Exploring of Biomass Energy Specific to Turkey and on a Global Scale

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Received: 06.04.2023 Accepted:30.05.2022

Abstract- In this study, the potential of biomass energy in Turkey and on a global scale, production and usage amounts, the status of biomass power plants, current problems, the importance of forest-based biomass energy in terms of renewable energy and successful country examples in forest and energy relations are examined in detail. Especially the biomass energy potential of the Central Anatolia region of Turkey is over 8 billion kWh. However, annual bioethanol and biodiesel production amounts are low in Turkey. Moss with high energy density is an important biomass energy source candidate for Turkey, which is surrounded by seas on three sides. New factories to be established in the southeastern part of the Marmara region, which has a high biomass energy potential, should be established in regions with low energy potential. Contrary to EU countries, heat generation from urban waste has started in Turkey since 2015. Therefore, the waste collection approach should be expanded. As in the example of UK, the importance of determining the necessary incentives in Turkey's energy crop cultivation has been demonstrated. Within the scope of forestry activities in Turkey, 25% of the forest-derived material remains in the forest. In this study, the importance of converting this material into biogas or evaluating it as wood pellets was emphasized. This study will make a positive contribution to the increase of domestic production in Turkey, to provide cheaper energy supply, to reduce dependency on foreign countries in energy demand, to increase employment, to reduce greenhouse gas emissions and carbon footprint.

Keywords Renewable energy, biomass energy, forest, organic waste.

1. Introduction

With the industrial revolution, technological developments, socio-economic developments and rapid population growth, people's need for energy has increased considerably [1]. In order to meet the increasing energy need, the use of fossil fuels and other non-alternative energy sources has increased considerably. This increase has caused negative consequences such as global warming, changes in precipitation regime, forest fires and greenhouse gas effect. Today, 81% of the global energy demand is provided from energy sources that have no alternative. In the 1960s, the tendency towards renewable energy has increased considerably due to the emergence of environmentalist movements, the fact that energy sources with no alternatives will be exhausted in the near future, and the destruction of nature [2]. Alternative energy is an energy source with much less greenhouse gas emissions and environmental pollution than fossil fuels. Therefore, it is also defined as “green” or “clean” energy for renewable energy [3]. Among the main alternative energy sources, biomass, solar, wind and geothermal are among the leading sources [4]. The IPCC's Sixth Assessment Report focused on reducing greenhouse gas emissions and preventing the negative effects of global warming. For this purpose, the target of limiting global warming to 1.5-2°C at the end of the 21st century has been set. In addition, in the IPCC's Sixth Assessment Report, the target of achieving net zero greenhouse gas emissions by 2050 has been set. After 2050, it is among the plans that greenhouse gas emissions will be at net negative emission values [5]. In order to reach these targets determined on a global scale and in accordance with the Paris Climate Agreement provisions, countries are following strategies to benefit more from

renewable energy sources and increase diversity. In addition, countries have started to follow the strategy of contributing to the process with research and development (R&D) studies, incentive and support policies related to renewable energy technologies [6]. Despite this situation, the process of replacing fossil fuels with renewable energy sources is progressing slowly. The main reason for this situation is that renewable energy technologies are new and therefore energy production costs are high [7].

Biomass energy is a type of energy used to meet the needs of people such as heating, electricity or liquid fuels by using traditional or modern technological conversion methods of all kinds of waste and residues of all kinds of biological origin [8]. As a source of energy, biomass contains a wide variety of waste and residual raw materials from agriculture, forestry, industrial, urban, livestock and marine areas [9]. Biomass is represented by cellulose, hemicelluloses, lignin, extractants, lipids, oil, proteins, simple sugars, starches, water, hydrocarbons, ash, and carbon, hydrogen, oxygen and nitrogen forming many components, as an elemental composition [10].

Bioenergy is the most common energy source used on a global scale and has a history as old as human history [11]. Biomass energy is preferred because of its low nitrogen, low sulfur, low ash and almost zero net CO_2 emissions qualities [12]. In addition, no sulfur is produced during energy production from biomass. It has many advantages in reducing greenhouse gas emissions, preventing climate change, and being the only energy source that can transform into solid, liquid and gaseous forms. It has the feature of being combustible with coal in thermal power plants and emits less CO_2 when it is burned together [13]. The residues formed in power plants after energy production from biomass offer the opportunity to renew soils, increase biodiversity, increase water retention and soil fertility [14]. Furthermore, biomass energy systems offer advantages compared to other renewable energy sources, especially in terms of installation, operation and maintenance costs [15]. For this reason, countries are very enthusiastic about the widespread use and further production of biomass energy [16].

Turkey has aimed to increase its installed power based on biomass and geothermal energies to 2,884 MW, 10,000 MW in solar, 11,883 MW in wind and 32,037 MW in hydroelectricity by 2023, and it has been successful in these targets [17]. However, the installed power of biomass energy was less than other renewable energy sources. Turkey's primary energy consumption is aimed to be 48.7 MTEP energy equivalent in 2035 and to have a 23.7% share of total primary energy consumption. Renewable energy sourced electricity installed power is targeted to meet 64 percent of the total electricity installed power in 2035. In this context, Turkey aims to reach 5.1 GW of installed power based on biomass and geothermal energies, 52.9 GW in solar, 29.6 GW in wind and 35.9 GW in hydroelectricity by 2035 [18]. Turkey is in the position of a country with an extremely high biomass energy potential due to its geopolitical and geostrategic location. In this study, it is aimed to present the current and future potential of bioenergy in Turkey and on a global scale, the production and usage amounts, the importance of forest-derived biomass in Turkey in terms of renewable energy and to provide detailed solutions to the existing problems encountered.

2. Biomass Energy on a Global Scale

Bioenergy currently accounts for at least 10% of the global primary energy supply [19]. In order to meet the increasing energy demand, it is predicted that energy production from biomass will increase on a global scale. It is also in the position of the most widely used renewable energy source due to the availability of biomass raw material throughout the year [20]. The increase in the production and consumption of bioenergy on a global scale offers great advantages over fossil fuels in order to maintain global energy security with stable economic development, effective energy use structure, decreasing ecological pollution and greenhouse gas emissions [21, 22].

2.1. Biomass Energy Potential

According to the IRENA 1.5°C Scenario, it is predicted that only agricultural and forestry biomass energy potential can be used in the electricity, heat and transportation sectors in the range of 97 EJ to 147 EJ on a global scale in 2030. According to this scenario, it has been emphasized that there is a producible energy potential of 37 EJ to 66 EJ from agricultural residues and waste, 33 EJ to 39 EJ from energy crops, and 24 EJ to 43 EJ from forest products including forest residues [23]. Based on these sources alone, it is predicted that there will be a potential of at least 200 EJ in 2050. However, in order to achieve the desired targets, less forest waste and residues are left in the production areas and more energy crop cultivation is among the main parameters to be applied at the point of reaching the targets. Data on the technical potential of biomass energy for 2050 are shown in Table 1. The potential outlined here is dependent on available technologies and thus changes as technology progresses [24].

Table 1. The potential of global bioenergy supply in 2050 [25]

Biomass category	Technical potential in 2050 (EJ/year)
Production of energy crops on excess agricultural land	0–700
Production of energy crops on marginal land	60–110
Agricultural residues	15–70
Forest ruins	30–150
Manure	5-55
Organic waste	5-50
Total	50–1100

The technical potential of biomass energy in 2050 is between 50 EJ and 1100 EJ energy values. Climate, the amount of environmental and industrial waste to be converted into biomass energy, the efficiency of conversion technologies in which biomass material will be converted into energy, and the contribution of renewable energy materials such as moss

in the status of a new biomass energy source are among the most important parameters that will determine the amount of energy production from biomass in 2050.

2.2. Biomass Energy Production Amounts

Biomass-derived fuels are produced as solid, liquid (bioethanol, biodiesel and bio-oil/bio-crude) and gaseous fuels (biohydrogen, biogas, synthesis gas) depending on the energy conversion method and raw material [26]. These produced solid, liquid and gaseous fuels are used for heating, electricity generation and fuel-oil production by using modern biomass conversion methods [27].

Countries have been working on modern transformation methods in recent years. In addition, biomass is the only renewable energy source that can be transported, stored and used through the existing fossil fuel infrastructure [28]. Thus, it offers the opportunity to produce energy from biomass at almost any time of the day [29]. It is predicted that this uninterrupted production biomass can provide 3,000 TWh of electricity until 2050 and save 1.3 Bt of CO2 equivalent per year [30]. World renewable energy supply, electricity generation and heat generation are given in Table 2.

Table 2. World renewable energy supply, electricity generation and heat generation [31, 32]

Source (Year 2021)	**World renewable energy supply (EJ)**
Solar	5
Wind	7
Hydro	16
Modern solid bioenergy	36
Modern liquid bioenergy	4
Modern gaseous bioenergy	1
Other renewables	5
Traditional use of biomass	24
Source (Year 2021)	**Global renewable electricity production (TWh)**
Solar PV	1,003
Wind	1,870
Hydro	4,327
Bioenergy	746
CSP	15
Geothermal	97
Source (Year 2020)	**Heat generation from renewables and waste by source (TJ)**
Primary solid biofuels	620,192
Industrial waste	229,650
Biogases	52,173
Geothermal	48,686
Liquid biofuels	4,050
Solar thermal	2,817

In 2021, the total biomass energy supply on a global scale was 65 EJ. Biomass energy has the largest share among the resources in renewable energy supply. The main reason for this situation is that the biomass material is storable, has long-term storage conditions, responds to different types of energy needs, especially electricity, heating and fuel consumption, and is not affected by light intensity are among the factors that affect energy production from biomass [33]. In 2021, the highest electricity production in terms of renewable energy sources was 1003 TWh in Solar PV systems. This value was realized as 746 TWh in total in biomass energy. In 2020, most of the heat generation from renewable sources and waste was produced from biomass energy. In 2020, a total of 906,065 TJ of biomass-based heat production was realized. The main reasons for the amount of heat production from biomass are that biomass energy material is very common on a global scale, easy access as an energy raw material, and the use of bioenergy is as old as human history. Biomass can be used in energy conversion with different biochemical and thermochemical conversion technologies such as combustion, pyrolysis, gasification and liquefaction [34]. The fact that biomass power plants are less affected by climatic conditions than other renewable energy crops, the availability rate of power plants, the higher average operating time and the high capacity factor are among the reasons why biomass energy production is higher on a global scale [35].

Globally, hydrotreated vegetable oil (HVO), biodiesel and ethanol are less environmentally harmful transportation fuels than fossil fuels. However, production costs and rising prices over time pose great challenges when competing with the traditional oil market [36]. Currently, despite the high oil prices, renewable fuels (biodiesel and ethanol) are more expensive than conventional fuels. Biofuel demand and production may have played a role in rising raw material prices, but global economic growth, population growth, energy price inflation and volatile market condition factors also contributed to raw material price increases. Among a number of factors involved in high biofuel prices, the main reason is raw material, which accounts for 75% of the total product cost [37]. In addition, varying government policies and incentives, processing technologies, land and labor costs in different regions also contribute to biofuel price fluctuations [38]. There are several available technologies and methods for biomass energy conversion. Two common methodologies used to convert biomass into fuel are thermochemical and biochemical conversion. Transesterification is used for first generation biodiesel production [39].

Table 3. Leading countries in biofuel production on a global scale [32]

	Biofuel production production in 2020 (billion liters)	**Biofuel production average target including 2021 and 2025 (billion liters)**
European Union countries	13.6	16.5
United States	8.2	14.2
Indonesia	7.9	10.5
Brazil	6	7
Argentina	6	7

The first technique uses heating for biomass decomposition, while the second uses microorganisms or enzymes to convert biomass into biofuels [40]. World biofuel

production has increased sharply from 9.2 Mt oil equivalents in 2000 to 95.4 Mt oil equivalents in 2018. The leading countries in biofuel production on a global scale are presented in Table 3.

Due to the Covid 19 pandemic, biofuel production amounts have generally been in a decreasing trend. In addition, there has been an increase in the production of hydrogen-treated vegetable oils as the cleanest fuel today. Among European Union (EU) countries, France, Germany, Spain and the Netherlands are among the leading countries in biodiesel and HVO production. With the EU countries, especially Germany's climate protection quota, and France, Italy, Poland and Spain's efforts to use cleaner fuels, it is estimated that biodiesel and HVO production will recover at the end of 2021 and the production has increased to 15.8 billion liters. Anti-dumping duties applied in the USA are among the reasons that increase the production of biofuels in the country instead of importing biodiesel and HVO. In addition, as a result of the conversion of the fossil fuel refinery to biofuel production facilities and the investments made, the amount of diesel obtained from HVO has increased considerably. Indonesia, on the other hand, makes incentives and legal regulations to prevent fuel imports. Brazil and Argentina make the necessary legal arrangements to reduce foreign dependency on fuel, increase the number of biofuel facilities and are in the strategy of increasing industrial plantation forest areas. In addition to land transportation, the annual production volume of biojet fuel used in jets has increased. While biojet production was below 10 million liters in 2018, it is predicted that 1 billion liters will be produced in 2023 and 8 billion liters potentially in 2030 [41].

2.3. Biomass Energy Consumption Amounts

Today, the use of biomass has turned to the use of processes aimed at more efficient consumption, especially pyrolysis, biogas and liquefaction, which are modern biomass conversion methods, instead of classical and direct consumption of firewood and charcoal [42].

Table 4. World primary energy resources consumption [43]

	Year			
	1980	**2000**	**2018**	**2035**
Source	**MTEP/%**	**MTEP/%**	**MTEP/%**	**MTEP/%**
Petrol	3,107/ %43	3,649/ %36.4	4,501/ %31.4	5,053/ %27.1
Coal	1,788/ %24.8	2,295/ %22.9	3,821/ %26.7	5,523/ %29.6
Natural gas	1,235/ %17	2,088/ %20.8	3,273/ %22.9	4,380/ %23.5
Nuclear	186/ %2.6	675/ %6.7	709/ %5	1,019/ %5.5
Hydraulic	148/ %2.1	225/ %2.3	361/ %2.5	460/ %2.5
Biomass	748/ %10.4	1,045/ %10.4	1,357/ %9.5	1,741/ %9.3
Other renewables	12/ %0.1	55/ %0.5	293/ %2	501/ %2.7
Total	7,224/ %100	10,034/ %100	14,315/ %100	18,676/ %100

Today, the demand for energy on a global scale continues to increase. Within the scope of the energy policies implemented by the countries, the energy consumption obtained from renewable sources has tended to increase with each passing time. Starting from 1980, the amount of biomass energy consumption on a global scale within the framework of the 2035 future projection is given in Table 4.

When Table 4 is examined, although biomass energy consumption has increased continuously, the share of biomass energy in primary energy consumption has decreased on a global scale after 2000. The main reason for this situation is the lack of widespread use of modern biomass energy and the developments in investments and technologies in other renewable energy sources. In addition, climate change and global warming are among the reasons that prevent energy production and consumption from biomass. According to the International Energy Agency (IEA) Net Zero 2050 scenario, Table 5 shows the amount of bioenergy consumed in the sector in 2020 and predicted to be consumed in 2050.

Table 5. Bioenergy increase in global final energy consumption by sector [41]

Sectoral use of biomass energy	**2020**	**2050**
Traditional use of biomass (EJ)	25	0
Electricity consumption (EJ)	3	12
Industry (EJ)	9	25
Transportation (EJ)	3	13
Buildings (EJ)	5	11

According to Table 5, the traditional use of biomass energy in 2020 is worth 45 EJ in total, including electricity consumption, industry and transportation. It is predicted that this value will be 61 EJ in 2050. The amount of traditional bioenergy consumption in 2020 was 25 EJ. With the increase in the use of HVO, biodiesel, bioethanol and moss-based fuel, 13 EJ of biomass energy for transportation purposes is expected to be used in 2050. With the developing modern bioenergy conversion methods, it is predicted that there will be no energy consumption from traditional bioenergy use in 2050. The bioheat produced and distributed for use in buildings and industry in 2020 is projected to be at the level of 35 EJ, mostly through central heating systems and generally using cogeneration systems. In order to reach the targets in 2050, the conversion of solid biofuels obtained from wood processing, forestry and agricultural residues and solid wastes into energy with modern biomass conversion methods is one of the important parameters for the 2050 targets. At the same time, it needs to be in a sustainable understanding. In addition, the supply of raw materials for liquid and gaseous biofuels should expand. In addition to this, combined heat power systems should be used more.

3. Biomass Energy in Turkey

Today, all countries on a global scale, especially Turkey, are in the strategy of increasing the amount and diversity of energy obtained from renewable energy sources. Recently, domestic and renewable energy investments in Turkey continue to increase. In this context, it is planned to increase its installed power of renewable energy, especially biomass

energy, and to commission its first nuclear power plant in 2023 [44]. Turkey's installed capacity of biomass energy and its share in total installed power are given in Table 6.

Table 6. Turkey's biomass energy installed power and its share in total installed power [45]

Year	Installed power (MW)	Share in total installed power (%)
2011	115	0.22
2012	159	0.28
2013	224	0.35
2014	288	0.41
2015	362	0.50
2016	489	0.62
2017	634	0.74
2018	811	0.92
2019	1,163	1.27
2020	1,485	1.55
2021	2,035	2.04
2022 June	2,173	2.14

Biomass energy has the least share in the total installed power of power plants in Turkey. The need for biomass energy is increasing in order to meet the electricity, heat and transportation needs in Turkey. The installed power of biomass energy in Turkey has also tended to increase each year.

3.1. Biomass Energy Potential

Turkey is an extremely rich country in terms of biomass energy potential. The main reasons for this situation are four climates, being at the intersection of the continents of Europe, Asia and Africa, the diversity of agricultural products and the high amount of urban and industrial waste. Turkey's biomass energy potential is detailed in Fig. 1.

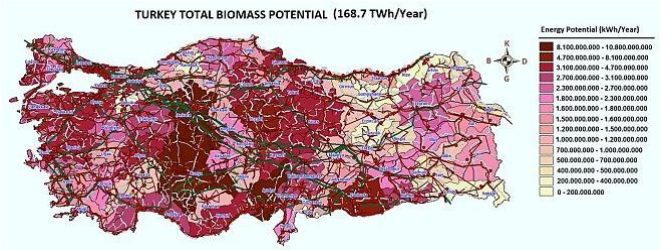

Fig. 1. Turkey's biomass energy potential [46]

Turkey's biomass energy potential atlas is a Geographical Information System application that presents up-to-date with numerical and graphical expressions how much electricity, heat and biofuel potential there is from which biomass source in Turkey, both on a general and local scale. In addition, in which regions of the country biomass resources are concentrated and biomass energy potential analysis can be done. In the studies of various researchers on the biomass energy potential in Turkey, there may be differences in the predictions of Turkey's biomass energy potential due to the material used, the calculation method and the accepted energy density values. The Central Anatolia region, which has the characteristics of a granary of Turkey, is very rich in terms of agricultural product diversity and amount, and animal biomass energy material. The Eastern Anatolia region, the east of the Black Sea region and the southeastern part of the Southeastern Anatolia region have less energy potential than other regions in terms of biomass energy potential. The main reasons for this are the high altitude, the rough terrain and the amount of living population. Although the annual biomass energy potential reaches up to 8 billion kW in the Central Anatolian region of Turkey, the amount of energy production from biomass energy and the installed power of the power plants are higher in the western regions with lower biomass energy potential. The reasons for the inefficient and effective use of biomass energy potential in Turkey can be cited as the lack of transportation and infrastructure, burning of stubble, small business farming, inadequacy of facilities and conversion technology, and delayed legal regulation and incentive steps [47]. Turkey's biomass energy potential for 2022 is given in detail in Table 7.

Table 7. Turkey's biomass energy potential [48].

	Potential
Population	82,003,882
Number of animals (pcs)	422,832,374
Amount of animal waste (tons/year)	193,878,079
Theoretical energy equivalent of animal wastes (TEP/year)	4,385,371
Economic energy equivalent of animal wastes (TEP/year)	1,084,506
Crop production amount (tons/year)	171,399,002
Amount of vegetable waste (tons/year)	62,206,754
Theoretical energy equivalent of plant wastes (TEP/year)	25,384,268
Economic energy equivalent of plant wastes (TEP/year)	1,462,159
Amount of municipal waste (tons/year)	32,170,975
Theoretical energy equivalents of municipal wastes (TEP/year)	3,373,011
Economic energy equivalents of municipal wastes (TEP/year)	485,858
Forest asset residues (ster/year)	3,914,904
Energy equivalent of forest asset residues (TEP / year)	859,899
Biodiesel processing license holders	8
Bioethanol processing license holders	5
Number of biomass sourced power generation plants	199
Total energy equivalent of wastes (TEP/year)	34,002,549
Total economic energy equivalent (TEP/year)	3,900,000

According to the studies carried out, it has been stated that the biomass energy potential of Turkey is between 14 MTEP and 32 MTEP [47]. According to the data of the Ministry of Energy and Natural Resources, the economic energy equivalent of Turkey's total waste is at the level of 3.9 MTEP. Considering only animal manure in Turkey, there is a potential to produce biogas corresponding to approximately 1-2 million tons per year by fermentation in anaerobic conditions [49]. According to IEA, Turkey's biomass potential is around 100

TWh [32]. Biogas potential varies between 17.4 TWh and 23.3 TWh. The reason for this difference in all studies is the difference in the calculation method, the differences in the accepted energy density values of the materials and the differences in the material selection that can be seen in the biomass energy potential [17].

3.2. Energy Production from Biomass

In Turkey, energy is produced from forestry, agricultural, urban, industrial and animal biomass. Turkey's renewable energy electricity installed capacity and production by years are given in Table 8.

Table 8. Turkey's renewable energy electricity installed power (MW) and production (GWh) by year [50]

	Year					
Source	**2010**	**2015**	**2020**	**2021**	**2022**	**2023**
Hydraulic (MW)	15,831	25,868	30,984	31,493	31,689	32,605
Wind (MW)	1,320	4,503	8,832	10,607	11,232	11,883
Solar (MW)	0	249	6,667	7,816	8,700	11,700
Biomass and geothermal (MW)	191	986	3,098	3,712	3,932	4,088
Total (MW)	17,342	3,606	49,582	53,627	55,553	60,276
	Year					
Source	**2010**	**2015**	**2020**	**2021**	**2022**	**2023**
Hydraulic (GWh)	51,795	67,146	78,094	55,927	73,666	75,723
Wind (GWh)	2,916	11,652	24,828	31,437	34,141	34,836
Solar (GWh)	0	194	10,950	13,943	14,878	18,007
Biomass and geothermal (GWh)	1,126	5,183	15,764	18,572	19,667	20,447
Total (GWh)	55,838	84,175	129,637	119,879	142,351	149,014

Table 9. Distribution of turkish electric power generation by resources in 2021 [51]

Source	**Production (GWh)**	**Contribution (%)**
Imported coal	54,948.40	16.42
Hard coal + asphaltite	5,450.30	1.63
Lignite	42,983.30	12.84
Natural gas	111,180.80	33.22
Liquid fuels	281.5	0.08
Hydro dams	40,746.30	12.17
Lake and stream	15,180.50	4.54
Wind	31,436.70	9.39
Renewable+waste+waste heat	7,779.10	2.32
Geothermal	10,793.20	3.22
Sun	13,942.90	4.17
Total	334,723.10	100

Turkey's biomass and geothermal energy installed power and its share in electricity generation are increasing every year. Investments and incentives for biomass and geothermal power plants, which are less affected by climatic conditions and have very good operational performance, have been increasingly continuing in Turkey in recent years. The distribution of Turkey's electricity generation in 2021 by resources is shown in Table 9.

In Turkey, electricity generation from total biomass energy, including liquid biofuels, is 8,060.6 GWh, contributing 2.4 percent to total electricity generation. Electricity generation from biomass energy has not been realized at the desired level due to many parameters such as the prevalence of traditional transformation technology in Turkey, the inclusion of urban waste in the waste category in 2015, infrastructure inadequacies, the distance between biomass energy raw materials and power plants. Turkey's heat production by source is given in Table 10.

Table 10. Turkey's heat production by source [41]

	Turkey's heat production by source (TJ)				
Year	**Coal**	**Fuel oil**	**Natural gas**	**Biofuel**	**Waste**
2000	916	1,124	14,143	0	0
2010	863	939	49,315	213	0
2015	3,055	2,261	33,666	1,655	859
2021	3,883	2,428	34,157	6,142	1,523

In Turkey, a total of 7,665 TJ heating needs are met from biofuels and wastes in 2021. Today, cooking and heating in a stove fire are traditionally at the forefront of energy production methods from biomass. The most widely used modern methods of producing heat from biomass are conversion to bioenergy by thermochemical, biological and chemical processes [52]. Thermochemical conversion of biomass is the most common. Traditional biomass conversion methods are widely used in Turkey. Turkey's coal production and imported coal use are still high today. At this point, biomass energy is the only renewable energy source that can be used for heating purposes. Wood pellet, which is known as a biomass energy source, is much less costly than coal, fuel oil and natural gas. In addition, it is a good alternative for heating in housing and industry because it has less greenhouse gas emissions, is domestic and has carbon neutral properties [53]. Stubble burning, the distance of power plants from raw materials, the use of agricultural biomass in animal feed or housing construction, competition with the food sector, transportation costs and the late inclusion of urban wastes in the waste category are among the main reasons why Turkey could not meet its heating needs from biomass energy.

With modern conversion technologies, biomass can be used more effectively and efficiently to meet the heat, electricity and fuel needs. Today, biomass conversion processes and technologies contribute to the understanding of modern biomass energy production. These processes consist of physical processes, thermochemical processes, and biological and chemical processes [54]. Efficiency can be increased up to 85% with cogeneration processes that will provide high efficiency based on the principle of combined heat and power system, especially forest residues, residues obtained by pruning, wastes generated by energy crops, paper,

mining pole industry wood and other forest industry wastes [55]. In Table 11, Turkey's current and planned bioenergy production by years is indicated separately as traditional and modern methods.

Table 11. Current and planned bioenergy production in Turkey [25]

Year	Modern biomass (TEP)	Classical biomass (TEP)	Total (TEP)
2008	1,640	5,976	7,616
2010	1,710	5,754	7,464
2012	2,121	5,364	7,485
2014	2,543	5,082	7,625
2016	2,854	4,856	7,710
2018	3,284	4,568	7,852
2020	3,598	4,234	7,832
2022	3,860	3,976	7,836
2024	4,086	3,785	7,871
2026	4,472	3,556	8,028
2028	4,732	3,322	8,054
2030	4,940	3,300	8,240
Total	39,840	53,773	93,613

While energy production from biomass energy has increased in time with modern methods in Turkey, the classical energy production method, which is used by more undeveloped or developing countries, has become less preferable. It is foreseen that the biomass energy production planned in Turkey in the following years will produce almost equal energy with the classical method and the modern method in 2022. For the first time in 2024, it is planned that Turkey's bioenergy production with modern methods will be higher than the amount of bioenergy obtained from traditional methods. The amount of biomass energy produced and planned by Turkey between 2008 and 2030, as of total modern resources, was 39,840 TEP, while the amount of bioenergy realized with traditional methods was 53,773 TEP. Thus, it is predicted that the total amount of bioenergy will be 93,613 TOE. Turkey's electricity and heat production from biomass energy is given in Table 12.

Table 12. Heat (TJ) and electricity (GWh) generation from Turkey's biomass energy [31]

	Year		
Source	**2010**	**2015**	**2021**
Biogas (TJ)	213	1,626	4,514
Industrial waste (TJ)	0	859	0
Primary solid biofuel (TJ)	0	29	1,628
	Year		
Source	**2010**	**2015**	**2021**
Biogas (GWh)	296	1,208	4,254
Industrial waste (GWh)	14	22	15
Primary solid biofuel (GWh)	36	32	1,959
Liquid biofuel (GWh)	0	2	54
Municipal waste (GWh)	0	0	17

In Turkey, biomass-based heat generation in 2010 was mostly from biogas with 213 TJ. In 2021, biomass-based heat production was provided by biogas with a maximum of 4,513 TJ, and primary solid biofuels ranked second with 1,628 TJ. Biomass-based electricity generation in Turkey in 2010 was realized from biogas with a maximum of 296 GWh. In line with the investments and technological developments made in Turkey, the highest electricity production from biomass in 2021 was 4,254 GWh from biogas. This value was realized as 1,959 GWh from primary solid biofuels. Electricity generation from urban waste in Turkey took place after 2018. Electricity generation from liquid biofuel started in 2014. Electricity production from liquid biofuel in Turkey reached 2 GWh in 2015. Turkey has switched to modern biomass conversion technologies later than the United Kingdom (UK) and EU countries. Despite this, it has recorded a very significant energy production in heat and electricity production from biomass in a short time. The reason for this increase is the energy policy that prioritizes the use of domestic and renewable energy [56].

Fast growing tree species, especially poplar, willow and acacia, are used as a source of biofuel for transportation purposes. Molasses is added to agricultural products, wastes and residues and transferred to bioreactors. Agricultural crops transferred to these bioreactors are used today in the production of bioethanol by fermentation method [57]. In addition, vegetable oils and energy crops are also used in the production of biofuels. The most widely used biofuels on a global scale are biodiesel, bioethanol and HVO. In Turkey, approximately 74,800 tons of biodiesel and 46,500 tons of bioethanol were produced from biodiesel and bioethanol in 2020. A total of 121 thousand 300 tons of biofuels were produced in Turkey from biomass. With this production, import fuel supply of approximately 50 million US dollars has been prevented [49]. However, there was no HVO production in Turkey. With the recent developments, the number of companies holding biodiesel and bioethanol processing licenses in Turkey has increased significantly [48]. Algae is among the newest renewable energy sources that can be used as rocket and jet fuel. In this context, Europe's first carbon-negative integrated biorefinery was established on the Boğaziçi University Sarıtepe campus. In this context, Turkey's ongoing R&D and infrastructure work continues unabated.

3.3. Energy Consumption from Biomass

Developing technology and population growth have increased the demand for energy day by day. Electricity consumption, which was 230.306 GWh in Turkey, was realized as 306.9 GWh in 2020 [58]. In order to meet the increasing energy demand, Turkey is in the strategy of increasing the amount of energy obtained from domestic sources. The final consumption of some energy resources in Turkey is given in Table 13.

Table 13. Final consumption of some energy resources in Turkey [59]

Source (TJ)	2010	2020
Petroleum products	1,188,601	1,671,323
Coal	620,572	513,103
Natural gas	550,039	1,116,314
Renewable waste and biofuels	185,963	108,961
Other renewables	76,334	117,105

In Turkey, the most consumed renewable energy source in 2010 was biomass. Energy consumption from biomass in Turkey was 185,963 TJ in 2010 and this value was 108,961 TJ in 2020. Between 2010 and 2020, energy consumption from biomass decreased by 77,002 TJ in Turkey. Since biodiesel and bioethanol production is very low and there is no HVO production in Turkey, it is accepted that the share of biofuels in transportation does not exist [32]. Biomass-based energy consumption has decreased over time due to Turkey's investment in other renewable energy sources compared to biomass energy, prioritizing natural gas consumption and delaying the transition from classical biomass conversion methods to modern biomass energy conversion methods.

4. The Importance of Forest-Source Biomass in Turkey for Renewable Energy

It is estimated that 840 million people, which corresponds to approximately 12% of the world population, collect firewood and charcoal from forests in order to meet their energy needs [60]. Forest and agricultural waste and residues and energy crops are extremely rich energy sources in terms of lignocellulosic material [61]. Bioelectricity from lignocellulosic-rich materials has the potential to provide 6.2% of all global renewable energy by 2050 [62]. Forests have many ecosystem services such as being a carbon sink, being used as an energy source, ensuring the sustainability of the ecosystem and preventing greenhouse gas emissions accumulating in the atmosphere. Today, forest-derived biomass is used in electricity generation, heating and fuel production. Cycle technologies used to convert forest-derived biomass into energy are pyrolysis, gasification, fermentation and anaerobic digestion methods [55]. In addition, air between 7 m3 and 9 m3 is needed to burn one kilogram of wood, while 15 m3 to 17 m3 of air is needed for lignite or hard coal. Wood needs less air than other fossil fuels and has the ability to give off heat in a short time [63]. Forest biomass and other solid biomass offer positive properties such as renewability, carbon-neutrality, versatility, high reactivity, high specific surface area, and low sulfur and ash content for some biomass types, locally available and low cost [64]. Forest biomass and other solid biomass have some negative aspects compared to fossil fuels such as low calorific value, low bulk density, poor grindability, low energy density and high moisture content [16]. The main parameters that are considered important for the transformation of forest biomass for thermochemical processes, which are among the modern bioenergy methods, are elemental composition, ash content, volatile matter content, moisture content, heating value and mass density. It is very important to evaluate the material to be converted into energy according to these parameters [65]. Originating from the manufacture of wood and its products, Turkey obtained 2.145 GWh of electricity and 65,000 TEP of heat. Turkey has obtained 16,000 tons of waste bioenergy material from the manufacture of paper and its products. While Turkey obtained 3.791 GWh of electricity from the manufacture of paper and products in 2020, it obtained 194,000 TEP of heat [66].

During forestry production activities in Turkey, at least 25% of the production residue of the tree is left in the forest. At the end of forestry production activities, leaving some biomass residue in the forest at the production site has a positive effect on the supply of organic matter and nutrients to the soil, the preservation of the soil microclimate, the soil carbon concentration and the future forest production activities [67]. However, the amount of forest waste and residue left in the production area as a result of forestry activities in Turkey is very high. It has been estimated that 5 million m3 of forest remains remain in the field in Turkey today [68]. The main reasons for this situation are transportation costs, technological inadequacy and possible damage to forest youth while removing the remains from the field. If this biomass remaining in the forest were produced as wood pellet, 0.57% of Turkey's total primary energy consumption in 2015 would have been met from wood pellets alone [53]. Comparison of heat values of biomass and coal is given in Table 14.

Table 14. Comparison of higher temperature values of biomass and coal [69]

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

Although the energy density value of wood pellet is less than coal, it provides advantages in many ways, especially in efficiency. The cost of wood pellet is less than natural gas and coal. The use of wood pellets will be beneficial in reducing energy imports. With the use of wood pellets, a family produces 5 tons less greenhouse gas emissions per year compared to Fuel Oil, and it has the opportunity to reduce at least 2.5 tons of greenhouse gas emissions annually compared to natural gas use [70]. In addition, the use of wood pellets provides less CO2 and SO2 emissions than natural gas and coal. A family living in Turkey consumes firewood to meet their annual energy needs of 5 ster. The amount of 13% of a wood burned with traditional methods can be used effectively and efficiently to meet the energy requirement. The remaining 87% is not used effectively and efficiently and is released to the atmosphere. The efficiency can be increased up to 85% if the waste and residues obtained from forest-derived biomass are converted into energy by cogeneration processes that will provide high efficiency based on the principle of combined heat and power system [55]. The population of the people living in the forest village by years and the amount of trees cut down are given in Table 15 in detail.

Table 15. Population living in forest village and amount of cut trees in Turkey by years [71]

Year	Population (units)	Amount of trees cut (m^3)
2015	7,096,483	18,326
2016	7,114,577	17,616
2017	7,013,592	20,305
2018	6,827,500	26,483
2019	6,970,077	33,742
2020	7,034,738	68,756
2021	7,451,124	38,783

The number of people living in the forest village of Turkey is about seven million, and the amount of trees cut has tended to increase until 2020. As a result of the study involving 70 villages in the Maçka district of Trabzon, wood was obtained by illegal methods and 92.7 thousand tons of wood was consumed. In other words, the amount of energy at the level of 26,000 TEP could not be used [72]. According to another study covering the interiors of Mudurnu and Yığılca in the city of Bolu in Turkey, it was determined that 70,000 m^3 of wood were obtained from the state forests illegally. In other words, the amount of energy at 33 TEP level was used illegally [73]. In Turkey, approximately 1 million tons of wood from state-owned forests is consumed illegally in order to meet the energy needs of people in the Eastern and Southeastern Anatolia regions.

Forest wastes are used as fuel in the production of bioethanol and biodiesel, especially in Chile, Brazil, USA, Canada and some EU member countries. Especially energy crops, fast-growing tree species grown in industrial plantation areas and vegetable oils are among the most important biofuel sources. Industrial plantation sites are especially in the position of heat and fuel source for the energy sector. When evaluated on a global scale, while the industrial plantation size per country is 7%, it is only 3% in Turkey. Turkey has followed a strategy of increasing the size of industrial plantation areas. From 2009 to 2019, the industrial plantation field size was doubled. In 2019, Turkey's industrial plantation field size is 671,257 hectares [74]. Biophotolysis, which is one of the increasing modern biomass energy conversion technologies, is used as gas oil in the automobile industry and is also used in the field of drying application. Diesel fuel is obtained from vegetable oils by esterification reaction conversion technology and is used as a fuel for heating and especially transportation vehicles.

Grove forests are forests that are grown from seed, have a high genetic diversity, respond to the demands of the forest industry, and are used as a modern biomass energy source today. On the other hand, coppice forests consist of root or stump shoots, do not respond adequately to the demands of the industry, only firewood is obtained from the forest, low genetic diversity and leaving certain biomass material on the field [75]. Coppice forest, grove forest and conversion to grove forest by years are presented in Table 16.

Table 16. Turkey's coppicing forest, grove forest and amount of conversion to grove forest [71]

Year	Coppicing forest (Ha)	Grove forest (Ha)	Amount of conversion to grove forest (Ha)
2005	1,439,595	5,749,152	11,225
2010	4.874,712	16,662,379	78,584
2015	2,723,217	19,619,718	87,275
2019	1,200,166	21.540,131	75,647
2020	1,276,634	21,656,366	72,843
2021	1,276,634	21,833,366	69,341

Turkey has abandoned the coppice forest management logic, which aims to produce only firewood from the forest and is a primitive energy generation strategy, since the beginning of the 2000s. Instead, it has adopted the grove forest management, which is based on the demands of the forest industry and the modern biomass energy generation strategy.Thus, it has made modern biomass energy raw material from root or stump shoots, which can be a national and local energy source [76]. In Turkey, 600,000 tons of firewood was sold in 2020 using modern biomass energy conversion methods [77].

4.1. Sustainability of Forests for Renewable Energy

Forest biomass is an energy source as old as human history as a building material, industrial raw material, fuel, heat and electricity source. In addition, forests have an important share in the absorption of greenhouse gases and harmful gases released by fossil fuels to the environment. Likewise, forest biomass has an important role in reducing the carbon footprint of countries and in the fight against climate change. In addition, natural forest areas are being destroyed due to incorrect land use [78]. It is estimated that greenhouse gas emissions will be 20% less on a global scale if improper land use activities in forests are prevented [79]. In this context, the EU has published the European Green Consensus in 2019, the EU biodiversity strategy for 2030 in 2020, and the new EU forest strategy documents for 2030 in 2021. According to the European Green Deal, it is aimed to reduce greenhouse gas emissions by 55 percent by 2030. In 2050, it was set as a carbon neutral target [80]. The scope of the EU biodiversity strategy for 2030, published in 2020, is mitigating the effects of climate change, fighting forest fires, ensuring food and bioenergy security, continuity of wildlife and illegal hunting [81]. In the new EU forest strategy for 2030, published in 2021, decisions were taken to plant 3 billion additional trees, reforestation of forests, forest restoration, enhanced sustainable forest management and sustainable use of forest-derived biomass by 2030 [82]. It is also aimed to minimize the use of quality round wood for energy production and to minimize energy production by burning logs, veneered logs, logs and roots.

Forests are terrestrial ecosystems that make up and store the most biomass. Therefore, forests have traditionally provided most of the biomass for energy [83]. In general, biomass in forest stands tended to increase over time. In addition, the structure of the stand, the species characteristics of the trees forming the stand, the field quality, individual tree interactions, the amount of cover of the forest area are among the main parameters that affect the amount of biomass accumulation in the forests [84]. In addition, plant diseases also affect forest biomass accumulation [85].

Determining the amount of above-ground forest bioenergy source material has a significant impact on determining the potential of biomass energy, predicting the amount of CO2 emissions into the atmosphere and determining the carbon footprint of the country. Today, geographical information systems, photo interpretation and remote sensing methods are used instead of terrestrial measurements to determine the forest biomass of a country [86]. In Table 17, Turkey's above-ground biomass stocks in the forest and the ratio of forest land to total land size are given as a percentage.

Table 17. Turkey's above-ground biomass stocks and ratio of forest areas to total land size by years [71]

Year	Above-ground biomass stocks in the forest (million tons)	Ratio of forested land to total land size (%)
2010	916	27.1
2011	944	27.1
2012	960	27.2
2013	1,000	27.5
2014	1,014	27.7
2015	1,035	28.1
2016	1,041	28.1
2017	1,031	28.3
2018	987	28.5
2019	1,029	29.2

The amount of above-ground biomass stock in the forest in Turkey was 916 million tons in 2010, and the ratio of forest land to the total country size was 27.1%. The amount of above-ground biomass stock in the forest in Turkey was 1.029 million tons in 2019, and the ratio of forest land to the total country size was 29.2%. In 2020, although the amount of above-ground biomass stock in the forest in Turkey has shown small changes over the years, it has generally been in small fluctuating movements in an increasing direction. Turkey's forest assets have tended to increase continuously, especially with the adoption and implementation of the grow forest management approach instead of coppice forest management. Turkey is moving forward with the strategy of covering 30% of the country's land in the total size of forest areas on the way to which it has progressed in 2023 with the green homeland strategy. In the light of these data, Turkey both increases its forest assets and follows a sustainable policy in terms of energy and raw material supply from forests between 2010-2020. Accordingly, biomass-based energy production is increasing. Determination and monitoring of above-ground biomass stocks in the forest has critical importance in determining the type of biomass power plant to be established, determining the energy production method from forest-derived biomass and ensuring the continuity of forest-derived biomass raw material.

4.2. Examples of Successful Countries in Forest and Energy Relations

Efforts to meet the electricity, heat and fuel needs from biomass energy, which is the most widespread area in the world, continue increasingly. In this context, the interest of countries in renewable energy sources, especially biomass energy, continues to increase over time. The Baltic countries are in a policy of reducing their dependence on natural gas and obtain their heating needs from wood chips and residues. In 2018, at least 50% of the heating need was met from forest-derived biomass. In addition, the transformation of the solid biomass energy materials collected by the municipalities of the Baltic countries consisting of Estonia, Latvia and Lithuania with newer technologies and the technological advances in electricity-operated heat pumps constitute the secret of their success in obtaining energy from biomass [59]. By 2030, it is predicted that the use of biomass for heating will increase rapidly. Denmark's most important renewable energy source is biomass energy. It is a leading player in variable renewable energy system integration and energy saving technologies such as combined heat and power [3]. Aiming to meet all its energy needs from renewable energy sources, primarily forest-based biomass, by 2050, Denmark is rapidly advancing towards its goals with its technology [87]. In Italy, in 2010, 1.3 million tons of wood pellets were imported for the heating of the houses and used to meet the heating need. In addition, Italy used 2.6 million tons of wood pellets for residential heating in 2019. In this context, Italy has followed a method that is cheaper and less harmful to nature than natural gas and coal. In Finland, on the other hand, the use of fossil fuels for energy production is decreasing every year. In 2018, the use of forest-derived wood pellets and chips for district heating and industrial heat continued to increase. Finland currently provides at least 54% of its heating needs from forest-derived biomass [88]. Sweden is also in the position of a country with more than 60% forests and is an extremely rich country in terms of woody biomass energy source. In 2017, it commissioned the Värtaverket power plant, the last of the Swedish biomass-fired combined heat and power plants, in northern Stockholm, with an installed power of 280 MW of heat and 130 MW of electricity. This power plant is the largest of its kind in Sweden and one of the largest in the EU. The annual production capacity of the facility is determined as 750 GWh of electricity and 1,700 GWh of heat [11]. Biomass energy is the second most used renewable energy source in electricity generation in Germany. Since 2014, Germany has been among the leading countries in the world in terms of modern energy conversion technologies. In addition, since 2014, the number of power plants producing energy from solid biomass has increased considerably compared to previous years. Wood pellet production amounts are also increasing every year [35]. Until the 1960s, the Republic of Korea converted half of its forest lands to agricultural lands, and at the same time, it made excessive and uncontrolled use of forests for heating, and since the mid-1960s, it implemented a forest improvement and restoration plan. With the implementation of the plan, the forest wealth of the Republic of Korea has increased rapidly, natural disasters in agricultural areas have decreased and extremely positive support has been provided for food production. In addition, the uncontrolled use of forests as an energy source has been prevented [89]. There are 660 biogas plants operating across the UK with an industrial capacity of 955 MW energy equivalent for heating and electricity generation. Construction of 390 new facilities is still ongoing [90]. According to the study, the total energy supply in the UK was 537,211 TJ from biofuels and waste in 2020. Total energy supply from wind and solar energy in the UK in 2020 was 320,588 TJ. In terms of renewable energy sources, the highest energy supply in 2020 was from biomass energy. While 39 TJ of heat was produced from solid biomass in 2010 in the UK, 4,205 TJ of heat was produced from primary solid biomass in 2020 [41]. The countries that make up the UK show a successful performance in transforming forest waste and residues into energy. Miscanthus plant and other plants with high energy value were given importance. Energy crop cultivation is operated in large plots. In addition, the countries that make up

the UK play a positive role in increasing energy production with existing laws, incentives and credit opportunities for forest and agricultural biomass [91].

5. Conclusions

Turkey and other countries follow a strategy to diversify their energy supply sources, to meet their energy needs from renewable sources and to reduce foreign dependency on energy in order to meet their energy needs. At this point, biomass energy draws attention with its feature of being as old as human history and being the most common energy source on earth.

- It has been determined that Turkey's biomass energy potential is between 14 MTEP and 32 MTEP. The main reasons for this difference are the differences in the calculation method, the differences in the accepted energy density values of the materials and the differences in the material selection that can be seen in the biomass energy potential. In terms of grain production and diversity, Turkey's Central Anatolia region is quite rich and its biomass energy potential is over 8 billion kWh. Although the biomass energy potential is extremely high in the inner regions of Turkey, the power plants with the highest installed power outside Ankara are located on the coastline. This situation causes difficulty in accessing raw materials and increases costs. It will take a long time to resolve the reasons why Turkey cannot use its biomass energy potential within the country in a balanced and efficient manner. Therefore, in order to solve these problems, the Ministry of Energy and Natural Resources, the Ministry of Agriculture and Forestry, sector representatives and relevant groups and stakeholders should follow a holistic road map.
- Annual biodiesel and bioethanol production quantities are low in Turkey. Turkey produced 74,800 tons of biodiesel and 46,500 tons of bioethanol in 2020, with a total biofuel production of 121,300 tons. In addition, HVO production is also very low. In order to increase biofuel production in Turkey, increasing the number of biofuel power plants, which are few in number, increasing the amount of investments and incentives, eliminating partial problems in necessary conversion and conversion technologies, increasing HVO production and increasing the size and quality of industrial plantation areas are among the solutions that will reduce foreign dependence on fuel.
- Moss is a renewable energy source with a higher energy density value than coal used in jet fuel. In addition, moss has a calopheric value of 33 MJ/kg and is a carbon negative energy source. It is foreseen that the studies on this energy source, which will reduce the domestic, national and greenhouse gas emissions of Turkey, which is surrounded by seas on three sides, will increasingly continue.
- It has been determined within the scope of the study that incorrect land use and wild irrigation are common due to the presence of organized and heavy industry factories in the cities in the southeastern part of the Marmara region, which is rich in bioenergy material and food production. New factories and facilities should be established in regions with low bioenergy and food production potential.
- Although it started in the EU countries in the early 2000s, in Turkey, heat generation from urban wastes started after 2015. A better waste management, waste collection approach should be developed and expanded.
- The operational performance indicators of biomass power plants have a better performance than wind, solar and hydroelectric power plants. Biomass power plants are less affected by climatic conditions such as optimum temperature, sunshine duration, wind blowing frequency, wind blowing intensity and precipitation amount. In this context, it would be beneficial to increase the installed capacity of biomass energy in Turkey. In addition, the size of the storage areas of bioenergy power plants and facilities should be increased and the storage area conditions of energy source materials should be improved.
- The number of combined heat-power generating power plants in Europe, which has examples of successful countries such as Sweden and Finland, is quite low in Turkey. Therefore, the number of combined heat-power generating plants should be increased in Turkey. In addition, as in the example of the UK, agriculture and forestry can be represented in separate ministries in Turkey, and energy crop cultivation should be carried out and supported.
- In 2020, Turkey's firewood production amount was 5,396,680 m^3, while industrial wood production was 24,751,066 m^3. In Turkey, at least 25% of the forest-derived material rots in the forest within the scope of industrial wood production activities. This biomass should be removed from the production area without harming the biodiversity of the forest and evaluated with modern bioenergy conversion methods. Within the scope of this study, it was emphasized that it would be beneficial to convert it into biogas or to evaluate it as wood pellet. It is predicted that if this carbon neutral energy source is utilized, it will have a positive effect on energy imports, increasing employment and reducing the amount of carbon footprint of Turkey.
- The forest crimes committed cause the sustainability of forests, their inability to use them as energy raw materials or their use with traditional methods, and the increase in the carbon footprint of the country. In this context, it would be extremely beneficial to implement measures to prevent forest crimes.
- In 2020, the total number of forest villages in Turkey is 23,100 and the number of people living in forest villages is 7,034,738. It is necessary to reduce people's consumption of firewood from forests using traditional biomass energy conversion methods. In this context, in order to reduce this social pressure on forests, the use of solar heating systems and floor heating systems should be expanded.

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