Chapter

Bioenergy Potential of Turkey's Forest Sources, Biomass Energy Conversion Methods, Products, and Applications

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Abstract

Forests have been an important bioenergy source for mankind through the long ages, and they will continue as biomass feedstock sources in the future. This study aims to investigate Turkey's forest source, biomass resource, fuel wood, and forest residue potential to discover the bioenergy potential of Turkey. How to convert this potential to energy was evaluated in terms of applications and products. Thus, the most common biomass conversion methods such as thermal processes, pyrolysis, gasification, and combustion, and biological processes, fermentation, anaerobic digestion, and biophotolysis processes, have been explained as biomass energy conversion methods. Besides, the products of biomass are explained by its energy application fields. Overall, the bioenergy potential of Turkey's forest sources and biomass energy conversion methods will be overviewed by this study. Thus, this study will be attracted attention to forests' biomass source the effects on economic, ecological, and socio-economic respects.

Keywords: Turkey's forest, biomass, bioenergy potential, biomass energy conversion methods, alternative biofuels

1. Introduction

Rapidly growing population and industrialization have increased the energy request. It is very important that this increased energy requirement is from sustainable and environmentally friendly resources. At this point, biomass energy stands out with it being sustainable, environmentally friendly, and an inexhaustible resource that can be obtained anywhere. Especially in rural areas, it is becoming the most promising energy source due to its positive effects on socioeconomic developments [1]. In addition to this, woody biomass is estimated to meet approximately 2–18% of primary energy consumption in 2050 [2].

Biomass is vegetative organisms that plants produce and store from organic matter using photosynthesis using solar energy. Bioenergy is used to define energy and energy-related products produced from biomass. Biomass is formed as a result of the combination of sunlight and carbon dioxide and water in the atmosphere with photosynthesis reaction [1, 3].

$$CO_2 + 2H_2O \xrightarrow[\text{light+heat}]{} (|CH_2O| + H_2O) + O_2 \tag{1}$$

where $|CH_2O|$ refers to biomass as carbohydrate [3].

Biomass has been the most common and crucial energy source that is used in heating and cooking for thousands of years. Thus, wood is still the most widely used and richest biomass energy source. Today, plants, agriculture and forest residues, organic household waste, industrial waste, and algae are used as biomass sources. The biomass sources can be used in wide areas such as producing heat, electricity, fuel, and some chemicals [4].

When technical, economic, environmental, and social effects of alternative energy sources such as biomass, wind, hydroelectric, solar, and geothermal energy are evaluated, it is concluded that the most suitable alternative energy is biomass energy. The most important reason for this is that its social benefit is the highest among others [5]. In addition to this, the use of bioenergy has considerably the potential to reduce emissions of greenhouse gases. Bioenergy produces approximately the same amount of carbon dioxide as fossil energy sources, but net carbon emission is zero since the plant uses carbon dioxide by photosynthesis during the day [4].

Three sides of Turkey are surrounded by seas so that it has different climates. Besides, it is located in the center of the triangle connecting the continents of Asia, Europe, and Africa [6]. In 2015 the amount of carbon absorbed by forests in Turkey is 1.9 billion tons. In addition to this, oxygen production was annually calculated as 42 million tons [7]. Turkey has a very rich fauna and plant species source due to moderate climatic conditions. For this reason, it is among the countries rich in biodiversity. Turkey's territory is covered with 27.6% of forests, 31.1% of agricultural land, 18.6% of pasture, 21.3% of other areas, and 1.4% of water. The distribution ratios of the land situation in Turkey are shown in **Figure 1** [8].

The objective of this study is not only to address the current situation of Turkey's forest sources and their bioenergy potential but also to present the recent methods of biomass utilization in the applications. This book section exhibits forest bioenergy potential of Turkey and discusses the biomass conversion methods, products, and applications in terms of the production process and usage of the products in the field. This section aims to attract attention to the forests' bioenergy source and help to seek proper investments for the government and investors regarding forest biomass energy potential.

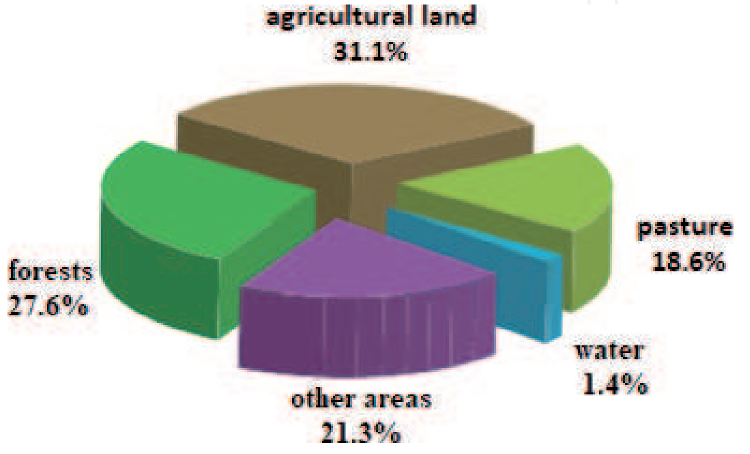

Figure 1.
The distribution ratios of the land situation in Turkey [8].

2. Turkey's forest biomass resources and distribution

Turkey is a transit point that connects the Asian and European continents. It is at the center of the triangle formed by the continents of Asia, Europe, and Africa. Besides, Turkey is surrounded by seas on three sides so it has a different climate. As a result, this situation makes it a rich country in terms of animal and plant diversity. Turkey's forests cover about 30% of the land area and have an equivalent of 11,000 plant species to plant diversity. Furthermore, 3708 of these plant species consist of endemic plant species. When we evaluate the forests of our country as tree species and the area they cover, the first three ranks are 18 species and 6,476,277 ha of oak (*Quercus* spp.), 5,420,524 ha of red pine (***Pinus brutia***), and 4,202,298 ha of larch (***Pinus nigra***) takes the forests. These are followed by beech (*Fagus orientalis* and ***Fagus sylvatica***), scots pine (***Pinus sylvestris***), and fir (*Abies nordmanniana* and *Abies cilicica*) forests. The classification of Turkey's forests is as follows: the Black Sea Region, the North Anatolia Forests which constitute 25% of the forests in Turkey, is the most forested area in Turkey, followed by Thrace, West and Middle Black Sea Forests, Eastern Black Sea Forests, Mediterranean Forests, and Central, East, and South East Anatolia Forests [6]. Turkey's forest asset map and the distribution of the forests are given in **Figure 2**.

2.1 Distribution of forest land in Turkey

Turkey has an ecologically rich diversity due to its geographical location and climatic diversity. The effects of forests on this ecological diversity and wealth are very important. Turkey has 78 million hectares of surface area. In addition to this, forest areas cover by 28.6% percentage except for treeless forest areas [7]. The ratio of land area and the amount of woodland in Turkey is given in **Figure 3**.

Forest areas can be divided into two classes as grove and coppice according to their operation types. Turkey's forests are composed of 88% of grove forest areas (19.6 million hectares) and 12% of coppice forest areas (2.7 million hectares) [7]. The rates of the forest areas according to the operation types are given in **Figure 4**.

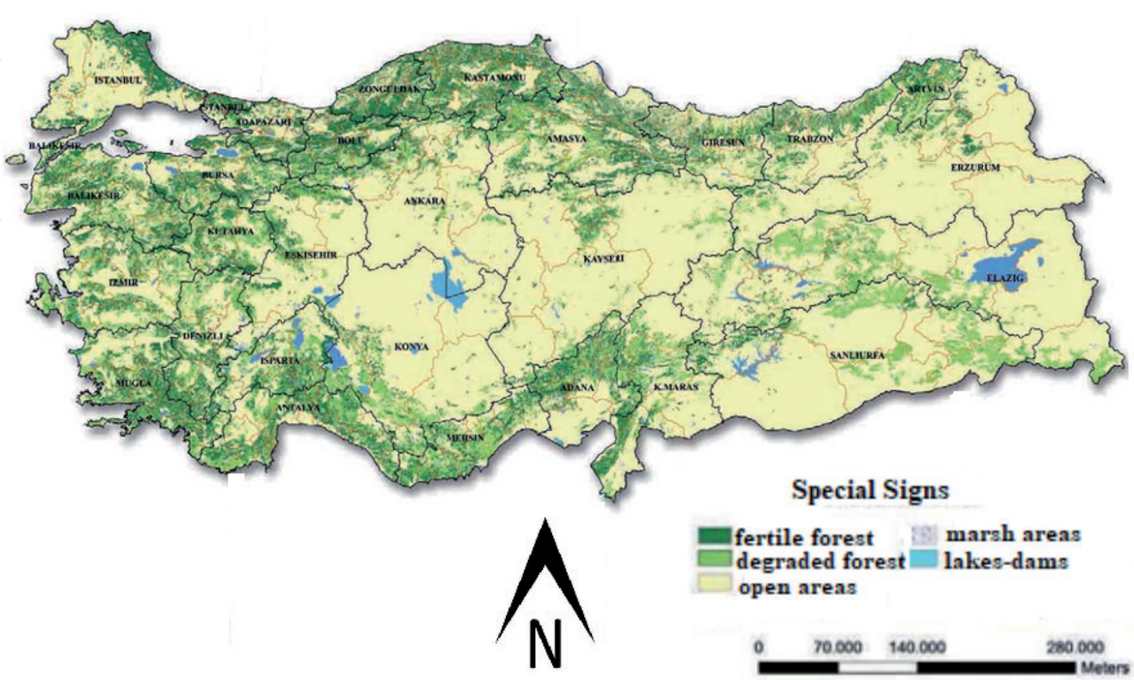

Figure 2.
Map of Turkey's forest assets [8].

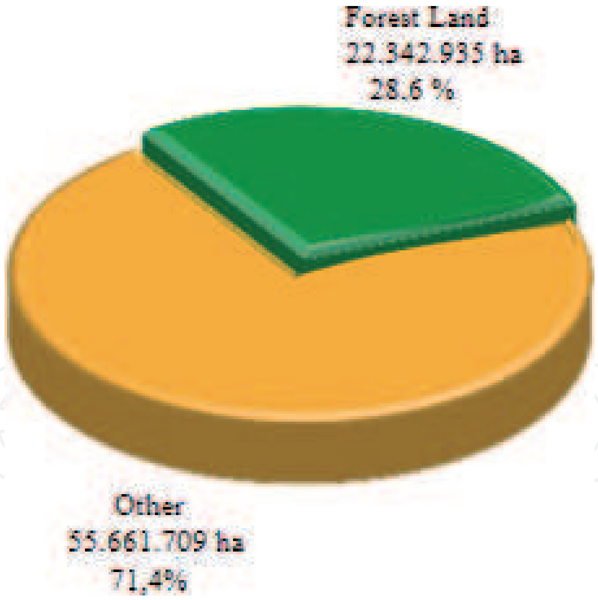

Figure 3.
The ratio of land area and the amount of woodland in Turkey [7].

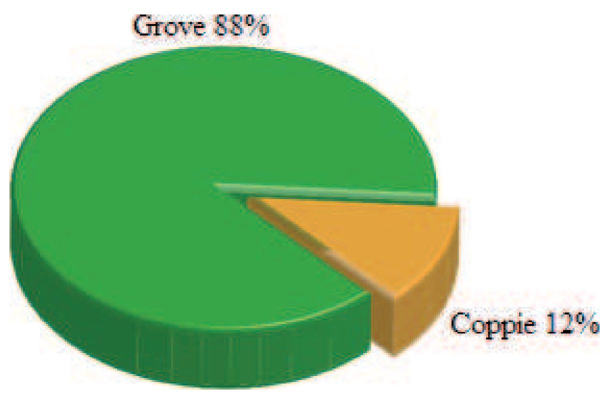

Figure 4.
The rates of the forest areas according to the operation types [7].

Turkey's forest lands' main function distribution is composed of 50% economic, 42% ecological, and 8% sociocultural [7]. Distribution rates according to the main functions of forest areas are given in **Figure 5**.

According to Turkey's forest lands taken into consideration for 42 years, the field of forest area size and change of forest wealth have increased through the years. Forest areas increased by 2.1 million hectares in 42 years. Activities such as protection, development, afforestation, and precautions for forests have been effective on this increase [7]. The amount of the forest area of Turkey through the years and the rate of the country land are given in **Table 1**.

2.2 Distribution of forest wealth

Turkey's forest assets are 20.2 million hectares in 1972 and reached 22.3 million hectares in 2015. In parallel with this, the wood wealth in forests increased from 0.9 billion m^3 in 1972 to 1.2 billion m^3 in 2003, to 1.6 billion m^3 in 2015. In respect to this, between 1973 and 2015, there has been an increase of 700 million m^3 in the tree wealth of the country's forests. In this increase, afforestation studies, migration of citizens living around the forest, and improvement of forest areas have been very effective [7]. The amount of coniferous, broad-leaved, mixed grove, and coppice forest areas of the forest asset in 2012 is given in **Table 2**.

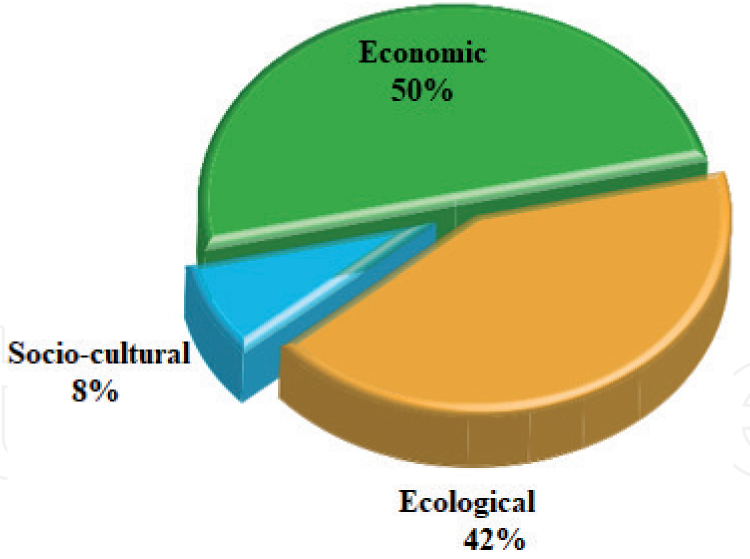

Figure 5.
Distribution rates according to the main functions of forest areas [7].

Years	Field (ha)	Rate (%)
1973	20.199.296	26.1
1999	20.763.248	26.7
2004	21.188.747	27.2
2012	21.678.134	27.7
2015	22.342.935	28.6

Table 1.
Forest area change by years [7].

According to the forest renovation plan in 2013–2015 in Turkey, the amount of forest area in 2015 was estimated to be 22.3 million hectares. The amount and rates of the distribution of the forest areas according to the operation types, the forest area, tree wealth, and annual current increase status are given in **Table 3**. Turkey's average annual amount of revenue derived from forests planted in 2015 is calculated as the volume-shelled body. This value was calculated as approximately 15.94 million m^3 from grove forests and 2.37 million m^3 from coppice forests. As a result, it was calculated as 18.31 million m^3 of total forest area [7].

Turkey's 13.9 million hectares of forest area (62%) is pure forest. In this amount, the rate of tree species entering the mixture is less than 10%. Besides, approximately 8.4 million hectares of forest (38%) is mixed forest [7]. The distribution of forest ratio of species to general forest area is given in **Figure 6**.

Qualification	Coniferous tree (ha)	Broad-leaved tree (ha)	Mixed grove (ha)	Total grove (ha)	Coppice forest (ha)	Total forest (ha)
Productive	6.792.336	2.156.746	1.332.464	10.281.728	1.276.940	11.558.668
Degraded	4.983.059	950.319	1.045.486	6.978.864	3.140.602	10.119.466
Total	11.775.395	3.107.066	2.378.131	17.260.592	4.417.542	21.678.135

Table 2.
Turkey's amount of forest assets in 2012 [8].

Operation types	Normal forest		Degraded forest		Total	
	ha	%	ha	%	ha	%
Forest area distribution						
Grove	11.919.061	54	7.700.657	34	19.619.718	88
Coppice	785.087	3	1.938.130	9	2.723.217	12
Total	12.704.148	57	9.638.787	43	22.342.935	100
Operation types	**Normal forest**		**Degraded forest**		**Total**	
	m3	%	m3	%	m3	%
Distribution of tree wealth						
Grove	1.506.131.410	93	59.996.731	4	1.566.128.141	97
Coppice	33.692.118	2	11.953.934	1	45.646.052	3
Total	1.539.823.528	95	71.950.665	5	1.611.774.193	100
Distribution of annual current increase						
Grove	42.322.876	92	1.484.455	3	43.807.331	95
Coppice	1.511.561	3	585.191	2	2.096.752	5
Total	43.834.437	95	2.069.646	5	45.904.083	100

Table 3.
The situation of forest areas according to their operation types [7].

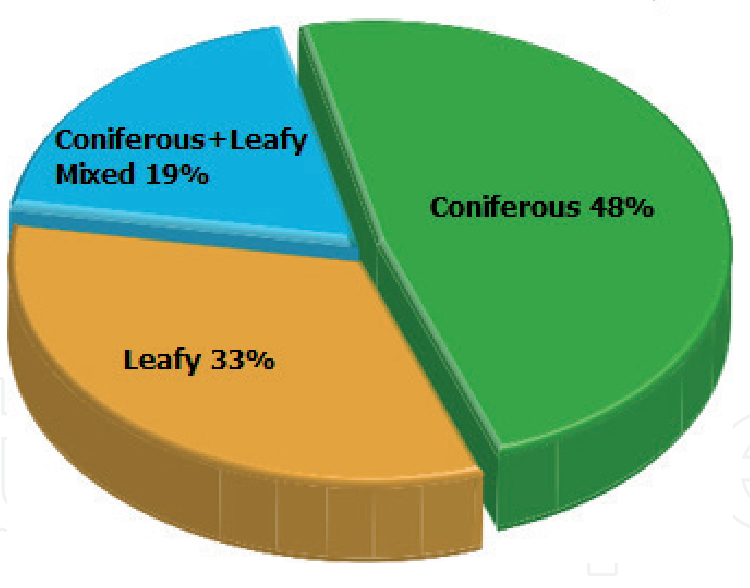

Figure 6.
Proportion of forest areas by tree type [7].

Turkey's forest areas consist of 33% broad-leaved forests (oak, beech, alder, chestnut tree species such as beech), 48% coniferous forests (tree species such as Turkish pine, crimean pine, scots pine, fir, spruce, cedar), 19% coniferous + broad-leaved mixed forests. Oak occupies the largest area in the forests (5.9 million ha), followed by Turkish pine, crimean pine, beech, scots pine, juniper, fir, cedar, spruce, stone pine, alder, chestnut, hornbeam, poplar, lime tree, ash tree, and eucalyptus [7]. Distribution values of forest areas by tree species are given for 2018 in **Table 4**.

Turkey's forest wealth distribution, the current value increment distribution, and distribution of forest areas by the year 2005–2018 are given as follows. **Figure 7** shows forest wealth distribution in 2018. The forest was composed of 95%

Total forest area by tree species (2018)	Forest form		
Tree type groups	**Total (ha)**	**Productive (ha)**	**Degraded (ha)**
Oak (*Quercus* spp.)	5,938,527	2,435,265	3,503,262
Turkish pine (*Pinus brutia*)	5,686,009	3,527,063	2,158,946
Crimean pine (*Pinus nigra*)	4,304,821	2,787,424	1,517,397
Beech (*Fagus orientalis*)	1,935,730	1,665,997	269,733
Scots pine (*Pinus sylvestris*)	1,538,304	901,606	636,698
Juniper (*Juniperus*)	963,217	223,097	740,120
Fir (*Abies* spp.)	593,201	391,842	201,359
Turkish cedar (*Cedrus libani*)	487,819	252,590	235,229
Oriental spruce (*Picea orientalis*)	327,890	234,224	93,666
Stone pine (*Pinus pinea*)	164,798	131,548	33,250
Alder (*Alnus* spp.)	149,215	115,646	33,569
Chestnut (*Castanea sativa*)	89,941	69,727	20,214
Hornbeam (*Carpinus* spp.)	35,609	28,872	6737
Poplar (*Populus* spp.)	16,430	6587	9843
Lime tree (*Tilia* spp.)	12,803	10,637	2166
Ash tree (*Populus* spp.)	7359	6854	505
Eucalyptus (*Eucalyptus* spp.)	1434	1383	51
Other species	368,826	192,784	176,042
Total	22,621,935	12,983,148	9,638,787

Table 4.
Distribution of forest areas by tree species 2018 [9].

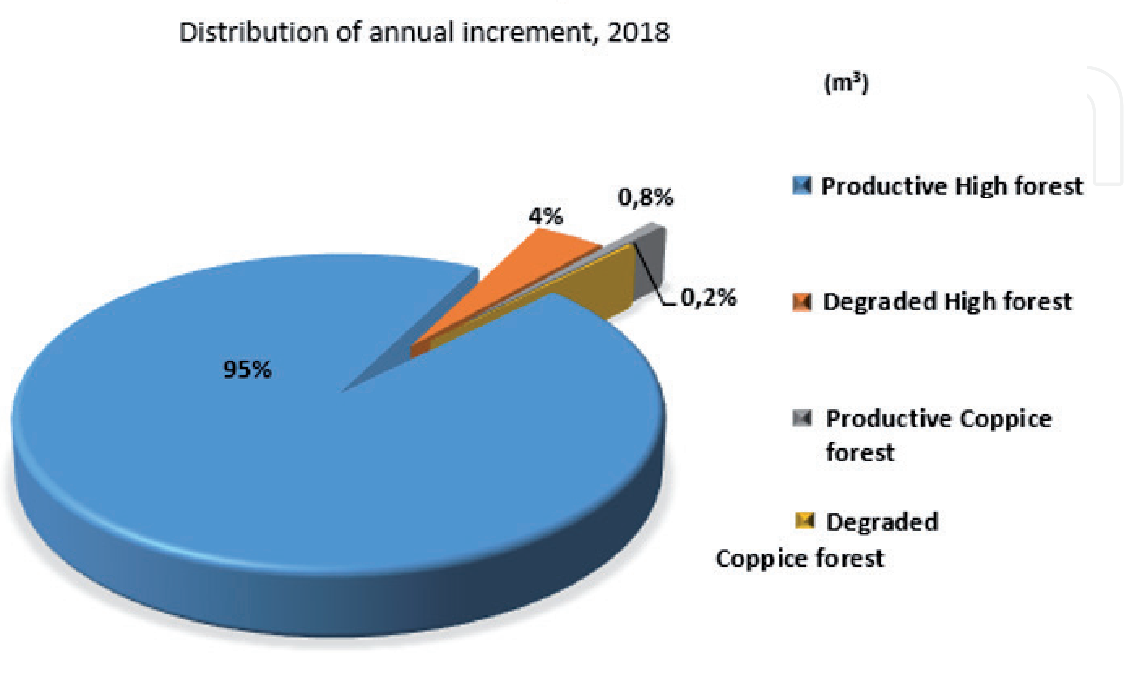

Figure 7.
Forest wealth distribution in 2018 [9].

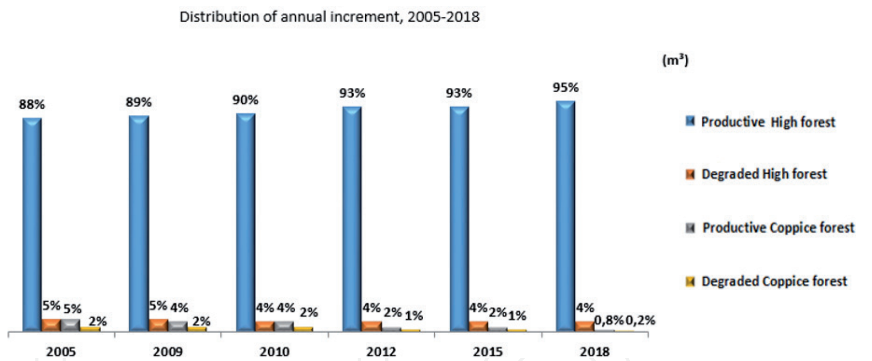

Figure 8.
Distribution of forest wealth between 2005 and 2018 [9].

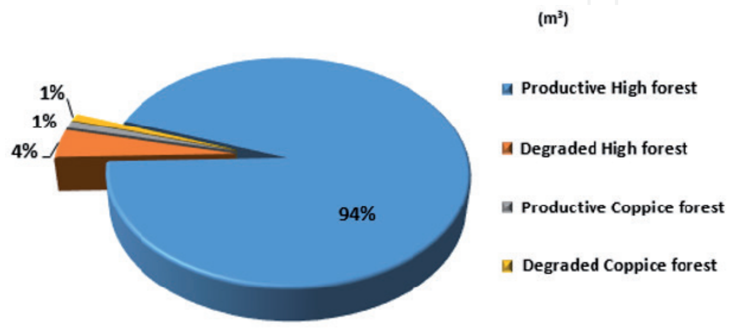

Figure 9.
Distribution of increment in 2018 [9].

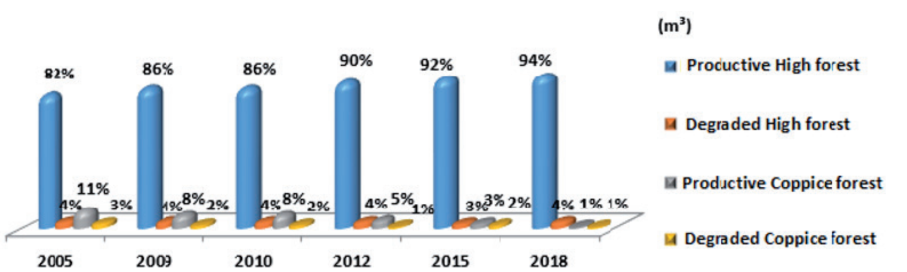

Figure 10.
Distribution of increment between 2005 and 2018 [9].

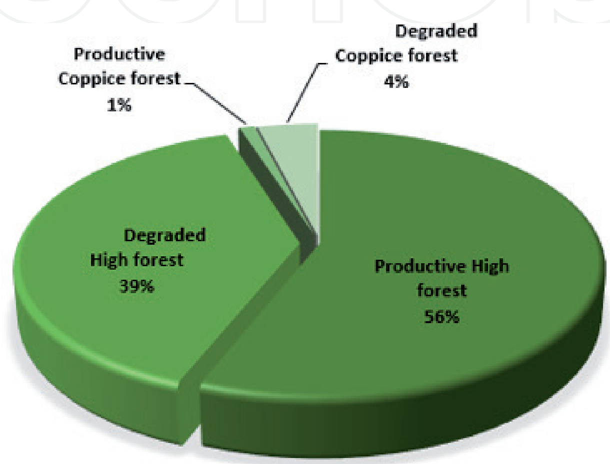

Figure 11.
Distribution of forest areas in 2018 [9].

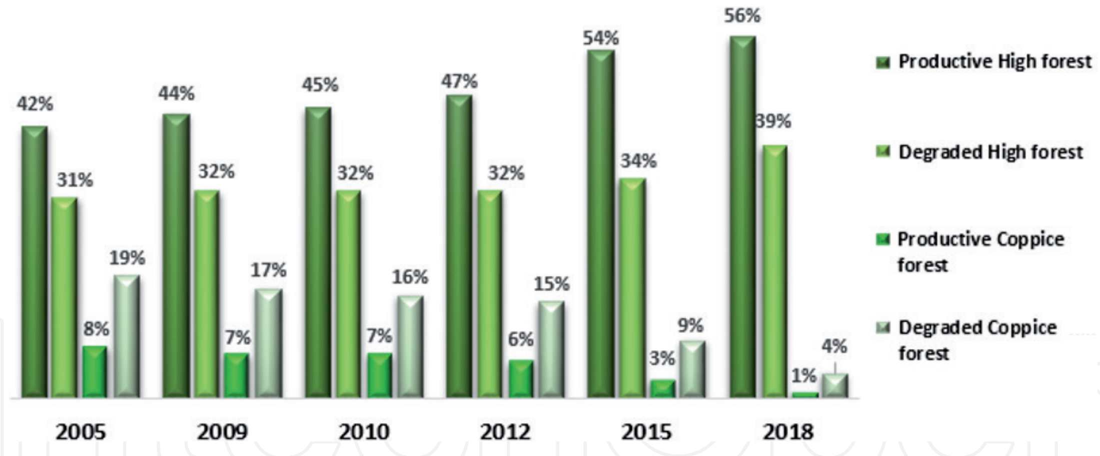

Figure 12.
Change of forest areas by years 2005–2018 [9].

productive high forest. **Figure 8** shows distribution of forest wealth between 2005 and 2018. The productive high forest percentage increased by 88–95% in 13 years. **Figure 9** indicates distribution of increment in 2018. **Figure 10** indicates distribution of increment between 2005 and 2018. **Figure 11** shows distribution of forest areas in 2018. **Figure 12** shows change of forest areas by years 2005–2018 [9].

In the last 30 years, an increase of approximately 990.000 ha has been achieved in forest areas with afforestation studies and increasing environmental awareness. Thus, not only superficial increase but also quality increase in forest areas was observed [6].

3. Turkey's forest bioenergy potential

Annual increment in volume of forests can be explained by the increase in total height and diameter of the tree in a cubic meter (m^3) during the growth period of the trees. Thus, the annual current increment was 28.1 million m^3 in total and 1.4 m^3 in a hectare in 1973. In addition to this, the annual current increment was calculated as 45.9 million m^3 in total and 2.1 m^3 in hectare in 2015. The reason for this increase is due to the increment in tree wealth and forest areas with the maintenance to forests [7]. In **Figure 13**, the wood biomass source that can be obtained from forests is given as a model.

Revenue in forestry is the annual revenue amount and is calculated in m^3. The amount of revenue in 2015 was determined as 15.942.459 m^3 in grove forests and 2.372.162 m^3 from coppice forests, with a total of 18.314.621 m^3 [7]. The change in forest revenue amounts by years is given in **Figure 14**.

3.1 Production amounts of fuel wood

The total amount of trees and annual revenue growth of forest areas can be considered as the biomass potential of forests. Thus, the amount of production and unprocessed wood production according to the tree species shows the potential of the production of firewood. **Tables 5** and **6** show the amount of wood that can be produced as fuel according to the forest area and tree types.

3.2 Forest waste bioenergy potential

It is estimated that available biomass energy potential from waste is about 8.6 million tons of oil equivalent (toe) in Turkey. Furthermore, it is anticipated that these waste biomass have a biogas potential of 1.5–2 Mtoe [10].

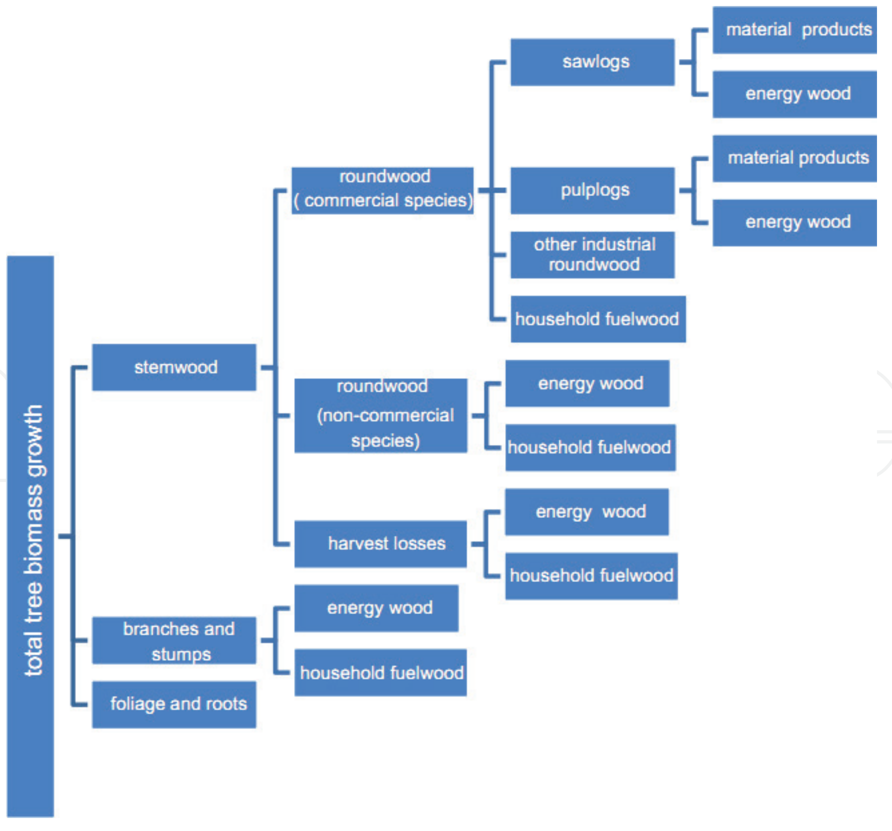

Figure 13.
Model of wood biomass source that can be obtained from forests [2].

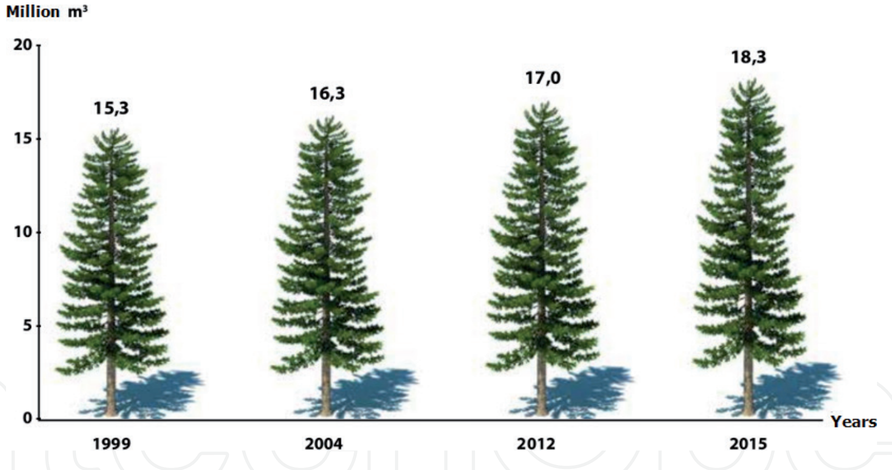

Figure 14.
Forest revenue by years [7].

Description	Unit	2014	2015	2016	2017	2018
Turkey (industrial wood)	m^3	14,923,209	16,637,598	17,009,998	15,521,622	19,080,137
Turkey (fuel wood)	m^3	5,257,994	5,022,986	4,877,067	4,359,646	4,890,455
Fuel wood (coniferous)	m^3	2,120,632	2,176,826	2,203,385	1,926,629	2,442,696
Fuel wood (non-coniferous)	m^3	3,137,362	2,846,160	2,673,682	2,433,017	2,447,759

Table 5.
Volume of wood between 2014–2018 [9].

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Range of products		**Coniferous**							
		Cedrus	***Juniperus***	***Pinus brutia***	**Other pinus**	***Picea***	***Abies***	**Other coniferous**	**Total**
Sewn shell body volume (m^3)		177,316	29,959	6,541,644	7,443,431	636,806	2,067,953	408,451	17,305,560
Fuel wood	High forest (from allowable cut)	33,739	12,092	717,120	400,748	57,043	27,731	31,358	1,279,831
	Coppice (from allowable cut)	4651	318	8893	8926		5155	1141	29,084
	Site clearance, wreck, etc.	5491	754	292,649	662,736	43,024	90,171	38,959	1,133,781
	Total	43,881	13,164	1,018,659	1,072,410	100,067	123,057	71,458	2,442,696
Range of products		**Non-coniferous**							
		Quercus	***Carpinus***	***Fagus***	***Populus***	***Alnus***	**Other non-coniferous**	**Total**	**Final total**
Sewn shell body volume (m^3)		2,286,005	301,162	4,032,484	138,236	49,932	324,418	7,132,237	24,437,797
Fuel wood	High forest (from allowable cut)	506,016	57,851	358,467	4559	8200	139,551	1,074,608	2,354,439
	Site clearance, wreck, etc.	209,091	5334	332,170	7432	1605	38,958	594,590	1,728,371
	Total	1,323,625	69,497	793,986	12,373	9805	238,473	2,447,759	4,890,455

Table 6.
Production amounts of the tree species for volume of wood per species in 2018 [9].

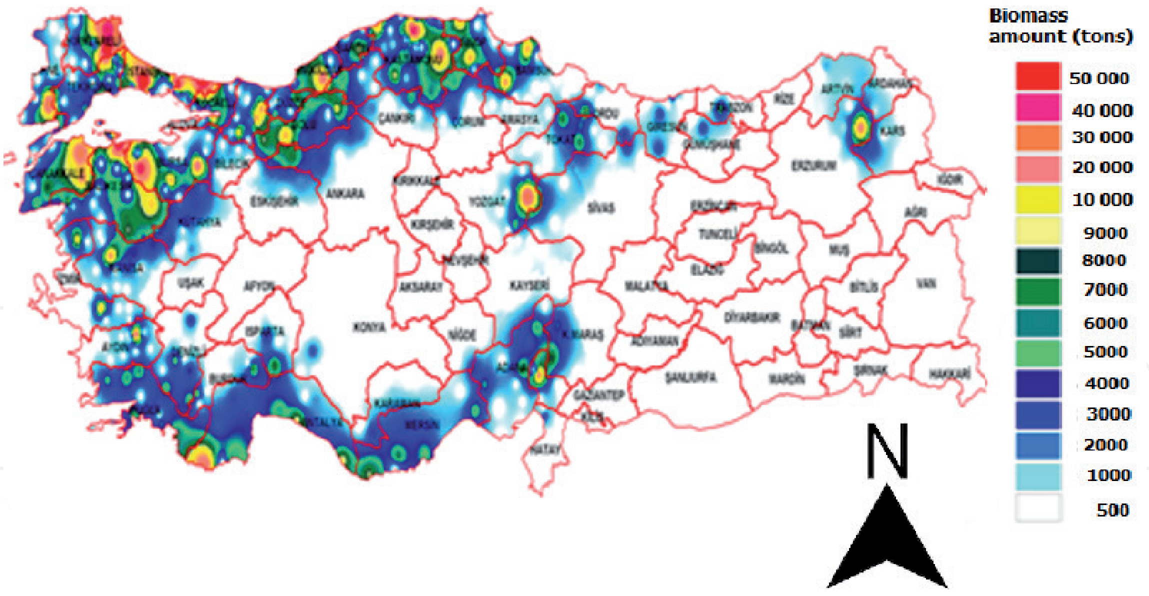

Figure 15.
Distribution of Turkey's forest waste amount [11].

The total amount of waste originating from forests was calculated as 4.8 million tons (1.5 Mtoe) in Turkey. The gasification plant capacity that can be installed is estimated to be 600 MW [11]. The energy value of forest waste is estimated to be 859.899 toe/year in Turkey. The number of biomass electricity generation plant in Turkey is 128 units [12]. Wood biomass potential in forests depends on factors such as forest biomass increase, forest area, and forest growth [2]. Therefore, the bioenergy potential is also highly dependent on factors such as forest biomass increase, obtained from forest wastes, forest area, and growth of the forest. **Figure 15** shows the distribution of the amount of Turkey's forest wastes based on the amount of biomass.

4. Biomass energy conversion methods, products, and applications

The majority of biomass energy is used for cooking and heating in households. Approximately 6.5 million houses use wood as the main fuel for heating purposes in Turkey. Moreover, in the paper industry, approximately 60% of the factories' energy needs are obtained from waste wood [5].

There are main processes such as direct combustion, gasification, alcoholic fermentation, pyrolysis, liquefaction, anaerobic digestion, hydrogasification, and transesterification where energy is obtained from biomass. These processes have their own advantages according to the biomass source and the type of energy obtained. If biomass is converted using modern technologies and energy conversion efficiency is ensured, biomass energy could be a primary energy source in the future [4].

Demirbaş [13] classified wood as a second-generation biofuel in the study. Besides, examples of these biofuels are bio-alcohols, bio-oil, bio hydrogen, and bio Fischer-Tropsch diesel. In addition to these, using alternative fuels from biomass as fuel additives can improve fuel properties such as cetane and octane number, viscosity, and density in diesel and gasoline engines. Thus, fuels produced from biomass can be used as alternative fuels in internal combustion engines [14].

Biomass conversion techniques can be applied on biomass materials to obtain solid, liquid, and gaseous fuels. After the conversion process, fuels can be produced with the main products such as biodiesel, biogas, bioethanol, and pyrolytic gas. Besides, by-products such as fertilizer and hydrogen can be also obtained [15].

Biomass	Conversion method	Fuels	Application fields
Forest wastes	Anaerobic digestion	Biogas	Electric power production, heating
Agricultural wastes	Pyrolysis	Ethanol	Heating, transport vehicles
Energy crops	Direct combustion	Hydrogen	Heating
Animal waste	Fermentation and anaerobic digestion	Methane	Transport vehicles, heating
Garbage (organic)	Gasification	Methanol	Jet engines
Algae	Hydrolysis		Synthetic oil, rockets
Energy forests	Biophotolysis	Automotive gas oil	Drying
Vegetable and animal oils	Esterification reaction	Diesel fuel	Transport vehicles, heating, greenhouse cultivation

Table 7.
Biomass, biomass conversion methods, fuels, and application areas [15].

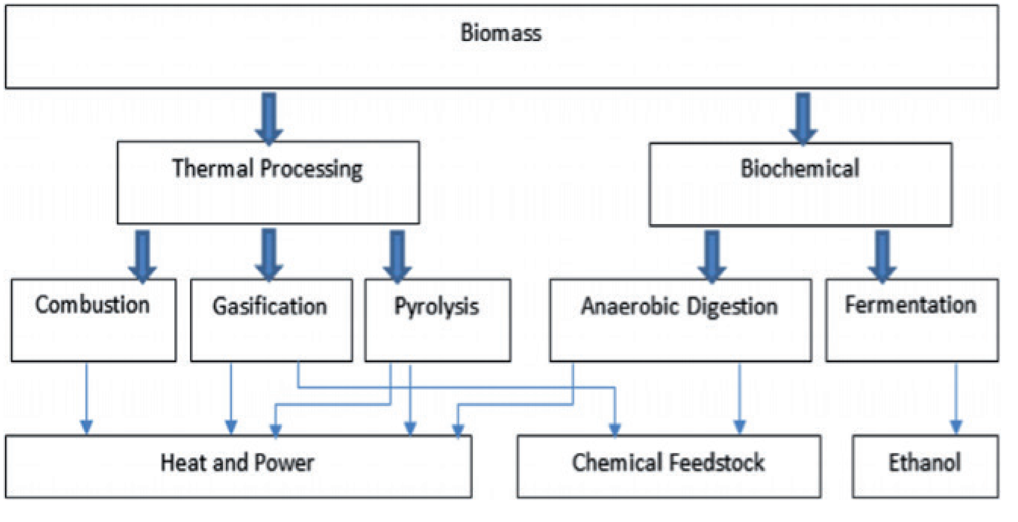

Figure 16.
Biomass processing method and products [16].

Alternative biofuels such as biogas and bioethanol fuels can be obtained by the biomass conversion process. Bioethanol can be used instead of oil, and biogas can be used instead of natural gas [16]. Conversion techniques using biomass sources, fuels obtained using these techniques, and application areas are given in **Table 7**.

The biomass processing process can be divided into two classes: thermal and biochemical. It can be divided into three subtitles as direct combustion, gasification, and pyrolysis in the thermal process. The biochemical process can be classified under two subtitles as fermentation and anaerobic digestion. **Figure 16** shows the methods and products obtained in the processing processes of biomass [16].

4.1 Thermal process

The majority of modern bioenergy plants are use biomass for obtaining heat and power. Developing gasification and pyrolysis bio-oil technology offers much more efficient energy conversion with turbine and combined cycle technologies [3]. Thermal process can be examined under three main headings: burning, gasification, and pyrolysis.

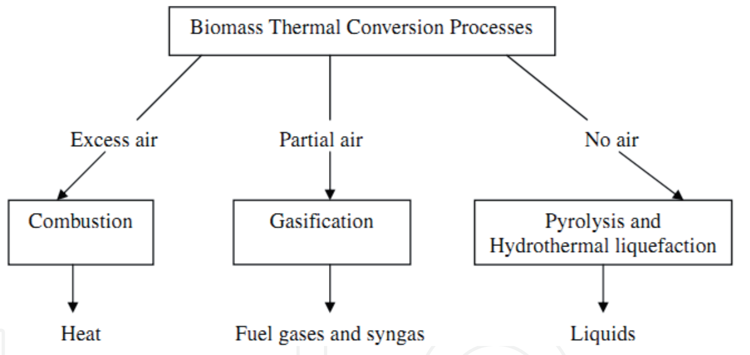

Figure 17.
Transformation of biomass in thermal process [17].

4.1.1 Pyrolysis

Pyrolysis process is the simplest and oldest method for biomass to gas from. Pyrolysis process is a physical and chemical situation that occurs by heating organic substances up to 500–600°C without oxygen. In this process, gas components, volatile condensates, charcoal, and ash are released. When it rises to high temperature, wood gas and components gas are released by heating the wood up to 900°C in an oxygen-free environment. As a result of pyrolysis, substances such as gases, water, organic compounds, tar, and charcoal are obtained [15, 18].

Pyrolysis is the method of obtaining solid, liquid, and gas products by breaking down the biomass with heat. Slow pyrolysis is a well-known method widely used in the production of charcoal. Fast pyrolysis is the method in which biomass converts more than 75% of liquid bio-oil at high temperatures. This bio-oil chemical composition obtained is very similar to biomass. This bio-oil can be used as renewable fuel in gas turbines, diesel engines, or boilers. Bio-oil has about 60% calorific value of conventional fuel oils by volume [3].

Bio-oil is a liquid fuel obtained by the thermochemical process of biomass. Bio-oil obtained from wood is liquid and dark brown-colored. Its density is 1200 kg/m^3 and it is more than the density of biomass and fuel oil. Bio-oil water content is 14–33 wt% by mass and cannot be removed by traditional methods such as distillation. Higher heating value (HHV) is 27 MJ/kg, and it is lower than traditional fuel oil (43–46 MJ/kg) [13]. The conversion of biomass into product by pyrolysis and the process steps of the products obtained are given in **Figure 18**.

4.1.2 Gasification

Gasification technology is one of the oldest conversion processes, and it has been used for more than 200 years [19]. The gasification process is the method for achieved combustible gas by dissolving solids like carbon-containing biomass at high temperatures. The process up to approximately 500°C in the gasification of organic substances is the pyrolysis phase. Here, carbon, gases (calorific value can be up to 20 MJ/m^3), and tar are obtained. When heating up to 1000°C, carbon reacts with water vapor to produce CO and H_2. Depending on the variable oxygen rate in the raw material, additional oxygen input may not be required for the gasification process. Gasification takes place in a reducing atmosphere with low air oxygen or steam injection. During this process, biomass is burned with the air supplied to the fuel cell under control, and the resulting products include combustible gases such as hydrogen, methane, as well as carbon monoxide, carbon dioxide, and nitrogen. Thus, combustible gases such as carbon monoxide, hydrogen, methane, and low

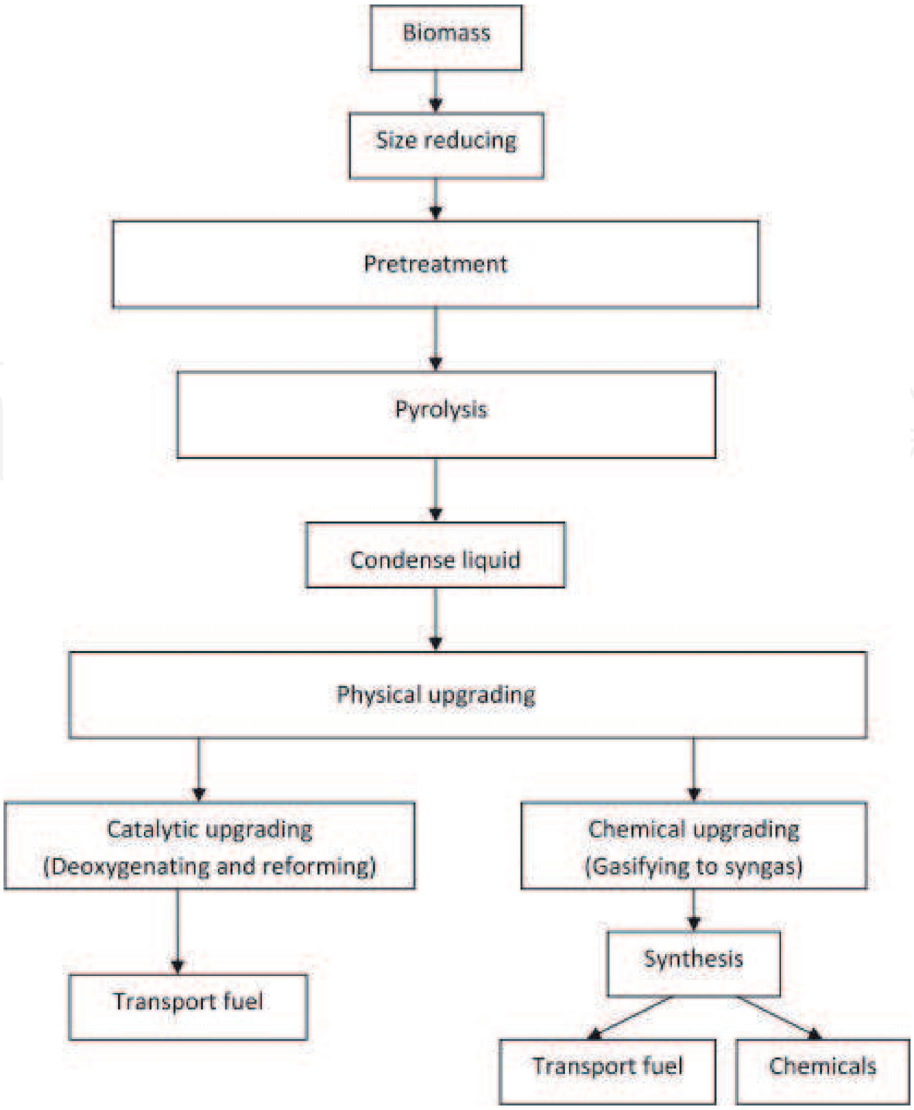

Figure 18.
Conversion of biomass to products by pyrolysis [13].

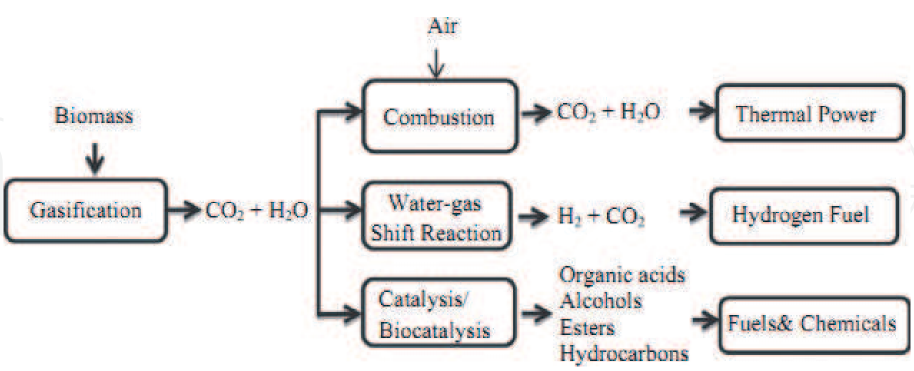

Figure 19.
Transformation processes of biomass into products by gasification [19].

amounts of other gases with low or medium calorific value are obtained. After cleaning the gas, it can be used as fuel in gas turbines, gasoline engines, dual fuel diesel engines, or in fuel cells after purification [3, 15, 18].

Biomass gasification technology provides the opportunity to convert renewable biomass resources into clean gaseous fuels or synthesis gases. Heat or electricity is produced from these produced gases. In addition to these, there is the potential to produce liquid transportable fuel, hydrogen, or chemicals from them. Gasification

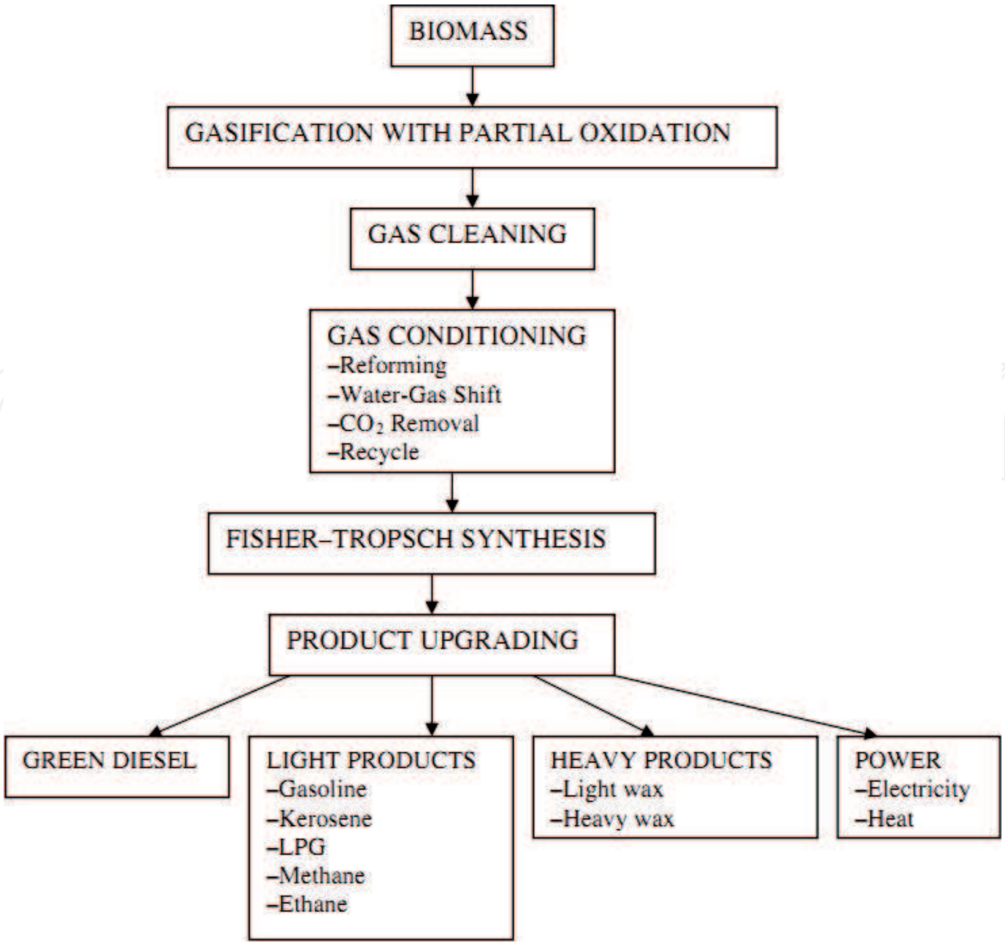

Figure 20.
Products obtained from biomass by Fischer-Tropsch synthesis [20].

is a promising energy conversion technology with its flexible, efficient, and environmentally adaptable features [17]. Besides, the most important feature of gasification is its high electrical efficiency. In the future, it is expected to be used instead of natural gas or diesel fuel in gas turbines or fuel cells, industrial boilers, and furnaces, to replace gasoline or diesel in internal combustion engines [19].

4.1.3 Combustion

The process of biomass giving a fast chemical reaction with oxygen is called burning. As a result of combustion, heat, carbon dioxide, water vapor and some metal oxides are given to the environment [15]. The biomass and full combustion components are given in **Figure 21**.

Industrial and commercial combustion plants can burn a wide variety of fuels, from tree biomass to urban solid waste. Furnaces are the simplest combustion technology, and biomass burns in a combustion chamber. Combustion technology can be divided into two main categories as grate burner and fluid bed burner. In biomass combustion plants, a high-temperature and high-pressure steam is obtained as a result of combustion. This steam is passed through the turbine and converted into electrical energy with efficiency in the range of 17–25%. It can be increased up to 85% with efficient cogeneration systems [3, 19].

Pellets are generally solid wood particles with a cylindrical diameter of 10 mm and a length of less than 35 mm. Pellets produced from wood or waste wood are used to generate electricity in cogeneration systems, for heating in residences and industry. Wood pellets are the fuel with the highest thermal value after coal [22]. A comparison of the higher heat values of biomass and coal are given in **Table 8**.

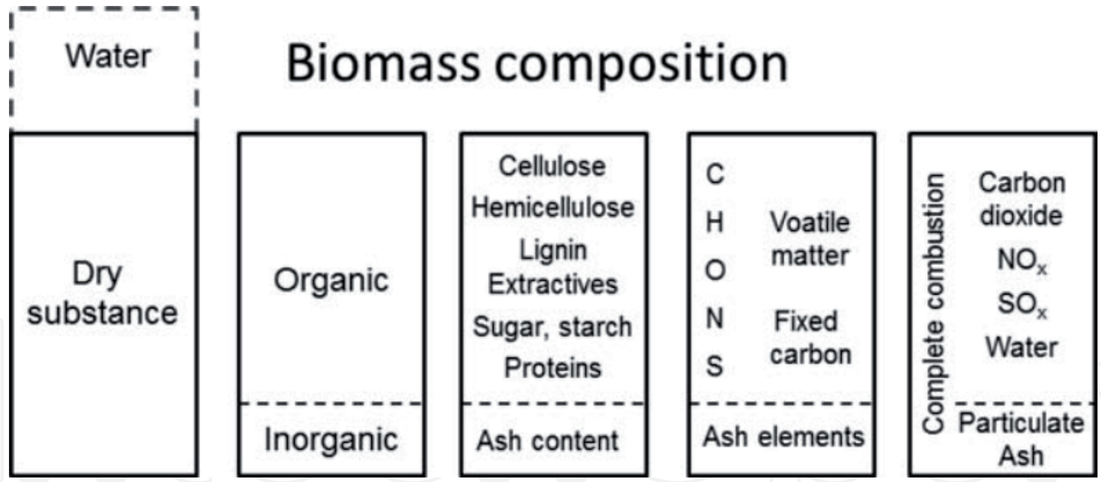

Figure 21.
The components of the biomass [21].

Fuel form	HHV (MJ/kg)
Wood	10–20
Vineyard pruning	14–18
Rice husk	12–14
Sawdust	12
Wood pellets	20
Coal	28

Table 8.
A comparison of the higher heat values of biomass and coal [22].

4.2 Biological process

4.2.1 Fermentation

It contains hemicellulose and lignin in different amounts in the biomass. Glucose can be obtained from cellulose using enzymes with chemical hydrolysis or after enzymatic hydrolysis with chemical processes. This process must be done with extreme care, as glucose can sometimes degrade during chemical hydrolysis. By fermentation of glucose, many chemical products can be obtained such as ethanol, acetone, and butanol which are equivalent to products from crude oil [15].

4.2.2 Digestion

Anaerobic digestion is a biological process and can take place in a completely oxygen-free environment. It is done by microorganisms that can live in an oxygen-free environment. The process is given in Eq. (2):

$$\text{Organic matter} + \text{bacteria} + \text{water} \xrightarrow{\text{heat}} \text{methane} + \text{carbon dioxide} + \text{hydrogen, sulfur} + \text{stable, fertilizer} + \text{bacteria} \tag{2}$$

Biomass can be separated by microorganisms through fermentation in an oxygen-free environment. End of the fermentation process, a valuable fertilizer, and gases such as methane and carbon dioxide products can be obtained [15].

Anaerobic digestion (AD) is a process of producing flammable gas, consisting of methane and carbon dioxide at a rate of 60:40 using microbes in an oxygen-free environment. Therefore, the biogas production process is a complex and sensitive process that contains many microorganism groups. Biogas is a flammable gas formed by decomposing biological wastes in an oxygen-free environment. Biogas approximately contains 50–60% methane gas. Biogas is a colorless, flammable gas. In addition to this, biogas consists of its main components such as methane and carbon dioxide. Besides, it contains a small amount of hydrogen sulfide, nitrogen, oxygen, and carbon monoxide. Generally, 40–60% of organic matter is converted to biogas. The general composition of biogas consists of 60% CH_4 and 40% CO_2, and its thermal value is 17–25 MJ/m^3. The remaining waste is an odorless solid or liquid waste suitable for use as fertilizer. After producing methane gas, methane gas can be used instead of LPG with very small changes. This gas can be used in spark ignition engines, gas turbines, and fuel cells [3, 16, 23, 24]. The components of biogas are given in **Table 9**.

Methane, CH_4	55–75%
Carbon dioxide, CO_2	25–45%
Carbon monoxide, CO	0–0.3%
Nitrogen, N_2	1–5%
Hydrogen, H_2	0–3%
Hydrogen sulfide, H_2S	0.1–0.5%
Oxygen, O_2	Traces %

Table 9.
Composition of biogas [24].

Biogas is a gaseous fuel as an alternative to natural gas. Thus, it can be used in the following fields: direct heating, motor fuel, turbine fuel power generation, fuel cells, additives for natural gas, and in the production of chemicals [23]. Flow diagrams of biogas production facilities are given in **Figures 22** and **23**.

4.2.3 Biophotolysis

Hydrogen and oxygen can be obtained by the biophotolysis process using some microscopic algae. These algae use solar energy in seawater, so they can work as a kind of solar cell. Thus, the microscopic algae can separate seawater photosynthetically to hydrogen and oxygen [15].

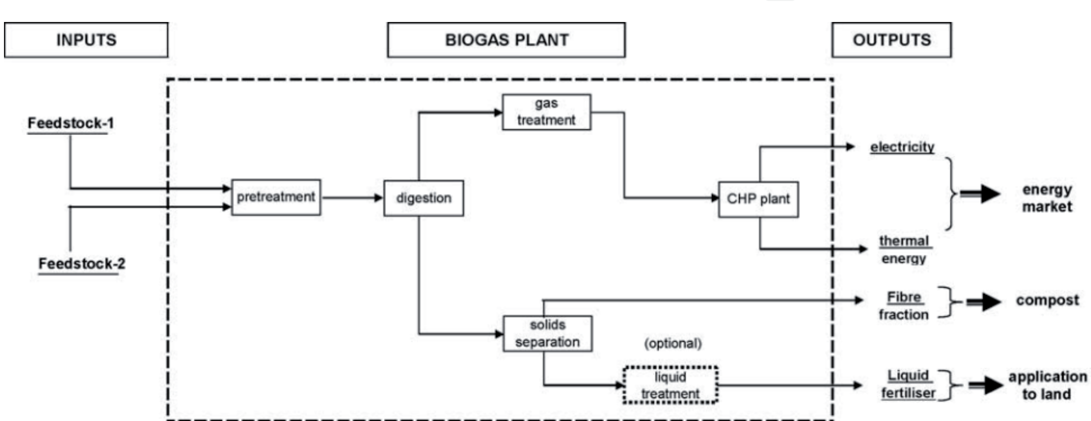

Figure 22.
Flow diagram of the biogas production facility [24].

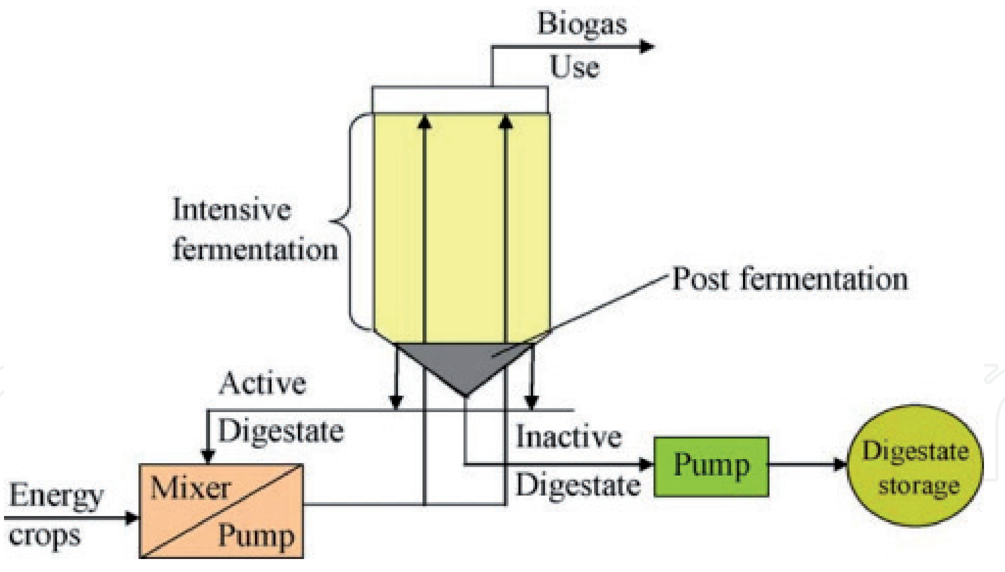

Figure 23.
Flow diagram of dry fermentation [24].

5. Conclusions

The study concludes that biomass energy in Turkey is seen as one of the most sustainable and promising renewable energy sources. Forest bioenergy potential can be converted to alternative biofuels. This process consists of the most common biomass conversion methods such as thermal processes, biological processes, and biophotolysis processes. The thermal processes consist of pyrolysis, gasification, and combustion, while the biological processes are fermentation and anaerobic digestion. Thus, forest bioenergy potential can be used for producing energy. In this regard, forest wastes or forest biomass can be turned into pellets and used in electricity generation in power plants. In addition to this, pyrolysis, gasification, fermentation and anaerobic digestion methods, alcohol, and biogas can be produced from forest wastes and used in the residential industry and transportation. Especially, bio-oils and bio-alcohols can be used in internal combustion engines, furnaces, or boilers as fuel. Besides, biogas also is used as a fuel in households or industry. Thus, Turkey can be reduced to its dependence on foreign energy demand due to the advantage of the rich forest resources. Besides, it is obvious that rich forest resources will contribute to both the ecological and socioeconomic structures of countries. Overall, the rich forest biomass potential is not only contributed to countries' economic field but also the ecological and socio-economic.

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Abbreviations

CH_2O	carbohydrate
CH_4	methane
HHV	higher heating value (MJ/kg)
LPG	liquefied petroleum gas
Mtoe	million tons of oil equivalent
MW	megawatt

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