maize stalks in Adana, Şanlıurfa, Konya and Sakarya as 1.60, 2.50, 1.30 and 1.75, respectively. When RPR data of a particular province could not be obtained, the average RPR data of the agricultural region belonging to this province with the same agricultural properties were adopted. The net potential of residues was determined using the availability of residues. The availability of residues is unused and the completely waste part of residue. The available potential of the agricultural residues in each province of Turkey was calculated based on Equation (1).

$$(AAR)_i = (ACP)_i \times (RPR)_i \times (A)_i \quad (1)$$

where, $(AAR)_i$ is the available amount of agricultural residues of i^{th} crop in ton; $(ACP)_i$ is the amount of crop production in tons; $(RPR)_i$ is the residue-to product ratio of the i^{th} crop and $(A)_i$ is the availability of residues.

The residues are material that is left over in the field after agricultural production. Some agricultural residues are already used for domestic purposes, heating, animal fodder, bedding, etc. Main residues from the production of industrial agricultural products are left over in the field. These species are cotton stalk, maize stalk, sunflower stalk, cereal straw, etc.

The calorific values of agricultural residues were determined by calorimeter according to ASTM D 5865 Standard Test Method for Coal and Coke 2002, and are given in Table 1. The energy potential of residues for each province was calculated by multiplication of the calorific values of a selection of agricultural residues taken from calorific values analyses results (Table 1) with the available residue amount via Equation (2).

$$(EP)_i = (AAR)_i \times (LHV)_i \quad (2)$$

where, $(EP)_i$ is the energy potential of agricultural residues of i^{th} crop in GJ; $(AAR)_i$ is the available amount of agricultural residues of i^{th} crop in tons and $(LHV)_i$ is the lower heating value of air-dry residues of i^{th} crop in MJ/kg.

Table 1 The availability and calorific values of a selection of field crop residues

Crops	Residues	Availability (A) /%	Calorific Value (LHV) /MJ·kg^{-1}
Wheat	Straw	15	17.9
Barley	Straw	15	17.5
Oats	Straw	15	17.4
Maize	Stalk	60	18.5
	Cobs	60	18.4
Cotton	Stalk	60	18.2
Sunflower	Stalk	60	17.4
Groundnuts	Shells	80	20.7

The energy content of the selected products for each province was calculated using the above equations. For each province, the calculated values that were the total amount and the total energy potential of annual crop residues were mapped using ArcGIS™ Software.

3 Results and discussion

The total field crop production and residues in Turkey are given in Table 2.

Table 2 The field crop production and residues of Turkey in 2012

Crops	Field crop production (*ACP*)/kt·a^{-1}	Residues	Total potential of residues (*AAR*)/kt·a^{-1}
Wheat	19 945.01	Straw	3 246.25
Barley	7 105.77	Straw	1 141.68
Oats	204.29	Straw	32.42
Maize	4 034.37	Stalk	5 209.91
		Cobs	1 773.87
Cotton	2 142.77	Stalk	1 499.54
Sunflower	1 263.65	Stalk	2 301.33
Groundnuts	68.51	Shells	38.77
		Total	15 243.77

Major crops included in the ratio of the total residue amount are maize (45.81%), wheat (21.30%), sunflower (15.10%) and cotton (9.84%). When the top 10 provinces are aligned according to the amounts of residue, the alignment is as in Table 3.

Table 3 The top 10 provinces with the highest potential for field crop residues of Turkey

Provinces	Total potential of residues/t·a^{-1}	Share in total residues/%
Şanlıurfa	2 088 880	13.70
Adana	1 386 492	9.10
Konya	1 173 249	7.70
Mardin	1 049 909	6.89
Diyarbakır	586 377	3.85
Sakarya	490 739	3.22
Kırklareli	470 842	3.09
Manisa	452 232	2.97
Osmaniye	403 663	2.65
Hatay	392 267	2.57
Total	8 102 383	55.73

More than half of the total amount of field crop residues in Turkey comes from 10 provinces, as shown in Table 3. Over 24% of total field crop residues in Turkey were found to originate from the GAP (South-Eastern Anatolian Project) provinces (Sanlıurfa, Mardin and Diyarbakır). Thus, investments to be made for obtaining energy from agricultural residues in this region will not only contribute to development in these provinces but also, there will be abundance. Apart from this, the provinces of the Eastern Mediterranean region (Adana, İçel, Osmaniye and Hatay) are also seen to have great agricultural residue potential. Furthermore, olive oil waste is expected to increase due to a dramatic increase in olive cultivation in recent years in these provinces. It is believed that there will not be a shortage of raw materials for investment and facilities to be made for obtaining energy from agricultural residue in these two regions.

It was calculated that the total energy value of the field crop residues was exactly 268.45 PJ/a (6.41 Mtoe) for the production period of 2012 in Turkey. The energy values of field crop residues that were calculated separately for each product are given in Table 4.

As shown in Table 4, the energy values of maize stalk and cobs are seen to top the list with 129 PJ/a.

Table 4 The energy values of field crop residues of Turkey in 2012

Crops	Residues	Total residues /kt·a^{-1}	Total energy value (*EP*) /PJ·a^{-1}
Wheat	Straw	3 246.25	58.11
Barley	Straw	1 141.68	19.98
Oats	Straw	32.42	0.57
Maize	Stalk	5 209.91	96.38
	Cobs	1 773.87	32.64
Cotton	Stalk	1 499.54	27.29
Sunflower	Stalk	2 301.33	32.68
Groundnuts	Shells	38.77	0.80
	Total	15 243.77	268.45

The amount of field crop residues and their energy values were calculated separately for each province and were mapped using Arc GIS Software. The distribution map of annual field crops residues and energy values of Turkey are given in Figures 1 and 2.

These maps showed that the potential of field crops residues was concentrated in the south of Turkey. In particular, it is observed that the type and distribution of field crop residues in Şanlıurfa province according to energy value are ranked as maize (55.6%), cotton (27.3%) and wheat (11.4%), respectively. In Adana, this ranking consists of maize (68.2%), cotton (14.5%) and sunflower (9.3%), respectively. This order is almost the same in other provinces. However, different crop residues are noteworthy in certain provinces. Cereals (wheat and barley) have a 45% share in Diyarbakır and 37.5% in Konya, while in other provinces, the distributions are as follows; 60% for sunflower in Kırklareli, 44% for cotton in Hatay and 96.4% for maize in Sakarya.

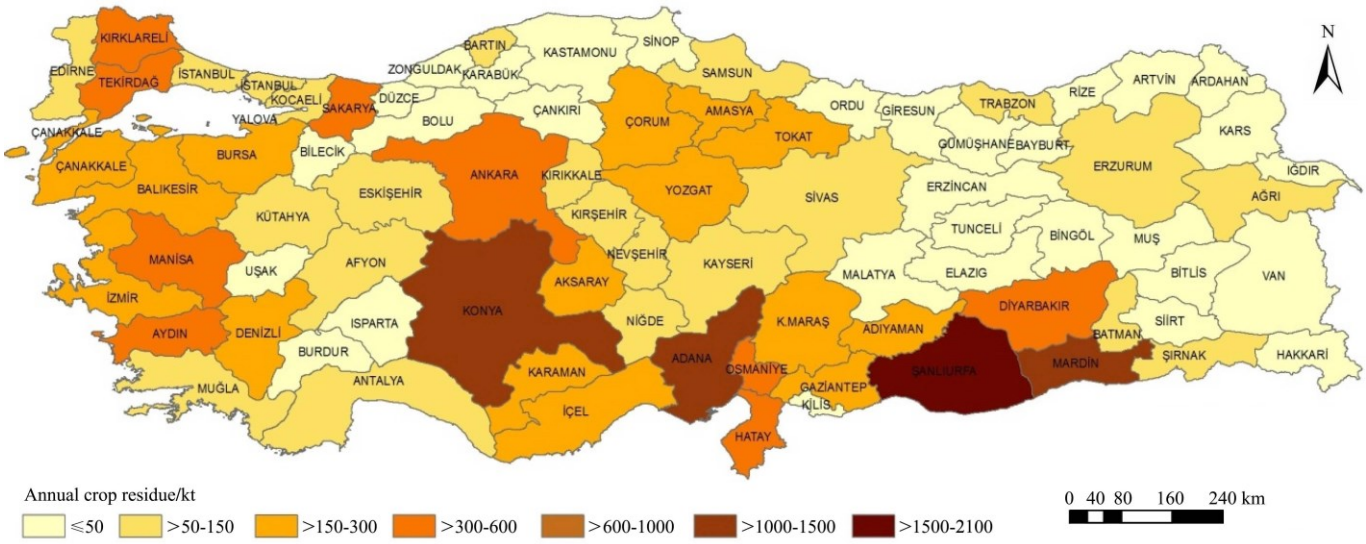

Figure 1 The map of amount of annual field crops residues in Turkey

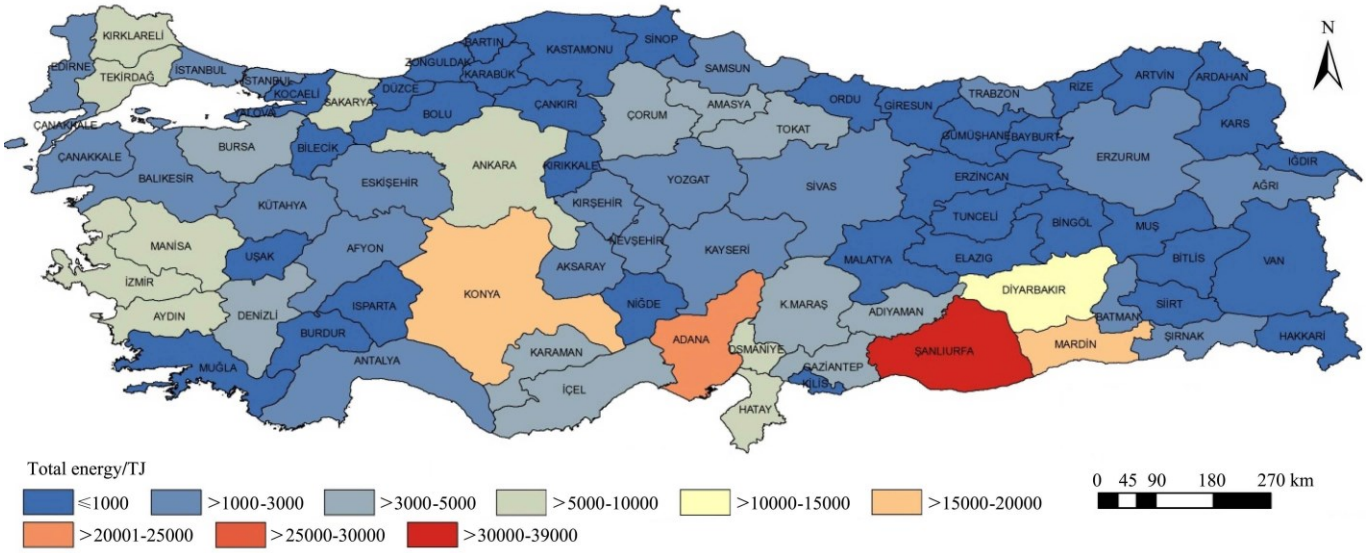

Figure 2 The map of energy values of annual field crops residues in Turkey

Besides, cotton ginning residue has great potential due to the high number of cotton ginning factories in Şanlıurfa, Adana, Hatay and Diyarbakır. Despite these facts, until now there has not been any investment in these areas related to agricultural residues, which have great potential for conversion to energy. However, the results of this study show that such large potential necessarily has to be evaluated by establishing modern facilities which are energy conversion methods as gasification, pyrolysis etc.

The CO_2 emission emitted into atmosphere with the use of coal as much as energy potential of agricultural residues was calculated approximately 30.8 Mt/a. If all agricultural residues is evaluated, this emissions value is to be 1 Mt/a[16]. So that the amount of CO_2 emitted into the atmosphere through the use of all agricultural residues is seen to be a reduction of 30 Mt/a. It is clearly seen that the evaluation of agricultural residues to be very useful from an environmental perspective

4 Conclusions

The aim of this study was to determine the distribution of field crop residues in provinces of Turkey as given in the map. The importance of this issue is increasing more due to the fact that Turkey is an energy-importing country. If Turkey's total primary energy consumption in 2012 is considered to be 114.5 Mtoe, 5.6% of which could have been supplied by these residues.

The investments for agricultural residues conversion

to energy will provide a major contribution to the Turkey's sustainable development. The purchase price of electrical energy from biomass was determined as 13.3 ¢/kW·h with the revision of Renewable Energy Law in 2010. The cost of electricity production has been determined as 5.13 ¢/kW·h in economic analysis study for a CHP plant which used cotton ginning residues as a fuel[17]. According to these data, it is clear that such a power plant's profitability will be approximately 2.5 times.

Turkey has great potential in terms of renewable energy sources, but unfortunately, it is an energy-importing country. Turkey needs to use more of its renewable energy sources in order to be independent with regards to energy. Therefore, agricultural residues can be a very attractive choice, since they are sustainable, environmentally friendly and a familiar energy source for Turkey. Furthermore, Turkey has several advantages and alternatives for the use of agricultural residue sources in terms of its regional climate.

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