Chapter 11

Potential of Biofuel Usage in Turkey's Energy Supply

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Additional information is available at the end of the chapter

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Abstract

Rapidly growing population and industrialization brought about the enormous need for energy, alongside the environmental problems. Since biofuel energy is inexhaustible, it is becoming increasingly important to address the energy problem. Today, it is possible to classify biomass energy into two classes: classical and modern. Classical biofuel utilization is the simple burning of wood obtained from tree cutting and animal wastes, where modern biofuel application consists of a variety of fuels produced from various sources. Turkey's potential for biofuels is estimated to be around 45 Mg. As a renewable energy, it's been under the Renewable Support Scheme by regulation for more than a decade now. By the end of 2016, installed biofuel electricity generation capacity had reached 468 MW with 2 billion kWh realized (~0.7% of national demand). The aim for 2023 is reaching at least 1000 MW (which will be around 1.3% by then). Many analysts believe that the potential for development is higher and realization therefore will surpass the official aims. Effective usage of biofuels for power generation may not be sizable but it's critical and will make multilayer contributions to energy supply and dependence as well as to meeting climate and sustainability targets of the country.

Keywords: energy policy, biofuel, agricultural and environmental interaction

1. Introduction

The civilization tendencies toward modernization mainly progress through industrialization of societies. Combining the economic results of modernization, which are mainly increased public welfare, eased access to consumption, alongside the growth in population, leads to enormous increase in energy demand, where the upward acceleration persists for decades [1].

Economic impacts	Sustainability
	Fuel diversity
	Increased number of rural manufacturing jobs
	Increased investments' innovation
	Agricultural development
	International competitiveness
	Reducing the dependency on imported petroleum
Environmental impacts	Greenhouse gas reductions
	Reducing of air pollution
	Biodegradability
	Higher combustion efficiency
	Improved land and water use
	Carbon sequestration
Energy security	Domestic targets
	Supply reliability
	Reducing use of fossil fuels
	Ready availability
	Domestic distribution
	Renewability

Table 1. Major benefits of biofuels [37].

In the current situation, the leading primary energy sources used are fossil-based sources, having a contribution around 85% globally, where the largest consumer is power industry, utilizing 42% of the total primary sources, followed by industry and transport [1–3]. Despite global consensus on the need to shift primary energy sources to renewables, the situation is not expected to change drastically. Future scenario studies show only a slight decrease, down to 75% in 2040, on fossil fuel dependence [4], even with implementing new policy measures promoting to wane fossil fuels. Given the abundance of coal, oil, and natural gas globally, with new extraction technologies, potential reserves, and unconventional reserve exploitation (e.g. for natural gas), it is highly possible the fossil sources will be available for a considerable period at low costs [5–7]. Although supply reserve and financial scenarios demonstrate that fossil resources will continue dominating in the future for a number of decades, it is widely accepted that the current position has drawbacks.

Besides, fossil fuel is not sustainable by definition and many countries have concerns over fossil fuel dependence mainly connected to four conditions: (1) depleting fossil fuel stock [8], (2) price volatility of fossil resources [9], (3) greenhouse gas emissions in the atmosphere [10], and (4) geopolitical supply security [6, 7]. Even though each of these conditions is enough to convince conversion to renewables, a dilemma arises for countries being forced to use fossil sources as a result of financial conditions accompanied by fossil-based technology infrastructure and hence the pace to migrate from fossils to renewables remains low.

It is more widely accepted that the thread of global climate change is increasing, which is addressed to the greenhouse emissions from fossil fuel utilization. Thus, global debates on migration from carbon emitting resources are held in order to find a common international understanding [11]. In conjunction with environmental consequences of fossil fuel mining, the associated climate change projections predict some serious threads [10], including several negative impacts on human health along with the Earth's ecology [12]. Therefore, in order to overcome two detrimental challenges, namely energy crisis and environmental pollution, new alternative energy sources are required, which are essentially renewable, sustainable, environment friendly, efficient, and economically viable [12–14]. Many power generation alternatives are put forward to replace fossil fuels; the primarily listed and tested ones are wind, solar (thermal and photovoltaic [PV]), nuclear, geothermal, tidal, fuel cells and biofuels [15]. Among these alternatives, each has advantages and drawbacks against fossil fuels, where biofuels are found favorable over petroleum fuels because (1) they can be easily extracted from the biomass, (2) they are sustainable due to their biodegradability, (3) their combustion is based on carbon dioxide cycle, and (4) they are more environment friendly [3]. Further benefits in integrating biofuels to the fuel mix are summarized in **Table 1**.

In this study, definitions, applicability, and potentials of biofuels as an alternative energy source are investigated, with their current and probable future positions in the Turkish energy mix.

2. Evolution of biofuels

Although in the common and popular context biofuel is used to define liquids, scientifically, the term "biofuel" refers to all fuels produced from biomass in forms of:

- solids (biochar),
- liquids (alcohols like bioethanol, biodiesel, vegetable oil, synthetic hydrocarbons, and their mixtures),
- and gases (biogas, syngas, and biohydrogen).

Biofuels are commonly classified as primary and secondary according to the form of utilization. Primary biofuels are organic materials directly used to extract energy. Primary biofuels include wood, wood chips, pellet, animal wastes, forest and crop residuals, landfill gas, and so on from which energy is extracted traditionally without a conversion process. Secondary biofuel refers to chemically converted fuels [16] in solid, liquid, or gaseous forms, derived from organic material. **Figure 1** illustrates the common classification of biofuels.

Primary biofuel has relatively low efficiency and has limited utilization possibilities in terms of energy conversion and transportability, compared to the so-called secondary biofuel technologies, which are also classified further into generations. The first-generation fuels are bioethanol/butanol chemically produced from rape seed, soya bean, sunflower, date palm,

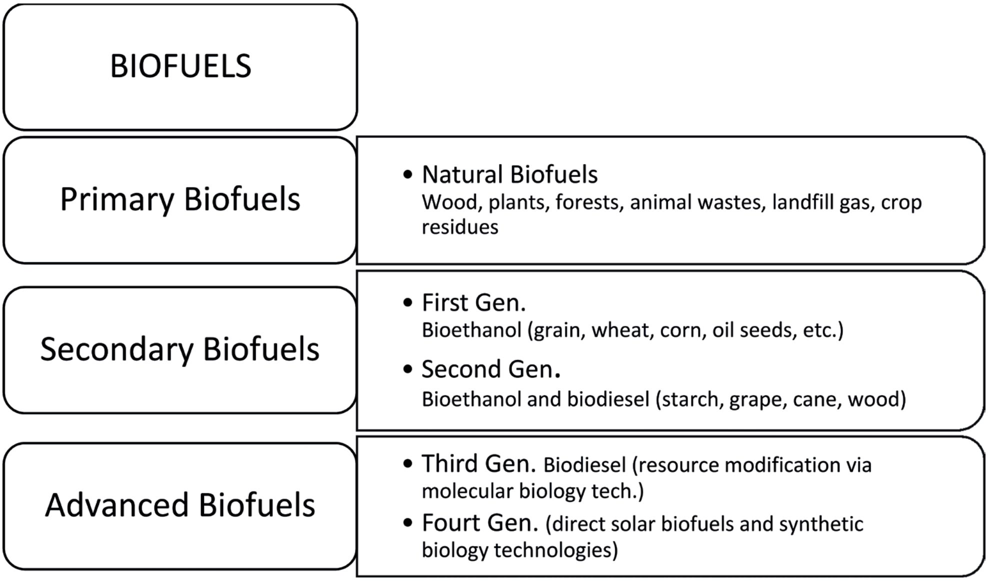

Figure 1. Classification and sources of biofuels [17].

coconut, and animal oils, fermented from the starch of wheat, barley, corn, potato, sugar cane, and sugar beet [17]. The first-generation biofuels are well defined and have reached commercials level, especially in the US, EU, and Brazil [18]. First-generation biofuel production systems require large-scale land acquisition and have some environmental and economic limitations. Since they are mainly derived from food and oil crops, they directly compete with food for crops and agricultural land [5, 19]. There are many studies not only reporting the competition between food and fuel for land use, but also defining the dependence between a remarkable increase in food prices, mainly corn and soybean, with increased oil prices [20].

In order to overcome the competition between fuel and food crops over the limited agricultural land, second-generation biofuels, produced from mainly agricultural wastes, are used. Second-generation biofuels can be defined as bioethanol/biofuel generation from jatropha, cassava, miscanthus and bioethanol, biobutanol, or syndiesel production from lignocellulosic materials such as straw, wood, agricultural wastes, and grass [21, 22]. They are derived from biomass sources mainly agricultural residue, forest harvesting residue, wood processing, and non-edible parts of food crops. Thus, second-generation biofuels are not directly competing with agricultural lands and have lower environmental footprint than the first generation [18]. Limitation of second generation comes from its lower conversion rates (see **Table 2**). At this moment, with current conversion rates the process is not economically feasible [19]. The low conversion rates also require the second-generation biofuels to occupy large amount of lands, particularly arable lands for energy crop cultivation [23].

The third-generation biofuels are differentiated from the second-generation biofuels to the point where the utilized resource is modified via molecular biology technologies. Because

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Crop	Seed oil (% oil by wt)	Oil yield (L oil/ha yr)	Land area use (m^2 yr./kg biodiesel)
1st generation			
Corn	44	172	
Soybean	18	446–636	18
Safflower	20	779	
Camelia	42	915	12
Sunflower	40	952–1070	11
Peanut	70	1059	
Canola	41	974–1190	12
2nd generation			
Castor	48	1307–1413	9
Jatropha	20–60	1892	15
Polanga	65–75	2000	
Coconut	65–75	2689	
Oil palm	36	5366–5950	2
3rd generation			
Microalgae	30–70	58,700–136,900	0.1–0.2

Table 2. Comparison of various biofuel sources [18].

of familiarity in other applications, algae, commonly known as weeds, are referred within third-generation biofuel production, and for long years they are known as nutrient additive for animal feedstock. Due to the environmental concerns as well as the increase in oil prices, studies on biofuel sources have gained importance and algae have been considered as a promising sustainability and energy source. Because the first-generation biofuels are prone to creating environmental pollution during production process, whereas second-generation biofuels require expensive and complicated production technologies [5], far more innovative solutions—the fourth-generation biofuels or direct solar biofuels and synthetic biology technologies—are pertinently needed for replacement of all fossil fuels. Researchers are focused on third- and fourth-generation biofuels, collectively referred to as advanced biofuels, which are promising in terms of conversion rates as shown in **Table 2**.

Microalgae are a large and diverse group of simple, aquatic, and mostly microscopic unicellular organisms [24], which are capable of performing photosynthesis. These microalgae utilize light and produce biomass from CO_2, water, and nutrients.

While the percentages vary with the type, in general, nearly 15–77% of the microalgae cell is made up of oil. High oil content and growth efficiency compared to other plants make microalgae a promising and attractive source for biodiesel and biogas production. Generation of these fuels from microalgae would help to meet the increasing global demand in addition to contributing to the prevention of global warming by partially sequestering the excess amount of carbon dioxide via photosynthesis and converting it to new products. Due to rapid growth rate, contribution to reduce greenhouse gas and high oil generation capacity, microalgae are one of the most preferred third-generation biofuel sources. They can grow on areas unsuitable for agricultural purposes and on aquatic mediums and therefore do not compete with arable lands [25]. Besides, unlike the terrestrial plants, algae have reduced environmental risks on drinking water resources, and they are very efficient at removing nutrients like nitrogen and phosphorus from water. Many researchers consider microalgae as the unrivaled energy source and also emphasize the contribution to gaseous emissions. With very limited amount of water, microalgae can duplicate their population in 1 day by using solar energy. In fact, some types of algae require only few hours to reach such growth rates. This allows for production of millions of liters of biofuel per hectare per year, which is fairly high when compared with the palm oil (5950 L/ha) and makes algae one of the most desirable alternative sources of energy. Although not all types of algae are suitable for biodiesel production, some types are convenient for this purpose. The studies are concentrated particularly on fresh water algae (Chlorella) since it is easy to grow at laboratory conditions and is one of the best alternative algae for biodiesel production. The main processes to produce fuel from microalgae are listed in **Table 3**.

Studies on energy production including the use of a variety of algal species are generally lab-scaled, pilot, or small-scaled studies. Although these studies are successfully completed, desired efficiency is not achieved at large-scale production due to the failure in creating ideal conditions in full-scale systems.

2.1. Biofuel generation from microalgae

Microalgae can be found in natural water resources. More than 300,000 types of microalgae were determined. These organisms are very effective in converting the solar energy into biomass and contain more than 80% oil. Industrial life cycle and product line of algae are shown in **Figure 2**.

The growth phase requires setting up and operating a supporting medium in favor of algae. Under ideal conditions, in fact, it is hard to achieve in full-scale plants; they reproduce easily and grow very rapidly [27]. Ideal temperature range for the growth of microalgae is 20–30°C. They also require organic and inorganic elements (nitrogen, phosphorus, iron, and

Final product	Production process
Biodiesel	Extraction of oil from algae and transesterification
Ethanol	Fermentation
Methane	Anaerobic fermentation of algae
Heat and electricity	Direct combustion of algae or gasification of biomass

Table 3. Use of microalgae.

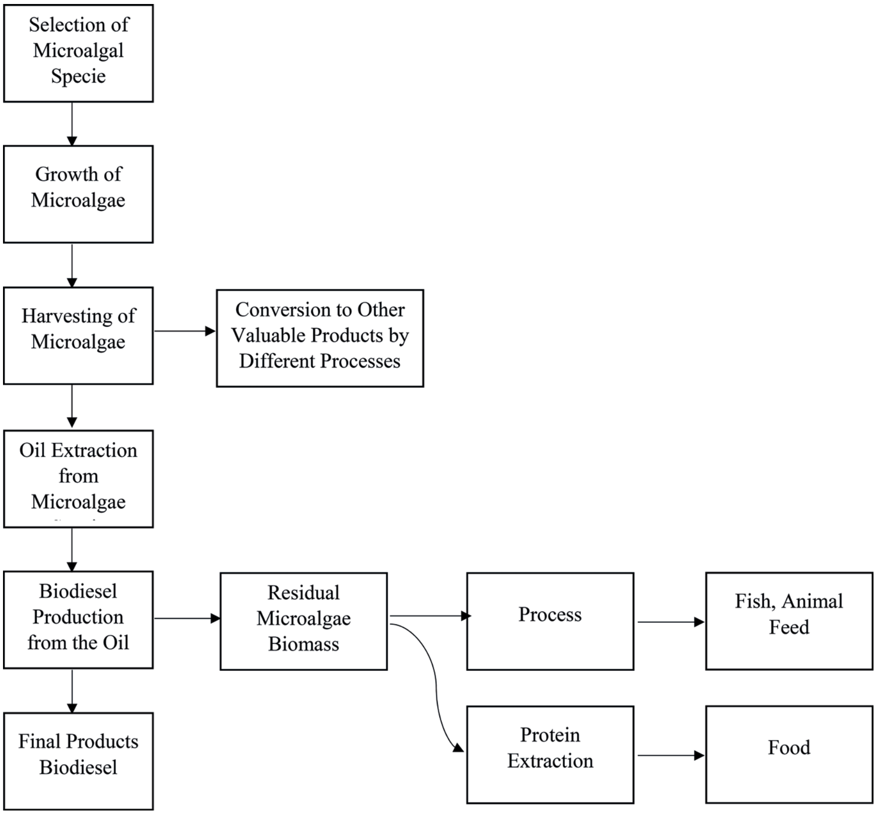

Figure 2. Industrial life cycle of microalgae [26].

silicon in some cases) to grow up. In addition to trace elements, they can reproduce at domestic wastewaters, animal wastes, industrial wastewaters, and some aquatic environments in the case of carbon deficiency [28]. There are two main methods used to cultivate microalgae, which are suspended cultures and immobilized cultures.

During the production of oil, they use sunlight and CO_2 more effectively than the oil plants. In addition, their growth rate is very fast. During the rapid growth period, doubling time of microalgae biomass is 3.5 h. For these reasons, larger quantities of microalgae can be produced at smaller areas with lower costs compared to the oil plants that are cultivated widely. The most popular algal species and microalgae are defined and their chemical compositions, properties, and cultivation techniques are mainly determined.

After the growth phase, algae should be harvested using various methods, which can be classified as chemical, mechanical, biological, and electrical methods. Among the processes of biofuel production from algae, one of the most costly steps is harvesting, summing up to

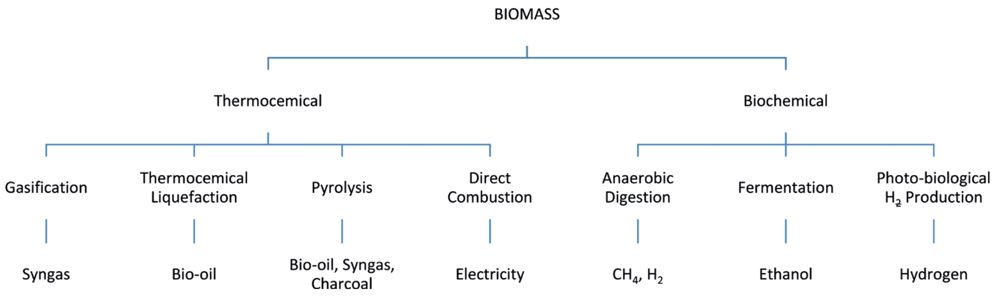

Figure 3. Conversion process alternatives and their end products [30].

20–30% of total production costs [29]. Harvesting is accomplished in two separate steps—bulk harvesting (using e.g. flocculation, floatation, and sedimentation) followed by concentrating the biomass (via centrifugation or filtration). Subsequently, the biomass should be prepared for conversion process, where dehydration is essential. Many dehydration methods, like sun drying, low-pressure shelf drying, spraying, drum drying, fluidized bed drying, and freeze drying, may be used. The trade-off is between choosing low-cost, time-consuming sun drying and high-energy-consuming efficient methods. Conversion process alternatives and their end products are given in **Figure 3**.

3. Renewable energy outlook

3.1. Global

In recent years, several developments and trends clearly demonstrate a tendency and increased attention on renewable energy. The continuing comparatively low global fossil fuel prices, dramatic price reductions of several renewable energy technologies (especially solar PV and wind power), increase in energy storage, and increased appetite toward renewable technology and facility investments can easily be interpreted in favor of renewables.

Although it varies by country widely, global primary energy demand has grown by an annual average of around 1.8% in the last 5 years (**Figure 4**). Growth in primary energy demand has occurred largely in developing countries, whereas in developed countries it has slowed or even declined [31].

Looking into carbon emissions, when it is combined with increased renewable use, it is not surprising to see that, from 2013 to 2016, for the third consecutive year, global energy-related carbon dioxide emissions from fossil fuels and industries were nearly stabilized. The average increase of carbon dioxide emissions was 2.2% annually, in the previous decade [31], which cannot be connected directly to the economic recession. The breakdown of global renewable energy shares is given in **Figure 5** and share of renewables by sector is given in **Figure 6**.

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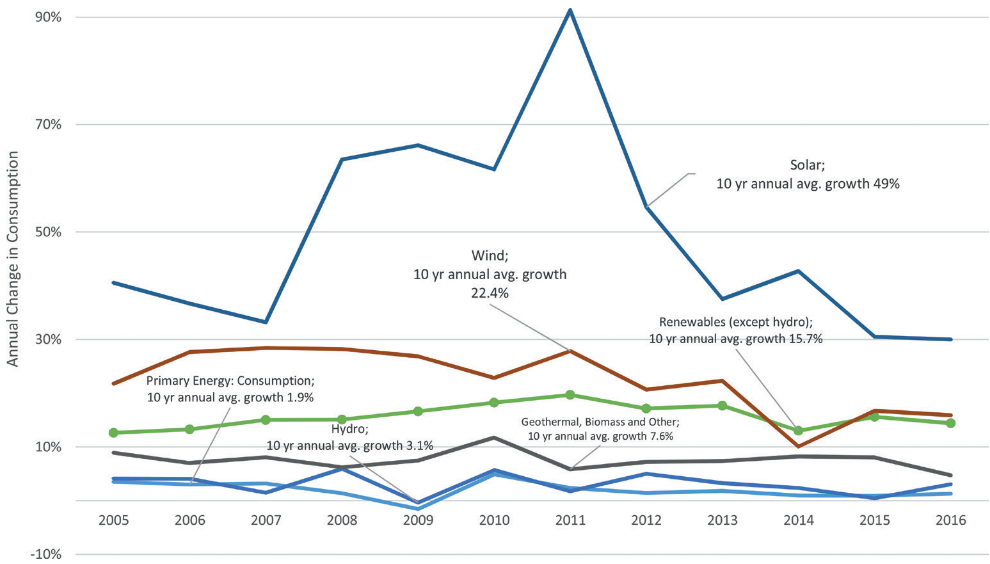

Figure 4. Growth in global renewable energy and total final energy consumption, 2005–2016 (data from [32]).

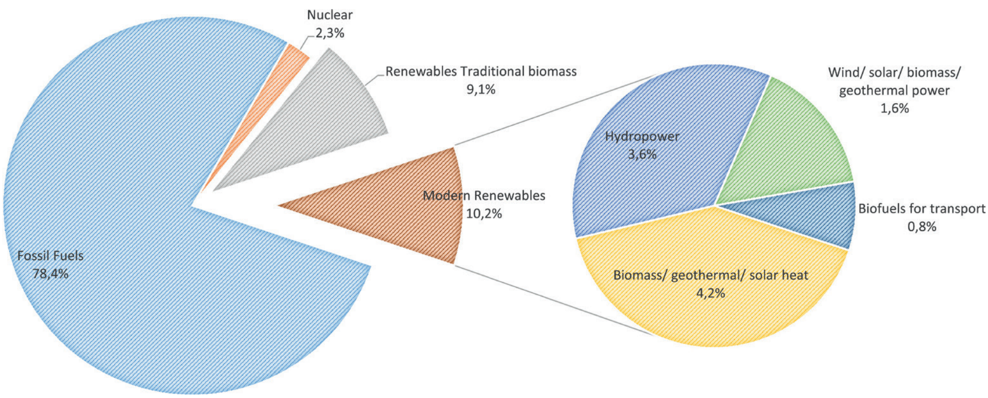

Figure 5. Global renewable energy share (data from [33]).

As it can be seen from **Figure 5**, biomass-originated fuels became the fourth largest energy resource after coal, oil, and natural gas. Currently nearly 10% of global primary energy is sequestrated from biomass used for heating, cooking, transportation, and electric power generation. The utilization pathways are diverse through traditional use of primary fuel and bio-based liquid fuels. Yet, for many countries setting targets on renewable energy, biomass is not the pointed focus, and the share in the energy mix is not expected to stack up in the future, as **Figure 6** implies.

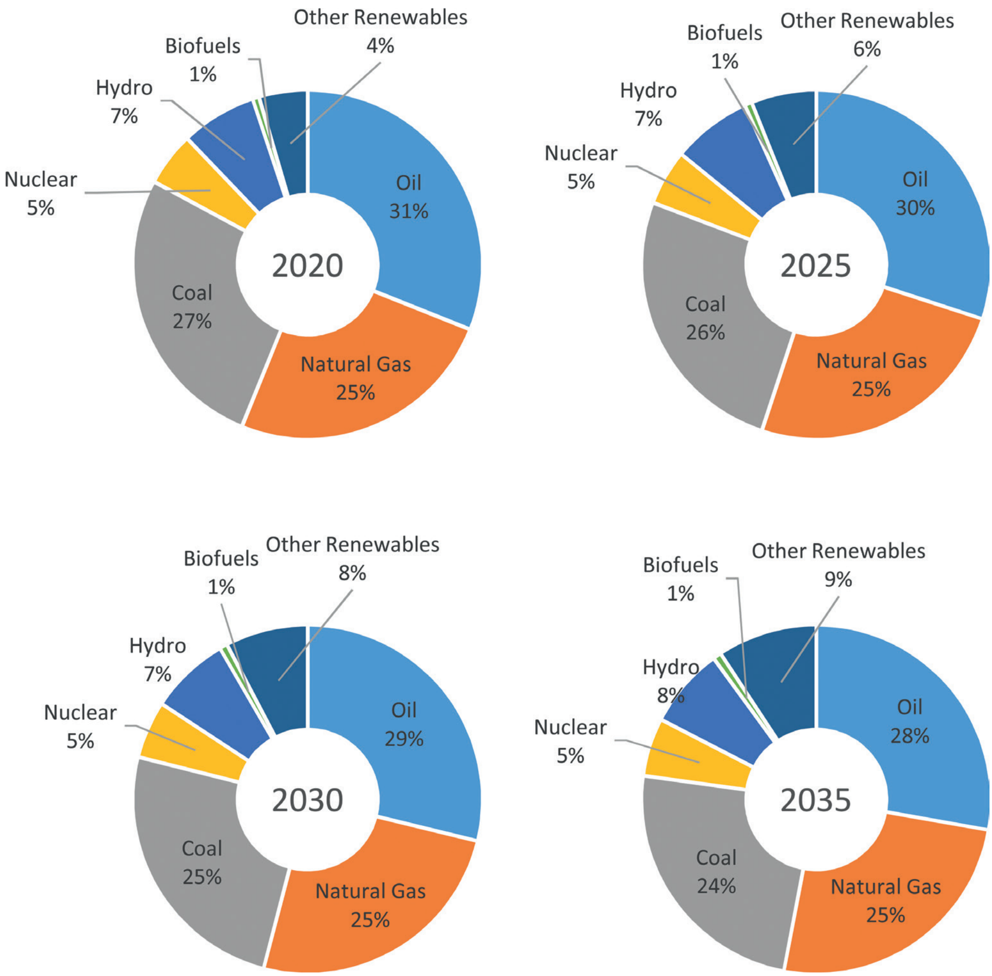

Figure 6. Projection of global primary energy consumption by fuel (MTOE) (data from [34]).

3.2. Biofuels in energy policy

Biofuels traditionally are attributed to transport because they are the only candidates used in vehicles, besides EV. Particularly, biofuels are options that do not require costly modifications to existing infrastructure and the vehicle fleet. Biofuel production is driven through blending mandates (e.g. Brazil and Indonesia, increasing their mandates in recent years), subsidies (e.g. the US), or a combination of both. In the EU, because of sustainability concerns, the trend is accelerating the transition to more advanced biofuels [35]. Currently, the EU set a 7% cap on conventional biofuels in final transport consumption while maintaining the 10% target for renewable sources in transport by 2020.

Even though biofuels have policy support for a number of years, the slow economic recovery and advances in conventional vehicle fuel economy have limited demand growth. There are also unsolved problems for biofuels to diffuse in the market, especially in distribution and lack of flex-fuel vehicles, as well as concerns on sustainability of first-generation biofuels. Nevertheless, developments like new biofuel plants and use of biofuels in commercial flights are still promising. Biojet fuels, with blends of up to 50% biofuel, have been used in more than 2500 commercial flights [36].

In addition to energy policies, biofuels are also connected to national economic policies, even to rural employment and rural development plans. Biofuel production line gets through agriculture, rural areas, producers and final consumers, creating multiple cross-industry effects. Thus subsidies towards biofuels are able to double their effects. Similar to any other renewable technology, biofuels have the ability to create new employment opportunities. Despite concerns on sustainability, some researchers argue that biofuels would perform better provided that barriers via regulations are removed and opened to the free market [37].

3.3. Turkey

Utilization of renewable energy, theoretically, backs up power generation by leading to three goals: (1) sustainable development, (2) decreasing energy import, thus relieving current account deficit, (3) and increasing energy security [38, 39]. Turkey has significant potential in terms of renewable energy. It is ranked 14th in the world with its geothermal energy capacity, 29th with its solar energy capacity and 16th with its wind energy capacity. For wind, the potential is estimated to be around 48 GW with a technically feasible capacity of 20–24 GW [40].

Historically, Turkish renewable energy generation was based on hydropower until privatization of the generation. From 2000s, renewable energy was put forward as one of the important issues on Turkey's energy agenda. Turkey's ambitious vision for 2023 envisages new and improved targets for the renewables, opening doors to other renewables other than hydropower [41]. Historical installed capacity of Turkey in terms of primary energy supply is given in **Figure 7**, and future projection of renewable capacity is given in **Figure 8**.

In addition to energy security and economical requirements, Turkey also connects the renewable source utilization targets into the low-carbon economy transition. Turkish Intended Nationally Determined Contributions (INDCs) [43] includes increasing solar energy capacity to 10 GW and wind capacity to 16 GW, until 2030. Looking back to 2008, where renewable capacity (excluding hydro) was 212 MW [44], Turkey has demonstrated a vast improvement within 9 years, carrying the capacity over 7800 MW, as of 2016. It is certain that if the increase is kept in the upwards direction, the 2030 targets seem highly probable.

The literature on the energy consumption-economic growth nexus has been widely researched (e.g. [45–47]); however, the renewable energy-based studies are still scarce [48]. It is well established that as a domestic natural resource, renewable energy source (RES) can make contributions to energy security. Some references [51] even proclaimed that RES could supply Turkey with full energy independence. It is clear that, even though it requires grid improvement and modular planning as well as grid operation, renewable energy supplies diversification into the grid, which in turn relieves energy dependence in the Turkish case.

Another focal point to be addressed is the dependency problem in terms of account deficit. **Figure 9** shows the imported energy bill of Turkey. It is notable that the decrease in the total

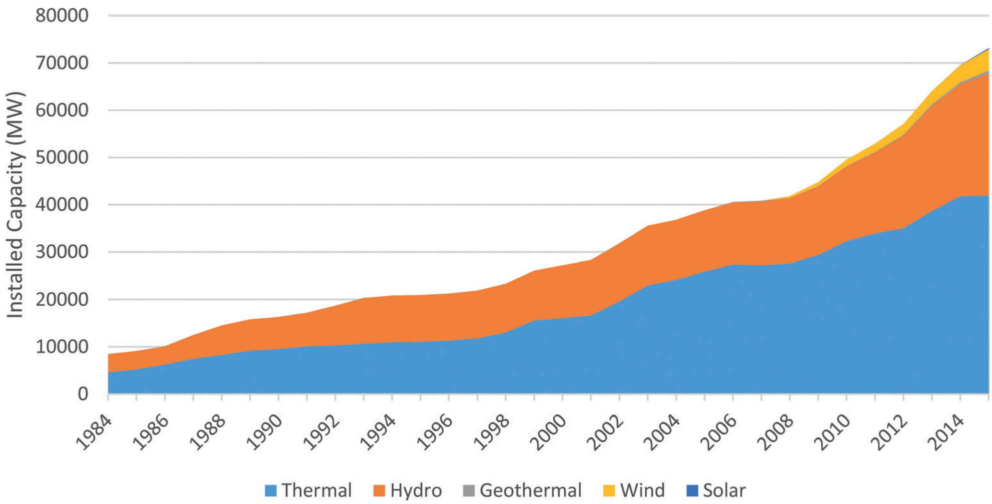

Figure 7. Development of installed capacity in Turkey (data collected from [42] and interpreted).

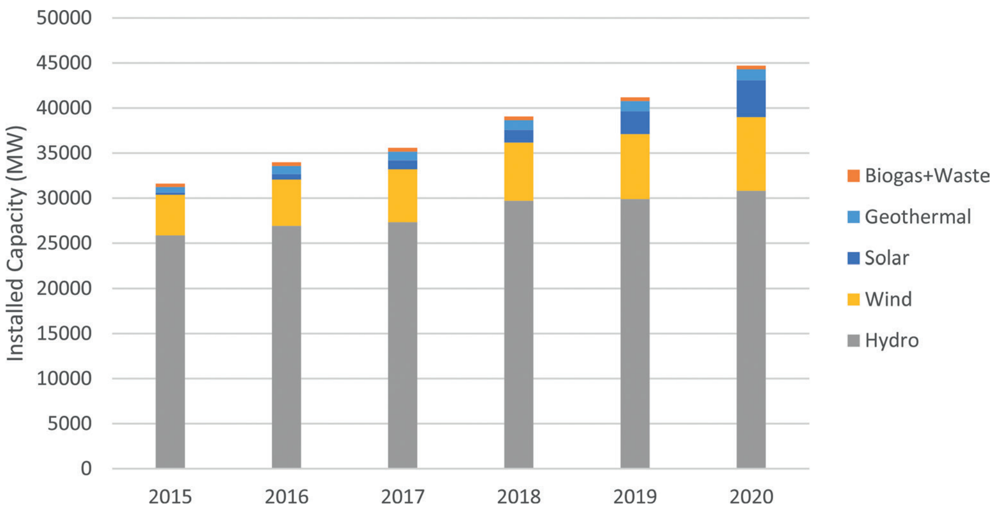

Figure 8. Installed renewable capacity projection in Turkey (data collected from [42] and interpreted).

import price results from the global energy sources (natural gas for the Turkish case), where imported energy sources have still been increasing and energy is the major expenditure in Turkey's national account.

3.4. Biofuel potential and utilization in Turkey

In line with the rapid growth (due to governmental support mechanism) of Renewable Energy Sources (RES) in power generation (see **Table 4**), the investment in biomass has also

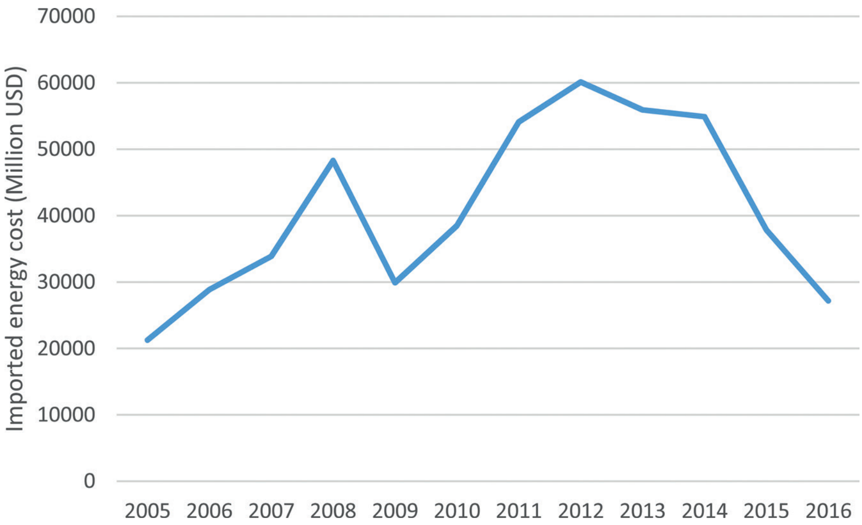

Figure 9. Imported energy cost of Turkey (TÜİK, 2017).

been increasing fast. While the installed capacity was only 43 MW in 2007, within 10 years, by the end of 2016, the installed capacity has reached 496 MW—that is more than a tenfold increase (**Figure 10**). The annual average growth rate is actually more than 30%.

As of today (end of 2016), there are more than 70 biomass/biogas power plants in diverse sizes (from less than 1 to 34 MW) (see **Table 5**). These plants were able to generate 2.372 GWh annually (which is 0.86% of total energy generated), with their 496 MW of installed capacity in total (0.63% of Turkey) (see **Figure 11**).

The ratio of generation to capacity shows that the capacity usage factor has been quite high in these plants, suggesting that they have functioned as reliable base-load plants as opposed to other intermittent (like wind and solar) RES, which are actually called variable renewable energy (VRE) and frequently referred to as one of the obstacles to full-fledged RES development.

Therefore, this is an important feature and an attractive point in relation to biomass-based power generation investment: base load, reliable, and stable power.

Although there is considerable potential (see **Figure 12**), other than traditional biomass and biogas, there is not yet any utilization of other types of biofuels in Turkey. Studies on microalgae are mainly conducted by the Faculties of Aquaculture at the larva bait production areas and at eutrophic marine and surface water sources. Although biomass production of algae has already been initiated at some universities, particularly at Aegean University, there are not enough studies and investigations focusing on energy generation from microalgae. Studies related with energy are concentrated on Izmir, Ankara, and Gebze. Studies on energy are generally lab-scaled, pilot, or small-scaled studies and completed successfully. However, desired efficiency is not achieved at large-scale production due to the failure in creating ideal conditions. General Directorate of Electricity Transmission Corporation states that the annual

Installed capacity	2008	2009	2010	2011	2012	2013	2014	2015	2016
Hard Coal + Imported Coal + Asphaltite	1,986	2,391	3,751	4,351	4,383	4,383	6,533	6,825	8,229
Lignite	8,205	8,199	8,199	8,199	8,193	8,223	8,281	8,696	9,127
Fuel Oil + Motorin + LPG + Nafta	1,819	1,699	1,593	1,300	1,286	616	595	523	445
Natural Gas	15,526	16,963	18,628	19,955	20,997	25,191	26,094	25,489	26,115
Biofuels	60	87	107	126	169	235	299	370	496
Hydro	13,829	14,553	15,831	17,137	19,609	22,289	23,643	25,868	26,681
Geothermal	30	77	94	114	162	311	405	624	821
Wind	364	792	1,320	1,729	2,261	2,760	3,630	4,503	5,751
Solar							40	249	833
Total	**41,817**	**44,761**	**49,524**	**52,911**	**57,059**	**64,008**	**69,520**	**73,147**	**78,497**

Table 4. Development of installed power generation capacity (MW)—Turkey (2008–2016).

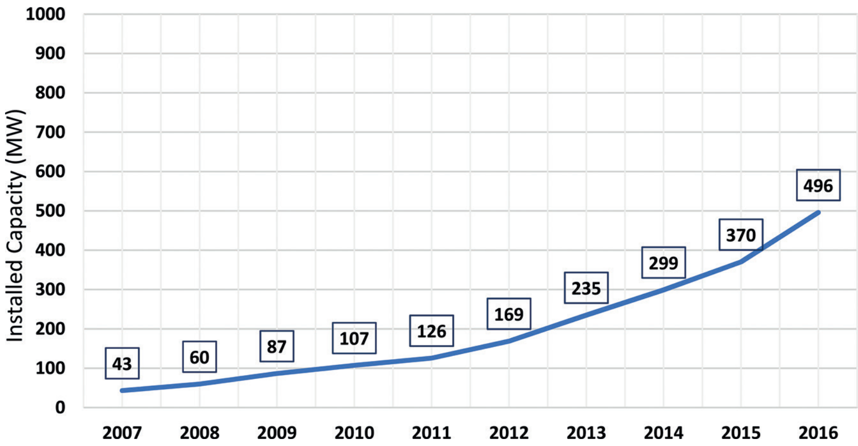

Figure 10. Development of biomass/biogas power generation capacity in Turkey (2007–2016).

sunshine average of Turkey is 2640 per hour; in other words, average amount of energy that can be generated is 3.6 kWh/m^2 in a day. Although, there are 50 licensed biofuel facilities in Turkey, having a total installed production capacity of 1.5 million Mg, only few of these are in production due to the misplanned raw material production or lack of feasibility. Algae are one of the main alternative fuel sources, and the weather condition of the country is suitable for algae production. In addition to this, all nutrient elements required for their growth are abundantly available. Alternative agricultural production is improving with the help of biofuel projects. Biofuels brought the agricultural activities back to the agenda and have opened new horizons for the countries by encouraging them to introduce new regulations.

Power plant name	City	Company	Installed capacity
Odayeri Çöp Gazı Santrali	İstanbul	Ortadoğu Enerji	34.0 MW
Toros Tarım Samsun Atık Isı Santrali	Samsun	Toros Tarım	31.0 MW
Mutlular Biyokütle (Orman Atığı) Enerji Santrali	Balıkesir	Mutlular Enerji	30.0 MW
Mamak Çöplüğü Biyogaz Tesisi	Ankara	ITC Katı Atık Enerji	25.0 MW
Çadırtepe Biyokütle Sanrali	Ankara	ITC Katı Atık Enerji	23.0 MW
Sofulu Çöplüğü Biyogaz Santrali	Adana	ITC Katı Atık Enerji	16.0 MW
Akçansa Çimento Atık Isı Santrali	Çanakkale	Enerjisa Elektrik	15.0 MW
Kömürcüoda Çöplüğü Biyogaz Santrali	İstanbul	Ortadoğu Enerji	14.0 MW
Eti Alüminyum Atık Isı Elektrik Santrali	Konya	Cengiz Enerji	13.0 MW
Zeus Biyokütle Enerji Santrali	Kırklareli	Zeus Enerji	12.0 MW
Eti Maden Bandırma Atık Isı Santrali	Balıkesir	Eti Maden	12.0 MW
ITC-KA Sincan Biyokütle Gazlaştırma Tesisi	Ankara	ITC Katı Atık Enerji	11.0 MW
Bağfaş Gübre Fabrikası Biyogaz Santrali	Balıkesir	Bağfaş Gübre Fabrikası	9.9 MW
Hamitler Çöplüğü Biyogaz Santrali	Bursa	ITC Katı Atık Enerji	9.8 MW
Çimsa Atık Isı Santrali	Mersin	Enerjisa Elektrik	9.6 MW
Batıçim Atık Isı Santrali	İzmir	Batıçim Batı Anadolu	9.0 MW
Prokom Pirolitik Yağ ve Pirolitik Gaz Tesisi	Erzincan	Prokom Madencilik	7.0 MW
Aksaray OSB Gübre Gazı Elektrik Santrali	Aksaray	Sütaş Süt Enfaş Enerji	6.4 MW
Karacabey Biyogaz Tesisi	Bursa	Sütaş Süt Enfaş Enerji	6.4 MW
Şanlıurfa Biyokütle Enerji Santrali	Şanlıurfa	Full Force Enerji	6.2 MW
Eman Enerji Mersin Biyokütle Enerji Santrali	Mersin	Mersin Büyükşehir Belediyesi	6.0 MW
Avdan Biyogaz Tesisi	Samsun	Avdan Enerji	6.0 MW
Modern Biyokütle Enerji Santrali	Tekirdağ	Eren Enerji	6.0 MW
Trakya Yenişehir Cam Atık Isı Santrali	Bursa	Trakya Yenişehir Cam	6.0 MW
Kayseri Çöplüğü Biyogaz Elektrik Santrali	Kayseri	Her Enerji	5.8 MW
Konya Aslım Çöplüğü Elektrik Üretim Santrali	Konya	ITC Katı Atık Enerji	5.7 MW
Gaziantep Çöp Gazı	Gaziantep	CEV Enerji	5.7 MW
Batısöke Söke Çimento Atık Isı Elektrik Santrali	Aydın	Batısöke Söke Çimento	5.3 MW
Kocaeli Çöplüğü Biyogaz Santrali	Kocaeli	Ortadoğu Enerji	5.1 MW

Power plant name	City	Company	Installed capacity
Ovacık Biyogaz Enerji Santrali	Kırklareli	Işıt Biyokütle	4.8 MW
Tire Biyogaz Tesisi	İzmir	Sütaş Süt Enfaş Enerji	4.3 MW
Hatay Gökçegöz Çöp Santrali	Hatay	Atya Elektrik	4.2 MW
Hasdal	İstanbul	İstanbul Büyükşehir Belediyesi	4.0 MW
Afyon Biyogaz Enerji Santrali	Afyonkarahisar	Afyon Enerji	4.0 MW
Gönen Biyogaz Tesisi	Balıkesir	Gönen Yenilenebilir Enerji	3.6 MW
Belka Çöp Gazı Biyogaz	Ankara	Ankara Büyükşehir Belediyesi	3.2 MW
Atlas İnşaat Osmaniye Çöp Gazı Santrali	Osmaniye	Atlas İnşaat	3.1 MW
ITC-KA Elazığ Çöp Gazı Santrali	Elazığ	ITC-KA Enerji	2.8 MW
İskenderun Çöp Gazı Elektrik Üretim Tesisi	Hatay	Novtek Enerji	2.8 MW
Trabzon Rize Çöp Gazı Santrali	Trabzon	Mustafa Modoğlu Holding	2.8 MW
Sivas Biyokütle Elektrik Üretim Tesisi	Sivas	Novtek Enerji	2.8 MW
Konya Atıksu Biyogaz Santrali	Konya	Konya Büyükşehir Belediyesi	2.4 MW
Malatya BŞB Çöp Gazı Elektrik Üretim Santrali	Malatya	Malatya Büyükşehir Belediyesi	2.4 MW
Arel Enerji Biyokütle Tesisi	Afyonkarahisar	Arel Enerji	2.4 MW
Manavgat Çöp Gazı Santrali	Antalya	Arel Enerji	2.4 MW
Senkron Efeler Biyogaz Santrali	Aydın	Senkron Grup	2.4 MW
Mauri Maya Bandırma Biyogaz Santrali	Balıkesir	Mauri Maya	2.3 MW
Tokat Çöpgazı Elektrik Üretim Santrali	Tokat	Tokat Belediyesi	2.3 MW
Bandırma Edincik Biyogaz Santrali	Balıkesir	Telko Enerji	2.1 MW
Eses Enerji Biyogaz Santrali	Eskişehir	Eskişehir Büyükşehir Belediyesi	2.0 MW
Karaduvar Atıksu Arıtma Tesisi Biyogaz Santrali	Mersin	Mersin Büyükşehir Belediyesi	1.9 MW
Albe Biyogaz Santrali	Ankara	Era Grup	1.8 MW
GASKİ Atıksu Biyogaz Elektrik Santrali	Gaziantep	Gaziantep Büyükşehir Belediyesi	1.7 MW
Karma Gıda Biyogaz Santrali	Sakarya	Karma Gıda	1.5 MW
Polatlı Biyogaz Tesisi	Ankara	Polres Elektrik Üretim	1.5 MW
Aksaray Çöp Gazı Elektrik Santrali	Aksaray	ITC Katı Atık Enerji	1.4 MW
Karaman Biyogaz Tesisi	Karaman	Karaman Yenilenebilir Enerji	1.4 MW
Pamukova Katı Atık Biyogaz Santrali	Sakarya	Biosun Pamukova	1.4 MW

Power plant name	City	Company	Installed capacity
Eman Enerji Silifke Biyokütle Enerji Santrali	Mersin	Mersin Büyükşehir Belediyesi	1.2 MW
Uşak Çöpgazı enerji Santrali	Uşak	Uşak Belediyesi	1.2 MW
Amasya Çöp Gazı Elektrik Üretim Santrali	Amasya	Boğazköy Enerji Elektrik Üretim	1.2 MW
Ekim Grup Gübre Gazı	Konya	Ekim Grup Elektrik	1.2 MW
Malatya 1 Çöp Gaz Elektrik Üretim Tesisi	Malatya		1.2 MW
Bolu Çöplüğü Biyogaz Santrali	Bolu	CEV Enerji	1.1 MW
Kırıkkale Çöp Gazı Enerji Santrali	Kırıkkale	Mustafa Modoğlu Holding	1.0 MW
Sigma Suluova Biyogaz Tesisi	Amasya	Sigma Elektrik Üretim	1.0 MW
Kemerburgaz Çöplüğü Biyogaz Santrali	İstanbul	Ekolojik Enerji	1.0 MW
Hayat Biyokütle Elektrik Üretim Santrali	Kocaeli	Hayat Enerji	1.0 MW
Eman Enerji Karaman Biyokütle Enerji Santrali	Kahramanmaraş	Eman Enerji	1.0 MW
Adana Batı Atıksu Biyogaz Santrali	Adana	Adana Büyükşehir Belediyesi	0.8 MW
Adana Doğu Atıksu Biyogaz Santrali	Adana	Adana Büyükşehir Belediyesi	0.8 MW
Beypazarı Biyogaz Tesisi	Ankara	Derin Enerji Üretim	0.8 MW
Frito Lay Gıda Biyogaz Santrali	Kocaeli	Frito Lay Gıda	0.7 MW
Frito Lay Gıda Kojenerasyon Santrali	Mersin		0.7 MW
Kumkısık Çöplüğü Biyogaz Santrali	Denizli	Bereket Enerji	0.6 MW
Sezer Bio Enerji	Antalya	Kalemirler Enerji	0.5 MW
Denizli Atıksu Arıtma Tesisi Biyogaz Elektrik Üretim Santrali	Denizli	Denizli Büyükşehir Belediyesi	0.5 MW
Solaklar İzaydaş Çöp Gazı	Kocaeli	Kocaeli Büyükşehir Belediyesi	0.3 MW
Cargill Tarım Bursa Bioenerji Santrali	Bursa	Cargill Tarım	0.1 MW
		TOTAL	496.4 MW

Table 5. Biomass/biogas: full list of power plants in Turkey (2017).

3.5. The contribution of biomass in power generation to energy dependence, supply security, and national economy

It is well established that as a domestic natural resource, RES can make contributions to energy security. BNEF [49] and Hill [50] even proclaimed that RES could supply Turkey with full energy independence. It is clear thus that renewable energy supplies diversification into the grid which in turn relieves energy dependence in the Turkish case. One of the main promising

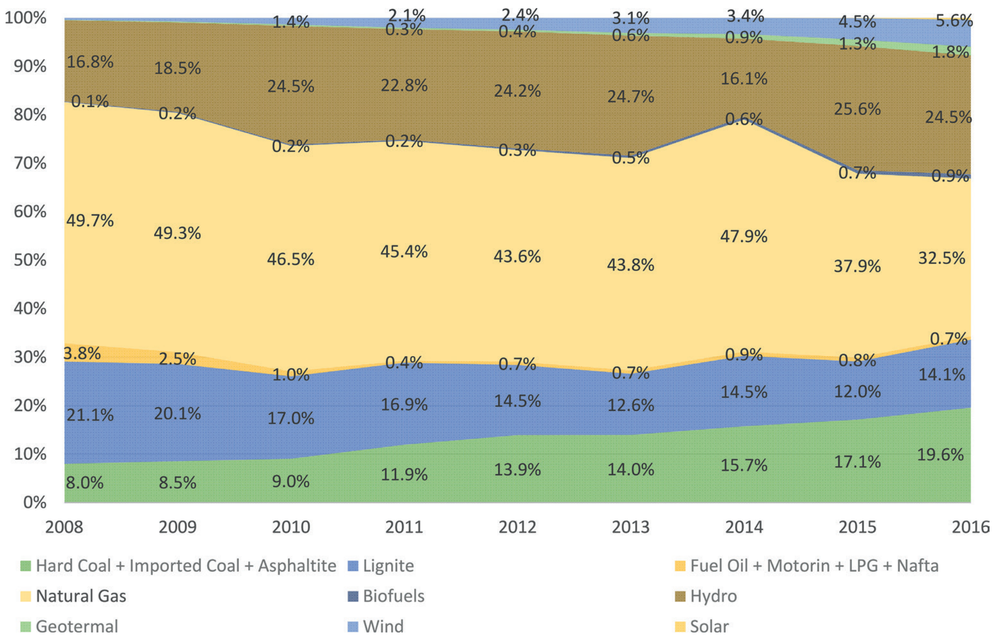

Figure 11. Development of power generation by sources (percentages) in Turkey (2008–2016).

Source	Potential (MTOE)
Agricultural Wastes	15,941,321
Municipality Wastes	2,186,228
Forestry	855,805
Livestock Wastes	1,323,714

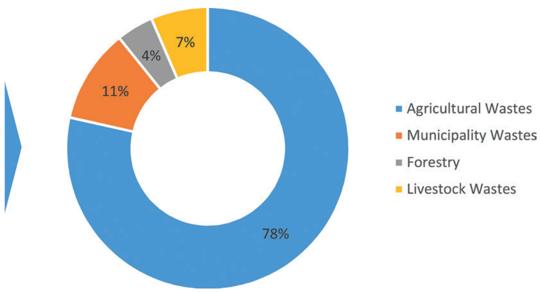

Figure 12. Biomass potential of Turkey by fuel type.

sources within RES portfolio of Turkey is therefore biofuels (especially biomass and biogas, which could help substitute the import fossil fuels.

Another focal point to be addressed is therefore the dependency problem in terms of current account deficit. **Figure 9** shows the imported energy bill of Turkey. It is notable that the decrease in the total import price results basically from the decline in global energy prices (oil and gas), but still energy is the major item in Turkey's trade balance.

In the analysis below, in order to calculate the contribution of biomass to energy security as well as to the relief of current account deficit, we make a comparison in terms of how much of energy imports from fossil fuels (in our case we take gas, which is the most expensive and the most used power-generation fuel) was actually substituted for 2016.

The cost of imported natural gas in each MWh of electricity produced can be calculated as about 38 USD (with an assumption efficiency of average 55% of a combined cycle gas turbine (CCGT) plant current BOTAŞ wholesale gas price as 704 TL/1000 m^3 or ~195 USD/1000 m^3). For the year 2016, the monetary value of avoided (not imported or "substituted with biomass fuel") natural gas can be currently calculated as approximately 90 million USD: 38 USD × 2.372 GWh (which is the total generated from biomass only in 2016) = 90.136 T. USD.

In other words, an amount of around 456 million m^3 of natural gas (which is around 1% of the total gas import amount) has been avoided to be imported, only with the utilization biomass as a fuel of choice in power generation from the biomass power plants of a total installed capacity of 496 MW in the year 2016.

Taking the official aim of reaching 1 GW (1000 MW) installed capacity by 2023 (which is around 0.8% of total capacity then) into consideration and assuming the same efficiency and capacity usage factors as was realized in 2016, 4800 GWh of power is then calculated that can be generated (which could yield a generation percentage of around 1.1% in general totally). This amount is equivalent to approximately 920 million cubic meter of natural gas as a fuel source to be burnt for power generation, which could be avoided (not to be imported) with a monetary value of approximately 182 million USD.

In this way, the imported energy bill would have been cut by about 182 million USD by 2023. If we consider the fact that the total amount of imported natural gas was around 46 billion m^3 and out of this amount 17.5 billion m^3 was consumed for power generation with an import price tag of 3.5 billion USD (which had yielded 88.271 GWh of electricity), the import fuel-saved electricity from biomass (calculated to be 4.890 GWh) would therefore be equivalent to ~5.4% of total electricity obtained from natural gas per annum. Although the amount 182 million USD (which was achieved by burning biomass instead of gas) as savings in a gas-for-electricity portion of ~3.5 billion USD and around total gas import bill of 9 billion USD and of total 27 billion USD energy import bill or 32.6 billion current account deficit seems small (though only annual) and negligible, one should also consider the fact that biomass is actually one of the many domestic and environmentally friendly renewable energy sources (several of which, like wind, hydro, and solar, are much more contributive than biomass), which has enormous potential altogether to reduce significantly energy-dependence ratio and the total energy import bill of Turkey (and consequently current account deficit).

That is, the total value of RES potential for 2023 (the official government target year) is—with 38% of total generation—actually more than total for the "gas-for-electricity" amount (which is around 30%). In other words, with the total RES-generated electricity, which would have otherwise been generated from imported natural gas, more than 3.5 billion USD could be saved per annum by 2023. Thus, it can safely be said that together with other renewables, biomass has a role to play to reduce both energy-import dependence and import bill of Turkey in a better way.

4. Conclusions

It has been understood for some time now that the dependence of the world (especially in power generation) on fossil fuels is not sustainable. One of the identified solid alternatives therefore has been biofuels. As biofuels are regarded as carbon neutral (x ref), they are listed under the renewable category of energy sources and are thus "climate friendly," as opposed to fossil fuels; they are given priority and are supported globally by government policies, as is the case with generous subsidies (such as the highest off-take guarantees from biofuel power plants) in Turkey. The potential of biofuels (although not as huge as solar or wind) especially in power generation is considered to be significant due to the fact that it is not actually an intermittent source of power as is the case with other renewables such as wind- and solar- (as they are actually called "variable renewable energies") based generation. Thus, biofuels can easily substitute other fossil fuels as a reliable and base-load source of power generation with high availability, as opposed to the variability and intermittency of other sources. This has been actually demonstrated in Turkey in relation to the operational conditions (high availability and reliability) of existing biomass power plants.

Another result of this study in terms of the reasons for utilization of biomass/biogas resources is (in addition to all abovementioned environmental benefits)the contribution (so far small but promising for the future) of them reducing energy import dependence and energy import bill of Turkey. As analyzed in the relevant section, the development of biomass/biogas plants has been very rapid and the generation reached the equivalent of more than 5% of power generation from natural gas. Thus, the gas imports were reduced by this amount, or according to unit-based calculation, 1 MW of power generated by local/domestic and renewable biomass/ biogas obviously meant "1 MW less of imported and fossil natural gas-based power". The total savings or avoided import value per year (for only the year 2016) is around 185 million USD. Considering the potential of biomass/biogas and the fast development in utilization of these resources lately, one could assume that this amount or value (also depending on the price of import gas) will increase and biomass will (along with other RES) play a meaningful role in terms of contributing to meeting national climate targets as well to reducing energy import bill of Turkey, thus enhancing energy security and independence of the country in the long run.

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