Trends in Woody Biomass Utilization in Turkish Forestry

Mehmet Eker

Abstract

This study aims to provide information to all stakeholders and present an analysis of the trends in the biomass utilization for bioenergy generation to the forestry sector. The analysis focuses on forest resources, production and consumption of wood products, actual situation and trends in the bioenergy sector and forest services. One of the major challenges faced by the Turkish forestry sector is to meet the increasing demand for wood raw material in the wood products industry taking into consideration the trends in the bioenergy sector to promote the renewable energy sources. Therefore, another objective of the study is to determine the available biomass and to reveal its estimated theoretical potential as energy wood. Two projections were performed by using a scenario-based analysis (pessimistic and optimistic projections for bioenergy) of woody biomass supply based on the existing databases, outlook studies, financial balance sheets and progress in renewable energy generation. Special attention was paid to the impact of the forest industry factors that determine the woody biomass potential and to the gaps and uncertainties in the current situation. Consequently, it was found that the bioenergy production based on woody biomass has not been developed yet, although there was 1,494.5 million m^3 of growing stock in nearly 21.7 million ha of forestland, in Turkey. However, the total amount of industrial roundwood production increased by approximately 2.12 fold while the fiber chip board production increased by 29 times in the Turkish forestry sector in the last three decades. Surprisingly, the traditional fuelwood production decreased by 69%. The findings reveal that fiber chip board industry is a competitor to the bioenergy sector and it seems to become an obstacle to the modern utilization of woody biomass for energy in near future. As the wood products favored by the forest industry sector, it can be assumed that logging residues will become a primary source of bioenergy without compromising the supply of the industrial roundwood and fuelwood. The estimated theoretical biomass potential that was only obtained from the logging residues and did not include secondary and tertiary wood residues and waste was estimated to be equivalent to 3.5–5.5 million tons according to the short-scale scenarios.

Keywords: woody biomass, biomass utilization, logging residues, wood supply and timber procurement

1. Introduction

There is an increasing tendency all around the world to use the renewable energy sources instead of fossil fuels with a view to mitigate climate change, supply renewable energy, adapt to climate change and for other reasons. However, certain criteria such as protection of the forest, enhancement of biodiversity, competitiveness for forest products, sustainability, development of appropriate policies, etc. should be met to use the forest based woody biomass for bioenergy (WBfB) as a renewable energy source. The woody biomass is a main component of the forest biomass, a significant potential as a primary energy source in the world, that has been used in various forms ranging from industrial raw material to energy wood through modern and/or traditional ways. Woody biomass from forestry is defined as all of the aboveground and underground biomass of trees, including all by-products and residues (Röser et al. 2008).

Woody biomass can be generated directly from harvest operations related to the commercial and pre-commercial forest management, forest restoration and fuel reduction activities. The natural gross potential of biomass energy (including agricultural, forestry and other products) was calculated as 135–150 Mtoe (million tons of oil equivalent)/year while it was assumed that the net potential was 90 Mtoe/year, the technical potential was 40 Mtoe/year, and the economical potential was 25 Mtoe/year in Turkey. According to the data obtained from the Ministry of Energy and Natural Resources (MENR), the total available biomass potential was roughly 8.6 Mtoe per year (Karayılmazlar et al. 2011). Furthermore, the total woody biomass was 1,633 million tons only in the productive forest area and 160.5 tons per hectare according to the statistical data of FAO (Eker et al. 2009). The total recoverable bioenergy potential from agricultural residues, forestry wastes and wood processing residues was estimated to be 16.9 Mton in 2000. The total biomass production was anticipated to be 12.6 Mtoe in 2020 (Kaygusuz and Keleş 2009).

For effective utilization of woody biomass, products with the highest added value are generated. Woody biomass utilization options can be grouped into four categories ranging from high value products (sawlog/lumber, veneer, poles, etc.), value added products (mining pole, engineered wood products, etc.), low value products (paper pulp and chips for board, etc.) to minimal value products (logging residues, etc.) (USDA 2007, Pincus and Moseley 2009). Besides several factors influencing the selection of biomass utilization, the current market demands and public necessities are the dominant factors that guide the sharing of the wood products generated from a forest tree. There is a common trend in favor of high value biomass products due to the economic balance, income and expenses.

However, a part of woody biomass with low value or minimal value is often called fuel wood (fire wood or wood fuel) used as a traditional or classic source of energy. Moreover, woody biomass has been used as a primary source of renewable energy and heat, while it is expected to become the secondary source of energy to be generated through modern methods in the future. Therefore, it plays a considerable role in the integrated systems of energy and industrial wood supply (Ladanai and Vinterbäck 2009). Despite the increased value of woody biomass for various forms of utilization, the use of some parts such as logging residues has been recently growing in parallel to the development of modern processing and utilization technologies for energy generation worldwide (Aruga et al. 2011), whereas it has also slowly progressed in Turkey (GDF 2009a, Saraçoğlu 2010a, Eker 2011) for modern biomass utilization. The slow progress in the modern utilization of biomass for energy generation is caused by several challenges and barriers such as available biomass potential, subsidies, demand, operational cost efficiency, technological infrastructure, etc. The sustainability of woody biomass utilization depends on technical, economic, ecological and socio-institutional factors.

It is vital and key to achieve the sectoral balance and meet the supply and demand for all sectors in order to identify the raw material requirements of the forest product based sectors so that the woody biomass can also be used for bioenergy production. Therefore, it is important to take into account the available potential, actual production and consumption quantities as well as the trends in woody biomass utilization in order to predict the long term supply possibility and distribution of woody biomass between forest product industry and energy production sector.

The wood industry and markets are under significant pressure due to the shortage of raw materials all around the world, especially in some developed countries where woody biomass is commonly used for energy production. The market demand fluctuations that depend on the increasing biomass costs, decreasing forest product prices, electricity prices, etc. have a potential to change the woody biomass utilization options. Furthermore, increased demand for energy wood could be the main driver behind the increase in the wood prices (NEP 2009). The periodical variation depends on time varying forestry paradigms and approaches can lead to the horizontal and/or vertical transfer of wood product range. This shows that the increased demand for woody biomass for bioenergy can also result in the increase of wood prices.

Many developed countries promote the use of biomass and other renewable resources for energy generation. Some of the European Union Directives aim to ensure that 20% of the EU's final consumption of energy should come from renewable sources by 2020 (Wunder 2012). To maintain the stability of wood supply in the forestry industry, many subsidies are provided in a balanced supply demand system. For example, in Germany, it was stated that the use of biomass as a raw material in manufacturing industry should be given priority because of greater value creation and benefit compared to the biomass energy production. The use of biomass as a raw material is guaranteed by the legislation and subsidies are also provided to prevent market distortion (BMU 2009).

The literature review of the interactions between conventional use of wood raw material and modern biomass supply (Galik et al. 2009, Guo 2011, Smeets and Faaij 2007) revealed that the biomass availability for energy production was based on industrial roundwood production. Sedjo (1997) found the interactions between the fuelwood prices and the prices of the traditional wood products, and highlighted that the traditional wood utilization was the main competitor of the biomass supply in energy production. Furthermore, it was stated that some wood products with low prices could also be used in bioenergy sector if the other sources of energy were not appropriate (Perlack et al. 2005). On the other hand, it was predicted that the sawlog and other high value and value added products would be too expensive to be used for bioenergy production due to the market conditions (Hazel 2006, Jonsson et al. 2011). Lundmark (2006) also suggested that the minimal value products such as logging residues could be used in energy sector without any adverse impact on the forest industry.

There is a raising awareness in Turkey regarding the modern ways of energy generation from woody biomass. However, it can be claimed that it has not been given as much attention as other primary energy sources (hydro, wind and solar). This is caused by various macro and micro level external and internal factors as follows:

- ⇒ The available woody biomass potential is not clear,
- ⇒ there is an uncertainty regarding the supply and utilization costs,
- ⇒ there is no sectoral structure,
- ⇒ the institutional and social structure in forestry is not convenient, etc.

The purpose of this study was to explore the following research questions: which type of woody biomass can be used for energy production, what is the theoretical biomass potential quantity, and which sectors might compete for raw material. The aim of the study was also to analyze using a bottom up analysis of some key factors such as the relationship between the industrial and fuelwood utilization. It was assumed that it was possible to project the type and proportion of woody biomass available for bioenergy production by using the wood production quantities at the scale of time series with historical data. To support the scenario-based assumption, the supply driven approach dependent on trend analysis was used in the study. Special attention was paid to the data and projections from existing database and outlook studies. Especially national trends and important drivers of change in woody biomass utilization were evaluated in addition to the past experience and projections of future use and supply of wood resources as well as the developments in the wood product market and bioenergy sector in Turkey for the last three decades. Thus, an attempt was made to fill the gaps and lack of knowledge on woody biomass utilization for the supply of biomass energy.

2. Material and Method

The research material used in this study was based on the Turkish forest inventory and forestry sector data (GDF 2011a, FAO 2011, EFSOS 2012, FAO 2012, FS 2012). The national statistical data and information contained the forest resources, forest biomass potential, wood procurement system, production and consumption of forest products, supply and demand profile of the forestry sector, procurement cost and selling price of forest products, report on wood stream in the forest industry sector, overall status of the bioenergy sector, etc. Future outlook and technological prospects of woody biomass utilization were predicted on the basis of the data and reports. The time horizon for the study of past trends was based on data availability. In most cases, historical statistics dated back to the year 1973. However, the analysis of trends only covered the past 30–32 years. The MS Excel was the main tool used to store data, while the statistical data was processed and analyzed through SPSS statistical software. To assess the developments and changes in the forestry and bioenergy sectors, the following information was used:

2.1 Forest resources in Turkey

In order to describe the trends and to argue the sustainability of the future wood supply, the data about forest resources was used in the study. Table 1 shows the data about the forest areas. The forestland has an area of approximately 21.67 Mha (million hectares) and covers 27.8% of the surface area of the entire country, 53% of which is productive forest land. (FS 2012). The productive and high forest area, where woody biomass could be produced, accounts for 10.3 Mha within the total forestland.

Moreover, Table 2 shows the trends in growing stock for the period 1973 and 2012. The total growing stock accounts for 1.49 billion m^3 among the forest resources. The growing stock has increased during the last four decades. It is also correlated with forest areas.

In order to give an indication of the sustainability of forest management for a comparative assessment, Table 3 presents the historical data on annual increment within the time horizon. The annual increment in the productive forestland is 40.02 Mm^3 (million cubic meter), 89 of which is from high and productive forest and the

Table 1 Distribution of forest area between 1973 and 2012 (FS 2012)

Forest form years	Total forest area		Productive forest area		Degraded forest area	
	ha	%	ha	%	ha	%
1973	20,199,296	100	8,856,457	44	11,342,839	56
1999	20,763,248	100	10,027,568	49	10,735,680	51
2005	21,188,747	100	10,621,221	50	10,567,526	50
2009	21,389,783	100	10,972,509	51	10,417,274	49
2010	21,537,091	100	11,202,837	52	10,334,254	48
2012	21,678,134	100	11,558,668	53	10,119,466	47

Table 2 Distribution of growing stock (FS 2012)

Forest form years	Total		Productive forest		Degraded forest	
	m^3	%	m^3	%	m^3	%
1973	935,512,150	100	847,033,015	90	88,479,135	10
1999	1,200,791,637	100	1,113,612,229	93	87,179,408	7
2005	1,288,124,772	100	1,199,034,187	93	89,090,585	7
2009	1,374,240,926	100	1,290,450,115	94	83,790,811	6
2010	1,428,504,717	100	1,347,453,572	94	81,051,145	6
2012	1,494,454,538	100	1,417,482,684	95	76,971,854	5

Table 3 Distribution of annual increment (FS 2012)

Forest form years	Total		Productive forest		Degraded forest	
	m^3	%	m^3	%	m^3	%
1973	28,063,205	100	25,604,869	91	2,458,336	9
1999	34,269,650	100	31,306,039	91	2,963,611	9
2005	36,282,291	100	33,834,897	93	2,447,394	7
2009	38,454,916	100	36,156,989	94	2,297,927	6
2010	40,061,594	100	37,800,646	94	2,260,948	6
2012	42,179,115	100	40,020,179	95	2,158,936	5

rest is from coppice. Only less than 50% of the net annual increment in forests available for woody biomass supply is harvested in Turkey. Therefore, the annual increment is a limitation criterion for the wood production potential.

2.2 Woody Biomass Demand and Supply

The data used in this study regarding the wood resources was divided into two groups: the supply side containing the state forest resources but not private and illegal resources; and the demand side con-

Table 4 Breakdown of wood production from 1980 to 2012 (GDF 2012a, FS 2012)

Year	Standing tree volume	Log	Tele-phone pole	Mining pole	Other industrial wood	Pulp and paper wood	Total round-wood	Fiber chip wood	Thin pole	Total industrial wood	Fuel wood
	x1,000 m^3										x1,000 stere
1980	11,225	5,343	111	621	398	144	6,617	164	–	6,781	21,949
1985	8,932	3,892	264	530	265	1,572	6,523	884	–	7,407	14,289
1990	7,560	3,310	60	513	639	923	5,445	1,113	23	6,581	12,145
1995	9,192	3,578	134	498	936	1,558	6,704	1,320	22	8,046	9,539
2000	8,880	3,007	155	413	830	1,533	5,938	1,371	20	7,329	7,861
2005	10,009	2,936	77	405	726	1,528	5,672	2,409	19	8,100	7,667
2010	16,424	4,375	56	577	788	2,146	7,940	4,608	20	12,569	7,194
2011	17,648	4,839	71	686	874	2,383	8,853	4,663	17	13,533	6,778
2012	16,700	5,028	60	693	875	2,334	8,990	5,425	11	14,424	6,432

m^3 – cubic meter
Stere – Stacked cubic meter =0.7 m^3 =500 kg

Table 5 The supply and demand balance in last decade (MFWA 2013)

Industrial wood, x1,000 m^3				Fuel wood, x1,000 stere		
Years	Supply	Demand	Difference	Supply	Demand	Difference
2002	11,305	12,359	–1,054	16,137	16,650	–513
2003	10,620	11,780	–1,160	15,981	16,359	–378
2004	11,553	13,189	–1,636	15,900	16,223	–323
2005	11,400	13,547	–2,147	15,067	15,519	–452
2006	12,599	14,440	–1,841	14,123	14,411	–288
2007	13,353	15,832	–2,479	13,717	14,093	–376
2008	14,841	15,297	–456	14,007	14,080	–73
2009	14,763	15,943	–1,180	14,101	14,081	20
2010	15,869	17,455	–1,586	13,897	14,357	–460
2011	16,832	17,705	–873	13,451	13,768	–317

* The supply and demand quantity includes state, private, off the record, import, export and illegal production and consumption

taining the industrial wood and fuel wood. The demand for woody biomass was defined as all wood raw materials supplied from forests. Table 4 shows a summarized part of statistical data regarding the production of industrial round and fuelwood obtained from forests via legal and planned allowable cuts in the last three decades. The tabular data was used in econometric modeling in order to produce projections of the supply of wood products and the material use of woody biomass.

Nearly all forests in Turkey are owned and managed by the state. 82% of the domestic industrial

Table 6 Average selling price (fixed price) of wood products in last decade (TL/m^3 – stere)

Wood product types and years	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Log/sawnwood, Pine woods, TL/m^3	184	199	229	225	211	204	189	171	172	212
Mining pole, TL/m^3	141	160	188	183	180	164	157	146	150	178
Other industrial wood, TL/m^3	131	151	170	169	161	150	142	127	133	154
Fiber chip wood, TL/stere	61	69	68	63	64	63	62	55	56	60
Pulp and paper wood, TL/m^3	104	125	130	124	124	124	117	105	119	134
Fuel wood, TL/stere	46	62	63	56	53	50	50	47	44	47

*1 € = 2.4 TL in 2011

roundwood is supplied from the state forests. The total industrial and fuel wood supply and demand in the period from 2002 to 2011 are presented in Table 5.

The state owned forests are the largest sources of wood supply. Therefore, the production from these forests account for 70–75% of the total domestic consumption. Domestic industrial wood production increased by 49% from 2002 to 2011, while the total consumption increased by 43%. However, the consumption of the fuel wood had a downward trend. In order to explain the reason why the high value wood products are preferred, a breakdown of the average selling price and procurement cost are illustrated in Table 6 (GDF 2012b).

Significant fluctuations have been observed in the prices of the wood product. The price of roundwood decreased by around 70% in the period before 2001, while a horizontal trend was observed after 2001.

2.3 Wood Procurement System

The forestry operation goals of the GDF dictate harvesting high quality wood products in a sustainable way. In this framework, the conventional wood procurement is realized through commercial harvesting (27,263 ha), thinning (466,427 ha), rehabilitation (320,525 ha) and conversion operations (81,416 ha), and fuel reduction in firebreaks and forest roadsides (GDF 2012a). The low and minimal value biomass may be left unexploited in the forest area if the selling price does not meet the harvesting and transportation cost due to economic balances. The high value and value added wood products, such as sawlog lumber and poles, etc. are primarily preferred and harvested in all operations. Logging residues are often left on the forest floor. The low-value branch woods are sold to the suppliers for fuel wood and chipboard production and majority of them are subsidized for rural residents with stumpage prices.

Wood procurement operations have been mainly performed by forest villagers as per the legislation and rarely by forest contractors. The workforce potential and employment capacity of forest villagers is around 300,000 people for annual wood harvesting that account for 13–15 million men/day. Conventionally, cut-to-length harvesting method has been preferred in

Table 7 The annual private placement wood product demands in 2011 (GDF 2011b, GDF 2012b)

Shared wood product types	Installed production capacity	Actually processed raw material	Capacity utilization ratio	Source of wood supply		
				GDF	Private sectors	Imports
	x1,000 m^3	x1,000 m^3	%	x1,000 m^3	x1,000 m^3	x1,000 m^3
Chip board	4,691	2,210	47	1,480	654	76
Fiber board	2,428	2,428	100	730	1,062	636
Fiber chipboard	7,119	4,683	65	2,210	1,716	712
Pulp and paper	1,754	1,098	62	485	232	381
Total	8,873	5,736	65	2,695	1,948	1,093

Table 8 Wood industry sectors and use of raw material (Sakarya and Canli 2011, GDF 2011b)

Wood industry sector demands	Institution number	Production quantity in 2010	Production capacity in 2010	Production quantity in 2011	Estimated capacity in 2011	Expected capacity
Shared products	Issue	x1,000 m^3/year				
Chip board	24	3,100	5,040	4,978	6,500	8,100
Fiber board	16	3,300	6,600	3,983	7,170	7,966
Plywood, etc	55	110	180	250	360	450
Veneer	18	96	165	107	165	190
Lumber	10,000	6,243	9,200	9,000	9,200	15,000
Total	10,111	12,849	21,185	18,318	23,395	31,706

Turkish forestry; the harvesting residues are left in stand. The operations have been carried out through moderate to intermediate harvesting technology (Eker et al. 2009).

2.4 Forestry sector

The forest industry demands for wood raw material could be supplied by GDF with both private placement method (20–22 %) and public action method (25–30%), while the rest of the demand is supplied by the private sector and through import (Table 7) (GDF 2012b).

The production quantities and capacities are shown in Table 8 to describe the current market conditions of wood industry in Turkey.

2.5 Energy production and consumption in Turkey

Turkey's annual primary energy production was 29.3 Mtoe, while the consumption was 106.3 Mtoe in 2008. The primary energy consumption is expected to be 222.4 Mtoe in the year 2020 (Karataş and Gül 2012). Turkey's demand for energy has rapidly increased and is expected to grow by 40% in 2035 (Yıldız 2011). Also, it was argued that the energy potential of the total woody biomass (including residues of wood product industry) was 7–8.5 Mtoe in Turkey. Table 9 depicts the annual biomass energy potential of forest residues and wood industry residues with other biomass.

Table 9 Annual biomass energy potential (Demirbaş 2008)

Type of biomass	Annual potential, Mtons	Energy potential, Mtoe
Forest residues (including logging residues)	18	5.5
Wood industry residues	6	1.8
Other	93	24.7
Total	117	32

According to the statistics of the MENR (2012), the material quantity for fuel wood was 3.4 Toe as the primary source of energy, accounting for 10.4% of the total national sources for residential heating. However, the final energy consumption of fuel wood is expected to reach 3.075 Mtoe in 2020 (Gökçöl et al. 2009). The estimate of the traditional and modern biomass requirements is shown in Table 10.

2.6 Method

Forest resources were taken into account as the only source of supply for woody biomass, while the demand side was divided into the industrial wood and fuel wood categories. Fuel wood (also referred to as energy wood or wood fuel) was classified into two groups: traditional fuel wood (fire wood) and modern

Table 10 Traditional and planned modern biomass requirements for energy production (Saraçoğlu 2010a)

Years	1999	2000	2005	2010	2015	2020	2025	2030
Traditional biomass, Mtoe	7.012	6.965	6.494	5.754	4.790	4.000	3.345	3.310
Modern biomass, Mtoe	0.005	0.017	0.776	1.660	2.530	3.520	4.465	4.895
Total biomass, Mtoe	7.017	6.982	7.260	7.414	7.320	7.520	7.810	8.210

fuel wood. Multiple correlation analysis was performed in order to determine the sharing of woody biomass types and relation between the product components, and to interpret the trends.

The fact was taken into account that demands for the wood raw material was limited to the supply, i.e. to total allowable cut/production quantity according to the management and silvicultural principles and to the annual increment quantity. Therefore, the historical course of production quantities was taken as the basis to analyze the trend in the utilization of woody biomass. For data reliability and acquisition, a table was prepared to show the wood raw material harvests in the period from 1973 and/or 1980 to 2012. The annual and periodical (with five year intervals) changes were calculated according to the sharing of the products by using this tabular data on MS Excel.

In order to determine the trend in the annual supply of woody biomass, time series analysis was performed (Güngör et al. 2004). For goodness of fit statistics, regression analysis method (least square method) was used. In order to select the best mathematical trend model, among quadratic, linear, exponential, polynomial and *S*-curve trend models, the R^2 and RMSE accuracy criteria were used having the highest coefficient of determination/R^2 and the lowest root mean square error/RMSE. The trend analyses showed that Polynomial Trend Model usually had better accuracy values compared to the other models.

In order to determine the periodical demand depending on the supply of woody biomass, the average value of »comparative annual variation (growth or shrinkage) quantity and ratio« was used to estimate the annual fixed changes in the periodical wood supply. As a different form of moving averages in a time series model, this method was based on the value of the differences in the supply between two consecutive periods to demonstrate the variation in the mix of wood products. It was claimed that the increase or decrease values found with this method could be a fixed coefficient to project the wood supply in the future. Such annual and periodical values were used to estimate the production amount of woody biomass by 2023 when the strategic forestry plan will expire. The period until 2023 also accounts for a decade required for the amortization of the bioenergy investment costs.

Furthermore, two scenarios were developed to interpret the trend analysis of woody biomass utilization. The first scenario was based on the fixed structure of woody biomass supply and demand that was regarded as a supply driven projection scenario. The estimations in the scenario were made using the statistical trends and qualitative (by means of simple/graphical regression) analysis of the annual production data regarding the state forestry sector. This scenario symbolized a pessimistic outlook (low potential for WBfB) in favor of the use of woody biomass for bioenergy production in Turkey. This scenario represented a condition in which the industrial wood utilization would increase and the ecological/environmental sensitivity would not surpass the socio economic objectives of the forestry industry.

The second scenario was optimistic (high potential for WBfB) for the bioenergy sector. The percentage derived from the demand profile of the forest industry was assumed to reflect the impact of the increased demand on WBfB. Woody biomass demand for total industrial wood was predicted by means of sector reports (OAİB 2011) and planned goals of state forestry sector. The energy wood requirements and the woody biomass market demand for bioenergy could then be calculated by reviewing the literature on sectoral basis. In this scenario, an unsteady coefficient obtained from the actual structure of the energy market was used to determine the variable wood demand. In this scenario, it was assumed that the modern utilization of biomass would increase depending on the production of the industrial wood and bioenergy policies and that the traditional fuel wood would be completely or partially used as energy wood in addition to the logging residues. In both scenarios, a recovery factor (7–20% green tons of total wood production volume (Eker 2011, Eker et al. 2013, Çoban and Eker 2014) was used to estimate the theoretical potential of logging residues to substitute the energy wood supply.

3. Results and Discussion

Turkish forestry has a growth trend with respect to the increasing forestlands and forest resources. Forest areas were enlarged by 7.3% in 39 years from 1973 to 2012 (Table 1) due to the aggregated forestry approach and best management practices. Furthermore, the area of the productive forests increased by 30.5% in the same time frame. According to the polynomial trend equation

$$y = 1{,}194.9x^2 - 5E + 06x + 5E + 09;\ R^2 = 0.997 \quad (1)$$

Where:

y forest area,

x year.

the area of the forests is expected to reach 22.5 Mha by 2023. This result guarantees the spatial sustainability of the forest resources for woody biomass.

Furthermore, in line with the forest land, the total growing stock in all forestland increased by 59.7%

during 39 years (Table 2). The growing stock refers to the inventory of standing trees in a forest. Therefore, wood harvesting, harvest scheduling, wood production intensity, and all forestry operations are considered according to the growing stock. This is also an excellent indicator for capital investment into wood products industry in the future. According to polynomial trend model

$$y = 332{,}521x^2 - 1E + 09x + 1E + 12;\ R^2 = 0.992 \quad (2)$$

the maximum growing stock is expected to reach 1.85 billion m^3 by 2023. Moreover, the annual increment increased by 50% in the last 39 years and, and from 1.38 m^3 to 1.86 m^3 per hectare. According to the polynomial trend model

$$y = 9{,}839.2x^2 - 4E + 07x + 4E + 10;\ R^2 = 0.984 \quad (3)$$

the annual increment is predicted to reach maximum 46–49 Mm^3 by 2023.

Depending on the incremental structure of forest resources, the annual allowable cut is also expected to increase as a function of standing tree volume. Eventually, the amount of standing tree volume has consistently soared since 2005, and peaked in recent years (Fig. 1). In Turkish forestry, the average annual allowable cut is approximately 16 Mm^3 according to last five year data, and it increased by 75% in the last decade. The trend has a polynomial incremental momentum and it shows that the standing tree volume should be between 25–30 Mm^3 by 2023. This symbolizes theoretical wood raw material to be supplied from state forests as both industrial and fuelwood, and threshold value of the annual supply quantity of woody biomass.

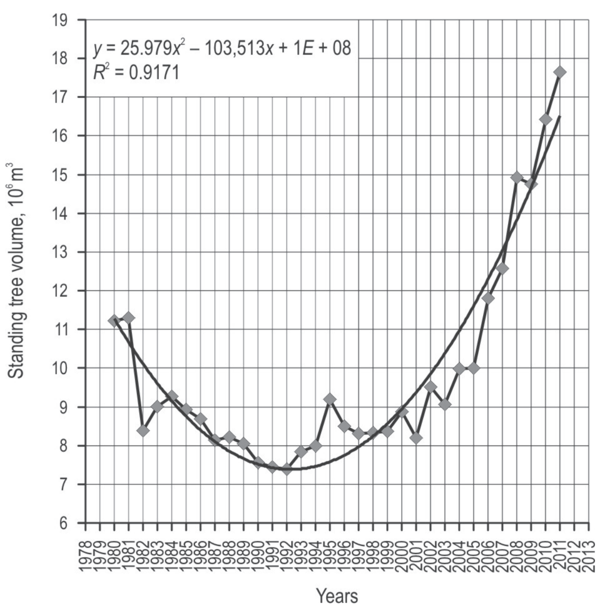

Fig. 1 Relationship between standing tree volume and years

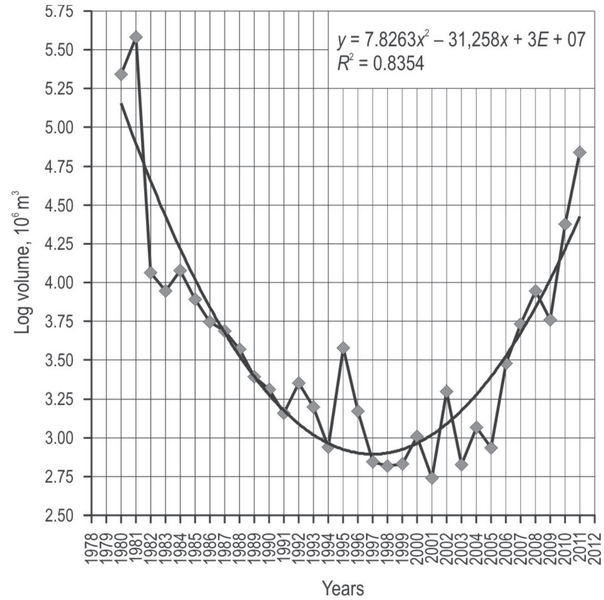

Fig. 2 Relationship between log volume and years

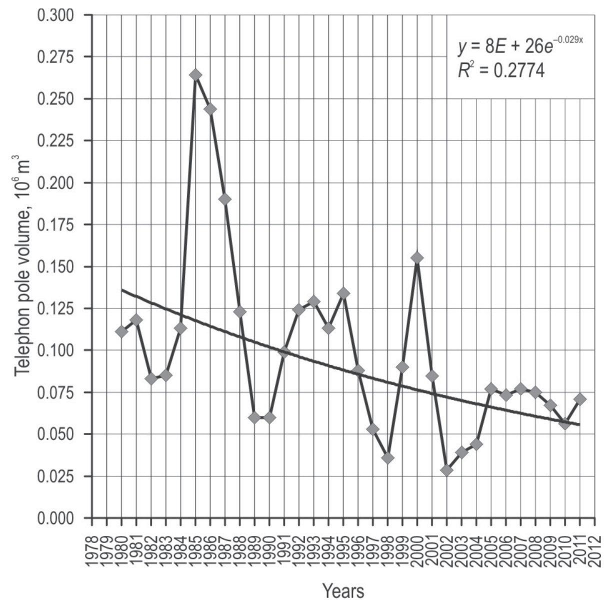

Fig. 3 Relationship between telephone pole volume and years

The available potential of woody biomass for bioenergy depends on distribution of wood products to be obtained by total wood supply, as shown through Fig. 2 to Fig. 10. Based on the production ratio and polynomial trend model of wood raw material, it was concluded that the industrial wood production

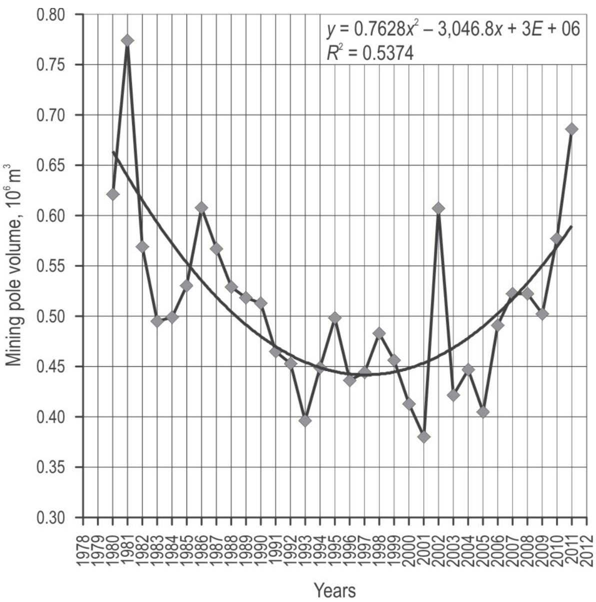

Fig. 4 Relationship between mining pole volume and years

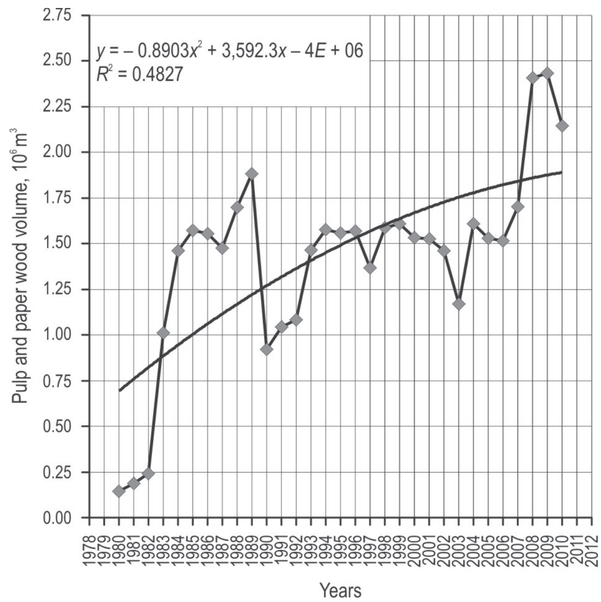

Fig. 6 Relationship between pulp and paper wood volume and years

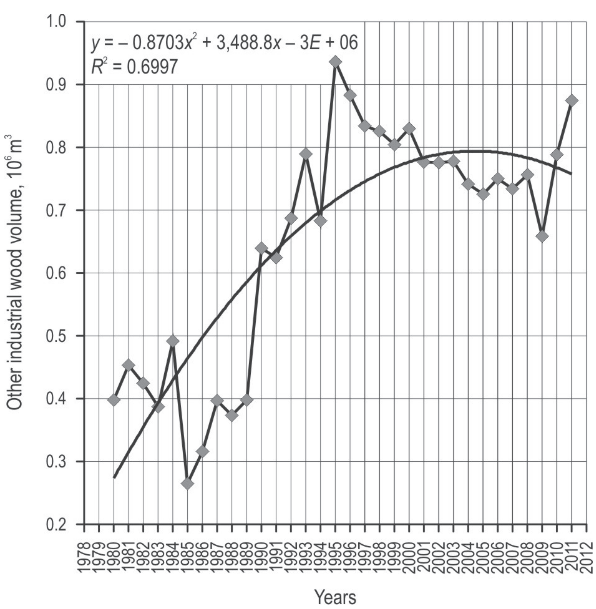

Fig. 5 Relationship between other industrial wood volume and years

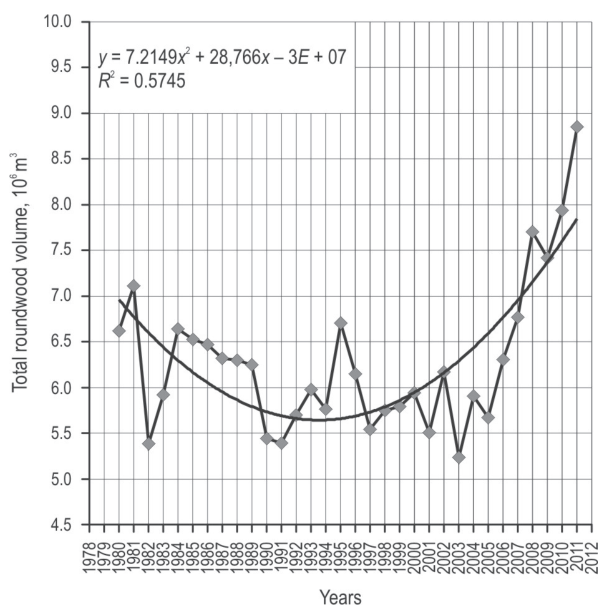

Fig. 7 Relationship between total roundwood volume and years

$$y = 12.976x^2 - 51{,}645x + 5E + 07;\ R^2 = 0.82 \qquad (4)$$

and especially sawlog production

$$y = 7.8263x^2 - 31{,}258x + 3E + 07;\ R^2 = 0.84 \qquad (5)$$

would continue to increase significantly. Furthermore, it was also estimated that there would be a tremendous increase in the fiber-chipboard production

$$y = 5.8288x^2 - 23{,}150x + 2E + 07;\ R^2 = 0.91 \qquad (6)$$

as shown in the figures above. This is an overwhelming growth rate, higher than the growth in other wood products in the last three decades. This is also consistent with the data given in Table 4 - the fiber chipboard wood production increased by 33.1 times from 164 thousand cubic meters to 5,425 million cubic me-

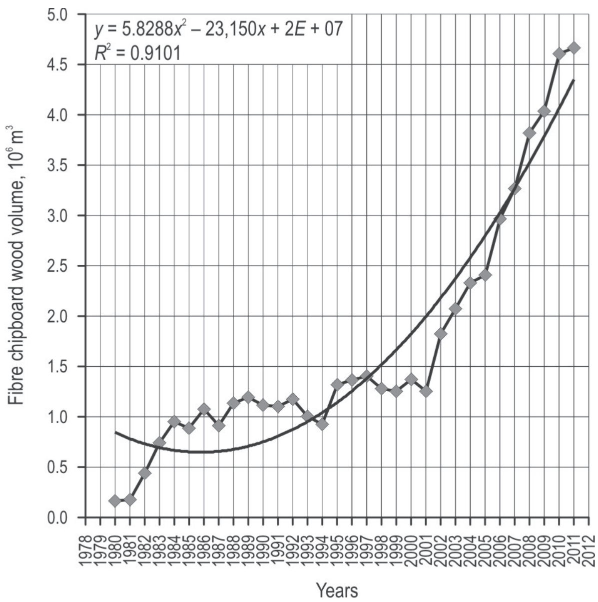

Fig. 8 Relationship between fiber-chipboard wood volume and years

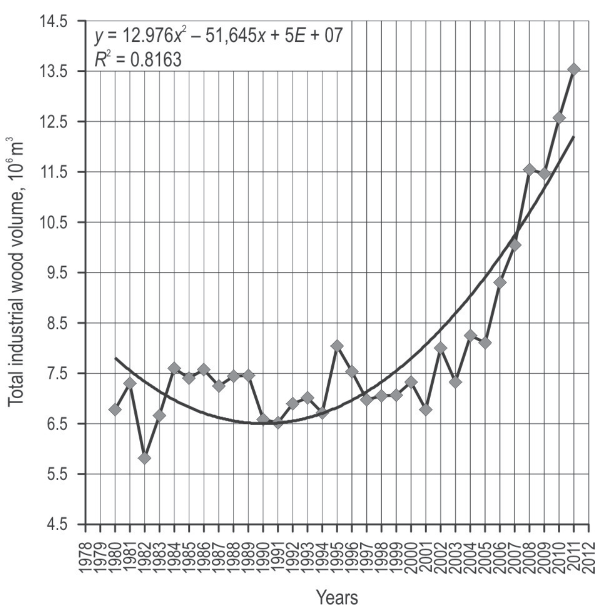

Fig. 9 Relationship between total industrial wood volume and years

ters in the last 32 years. At the same time, fiber chipboard wood products had the highest proportion (24%) in total woody biomass (standing tree volume) in the period between 2001 and 2012. This is a result of the increased demand from the fiber chip board industry. This sector is the fourth biggest producer in the world after China, USA and Germany (OAİB 2011). Therefore, the demand of the fiber chipboard industry for wood raw material has been steadily increasing due to the

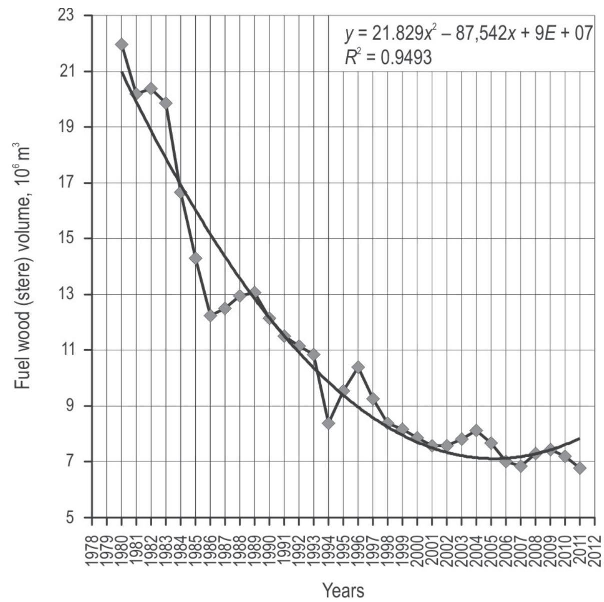

Fig. 10 Relationship between fuelwood in stere and years

increasing imports of manufactured wood products. Over 70% of the demand of the fiber chipboard industry could be supplied by GDF, and the rest by private plantations and imports (GDF 2011b).

However, the traditional fuel wood production remarkably decreased 3.4 times, from 21,949 to 6,432 stacked cubic meters:

$$y = 21.829x^2 - 87{,}542x + 9E + 07;\ R^2 = 0.95 \qquad (7)$$

The decline has been supported by GDF through National Forestry Programs (ÇOB 2004) and Strategic Planning in Turkish Forestry (GDF 2009b) for fuel wood production. The aim was to reduce the fuel wood production to 3.5 Mm^3 (5 million stere) in 2014. Depopulation within and near the forest areas, use of substitution or alternative energy sources instead of fuel wood for heating and cooking, seasonal emigration of local people living in the forest areas, etc. led to a decrease in the consumption of the fuel wood by around 70% in last three decades. This findings are supported by the fact that the logging residues as fuel wood (Eker et al. 2011) have not been collected any longer by rural people for traditional heating and cooking.

When compared with the increase in the fiber-chipboard production and decrease in the fuel wood production by means of correlation analysis, a negative/inverse significant ($p<0.01$; $r=-0.674$) relationship was found between the chipboard and fuel wood supply in Turkey. The severe decline in the fuel wood production demonstrates the horizontal shift in product range from fuel wood to fiber chipboard. Fiber chipboard and fuel wood sector can use the same type of woody materials such as low and/or minimal value added products. According to the findings, it can be claimed that the fiber chipboard industry is a competitor to the fuel wood and other non-industrial wood products and has an extensive manipulation capacity for all woody biomass at low procurement cost. The results of the analysis, graphical inferences and market reports are also consistent with this assumption (Sakarya and Canlı 2011, GDF 2011b).

On the other hand, the biomass has the potential to become a more reliable source of energy; therefore, there is a need for improvement in collaboration with all relevant sectors in order to increase the utilization of WBfB. Price competitiveness, raw material distribution, sustainable supply of woody biomass and market conditions in the forest industry have important roles in the growth of biomass in energy sector (Gökçöl et al. 2009, Heinimo 2011). Thus, it seems that the use of annual modern biomass demand will increase significantly up to almost 5 Mtoe by 2030 (Saraçoğlu 2010a, Saraçoğlu 2010b), although biomass energy only accounts for 4–5% of primary energy consumption in Turkey (Karataş and Gül 2012). However, to satisfy the demand, Turkish Assembly ratified a renewed legislation »Renewable Energy Law« at the end of 2010, which proposed that the highest purchase guarantee for the selling price of the energy produced from biomass biogas power would be 13.3 cent € /kWh for 10 years (Türkyılmaz 2011). This subsidy encouraged the energy producers, thus the number of power plants licensed for electricity generation from biomass resources increased to 11 and the capacity to roughly 50 MW (Gözen 2011). To promote the progress, the GDF, which was the only state owned wood producer, declared that maquies, rhdododendron woods and residues of red pine (*Pinus brutia*) forest could be used in bioenergy sector as raw material.

As in most developed countries, biomass energy sector primarily uses the minimal and/or low value added products and by-products, including logging residues, small sized trees, mill residues and other coarse debris (Hakkila 2004, Mendell et al. 2011). Despite this trend in favor of WBfB, selling price is a key factor and deterministic component for utilization and sharing of woody biomass, such as fuel wood and logging residues, among the competing sectors. As stated by Spinelli (2011), if the selling price offered by a traditional supplier, vendor or user cannot cover the cost of recovering the main forest products, then the products will end up as by-products for energy or other utilization. The higher price proposed by the energy supplier not only may contain the cost of recovering non-merchantable trees and tree parts, but it can also exceed the price of low value forest products. In Turkey, although the bioenergy sector has not been developed yet, the particleboard supplier has offered a higher purchase price for tree branches, small diameter trees and wood chips and this price is higher than the price offered by fuel wood supplier. The fiber chipboard industry sector is dominant in terms of the price competition and raw material demand. Therefore, there has always been a tendency towards the high value types of woody biomass. However, this is a driver of the change of wood product market and negative factor for WBfB potential. It can be claimed that the fast growing demand of particleboard industry has also influenced the fuel wood demands because of their diameters, which are greater than those of the logging residues. Therefore, logging residues and small diameter branches have a potential to be used as energy wood source, so that more forest biomass can be actually utilized to reduce competition between the industry and energy sectors. This trend confirmed that the demand of fiber chip board industry was a barrier to bioenergy sector in providing WBfB.

Depending on the results on forest resources, woody biomass (theoretical) potential and development of bioenergy, the scenario analysis gave the following results: In the pessimistic scenario, a demand profile based on the increasing industrial wood production and consumption was taken into consideration for energy woody biomass. It was assumed that the demand for both industrial roundwood and fiber chipboard wood would increase, while the fuel wood demand would decrease. This scenario limited to the energy wood procurement from commercial harvesting operations. The growth of the fiber chipboard industry has strengthened the possibility that a part of logging residues can be used in the particleboard production. It makes it possible to use only the unutilized part of logging residues as bioenergy resource. The selling method, such as standing tree sale (time bargain) or public auction, behavior of the logging operators and the request of the manager or customer have an impact on the decision whether to leave the logging residues in the forest site or not. During the conventional harvesting operations, small diameter branches, with the diameter smaller than 4 cm, are not collected as fiber chipboard wood or fuel wood and they are left in the stand as residue because of their high procurement cost and non-merchantable value. If forest villagers do not collect the woody biomass and logging residues for fuel wood based on their legal rights, they can be used in the bioenergy sector.

Table 11 The estimated projection of the supply of woody biomass (x1000)

Year	Scenario	Standing tree volume	Sawlog	Leaf/fiber chipboard	Fuelwood	Logging residues
		Mm^3			Mstere	Mton
2023	Pessimistic	27.55–30.87	5.81–12.05	9.35–29.77	2.40–5.04	1.60–2.80
	Optimistic	19.17–27.55	4.69–5.81	6.72–10.23	5.04–5.15	3.83–5.51

The theoretical potential of logging residues to be used in bioenergy sector depends on harvesting volume. Therefore, the estimated supply trend of woody biomass is given in Table 11.

It was calculated that the theoretical potential of WBfB, including logging residues plus a portion of fuel wood, should be minimally 1.6 $Mtons_{green}$ as energy wood. The available potential is not substantially sufficient to supply the demand of the large or medium scaled bioenergy sector, with the pessimistic scenario.

With the optimistic scenario, the trend of the modern utilization of woody biomass for power and heat was taken into account. It was assumed that the international protocols (Kyoto and others) that Turkey signed promoted the use of woody biomass in bioenergy to reduce greenhouse gas emissions, provide cleaner air, reduce fuel materials on forest floor, etc. In the light of the development around the world, Turkey has a tendency to use the logging residues as a source of bioenergy (EFSOS 2012). According to the trends, it can be claimed that there will be a market opportunity for energy wood.

The theoretical potential of WBfB dependent only on logging residues was estimated to be 3.8–5.51 $Mtons_{green}$ according to the optimistic scenario (Table 11). It is possible to expand the annual WBfB potential range to 5.5–7 $Mtons_{green}$ when adding thin branch wood, which is inutilizable for chipping, and other forest biomass resources such as shrubs, stumps, very small diameter tree residuals, fast growing species, energy forestry crops, etc. The use of branch woods and other parts of trees for fuelwood has been decreasing because there is a rural depopulation and coal and other fossil fuels (natural gas, fuel oil) are preferred for heating and cooking. However, the woody biomass that is not used for fuelwood can be used in the fiber chipboard industry or pulp and paper wood industry. In this sense, the horizontal variations in the sharing of the products depend on the market demands, production costs and selling prices. In this study, it was found that the roundwood production has increased and thus the production of the fuelwood decreased. This indicates that there has been a change in the sharing of the products although the production amount has increased.

The quantities of utilizable WBfB wood are variable, and depend on some stand characteristics, types of silvicultural interventions and harvesting methods. 7–15% can be utilized as green tons of residual biomass from clear cutting (Eker et al. 2013) and 20–30% of the harvested small diameter trees from thinning operations. However, the policies encouraging the use of renewable natural resources for energy production can result in significantly higher demand for bioenergy and other renewables in the future. The rapid energy expansion in biomass energy production seems to continue until the electricity prices decrease, the wood supply exceeds the demand, and new fossil fuel based cogeneration plants have emission rights at no cost.

4. Conclusion

The relationship between demand and supply in the wood industry has an impact on the development of WBfB market. The national woody biomass supply is a function of the current growing stock, standing tree volume, annual growth rate and demand profile with current wood prices. Turkey has a tremendous natural woody biomass potential, whereas technical, economic and ecological potential for energy wood is limited by various factors.

The industrial wood supply is insufficient to meet the demand of the domestic wood industry. Although the annual wood procurement increased within the last three decades, the growing demand has not been satisfied, yet, because the wood industry has a growing trend. Particularly the fiber chipboard industry has increased the production capacity and demand. However, fuelwood production from state owned resources has a severe decline. There is a significant relationship between the fiber chipboard and fuelwood sectors. The GDF has partially guaranteed the supply to the fiber chipboard sector via private placement method. Furthermore, the GDF have to subsidize the fuelwood demands of the forest villagers. The growing demands lead to horizontal product variation between low and minimal value woody biomass. However, a number of tradeoffs between different needs of Turkish forest sector have also changed the woody biomass supply.

On the other hand, Turkey is willing to mitigate the greenhouse gas emissions and to meet other environmental requirements by using the renewable energy resources such as biomass. Therefore, woody biomass should be utilized through modern ways. However, the utilizable WBfB is also insufficient due to the lack of supply. Logging residues as a type of biomass is a crucial alternative for small scale energy production, but it is insufficient to satisfy long term biomass energy production requirements. If the wood markets as well as the production and consumption trend remain unchanged, only the logging residues can be used for bioenergy production and thus it could be reasonable and economic to establish only local and small scale heat and power plants. If the demands for woody biomass for energy exceed the supply of logging residues, the entire wood products industry can be influenced by the increased raw material prices. There is uncertainty as to how the demand growth and price increases will influence the production of wood products, market conditions and supply agreements between GDF and forest products industry. As regards the demand, the global bioenergy production from woody biomass will have an impact on the fiber chipboard sector. The shrinkage of the fiber chipboard market and increased necessity to use the renewable energy sources have enabled the use of fuelwoods obtained from the branches for bioenergy and created an opportunity for sustainable raw material supply.

The methodology used in this study was based on a static approach to the supply of forest growth, forest areas, wood production, etc. No attempt was made in the study to include technological and socio-economical system to calculate the implementation potential of WBfB supplied only from state owned forests. The study results present a rough estimate of the trend of woody biomass utilization for bioenergy in 2023. Further research should include all variables related to technical, economical and ecological limitations and other woody biomass resources to make a comprehensive projection of the future demand and supply.

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Author's address:

Assoc. Prof. Mehmet Eker, PhD.
e-mail: mehmeteker@sdu.edu.tr
Süleyman Demirel University
Faculty of Forestry
Department of Forest Engineering
East Campus, Cunur, Isparta – 32260
TURKEY