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Fuel supply chain analysis of Turkey

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Abstract

In spite of its natural sources, Turkey depends on other countries in terms of energy production, and a transfer from conventional fossil sources to sustainable energy sources is strongly necessary. Among the sustainable energy sources, biomass is the subject of this study. The characteristics, logistic aspects, environmental aspects, economical, legal and technical aspects are investigated in order to show that the possible biomass co-firing is very important for the construction of economic, sustainable and environmentally friendly energy systems.

Keywords: Biomass; Coal; Co-firing; Environment; Economy; Logistics

Contents

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1. Introduction

Continuity of industrial and social life strongly depends on the energy supply. Although energy is indispensable in our lives, consumption of the large amounts of fossil fuels causes many serious problems.

Most significant critical environmental problems are global warming which is due to the absorption of infrared radiations by greenhouse gases (CO_2, H_2O, CH_4, chlorofluorocarbons etc.), acid rains due to SO_2 and NO_x emissions and carbonaceous particulate matter and other emissions [1]. One possibility to reduce greenhouse-gas, SO_2 and NO_x emissions of coal is co-firing; to burn low-sulfur and low-nitrogen-biomass together with coal in pulverized coal-fired boilers or fluidized beds. In order to decide the type of the biomass that will be used in the co-firing process, determination of the combustion characteristics of the biomass such as, calorific value, ash properties and elemental analysis, is very important. On the other hand, the final decision on the usage of the biomass is closely related with the economical feasibility of the biomass.

The aim of this study is to carry out an overall analysis of the whole supply chain of Turkey, based on the biomass species as well as waste materials [2].

2. General information and energy situation of Turkey

Although Turkey has most of the energy resources, it is an energy importing country, since these resources are limited [3]. More than half of the primary energy consumption in Turkey is met by imports and the share of these imports increases continuously. Therefore, if the country wants to supply its demand of energy by its own resources and become less dependent on foreign resources, the policy about using conventional energy resources (i.e. fossil fuels, such as hard coal, lignite, oil and natural gas) should be converted to renewable energy resources, and this must be realized in a reasonable period of time [3].

Turkey has several advantages for the use of the biomass as an energy source in terms of its climate. Turkey has a climate which is mainly characterized by the Mediterranean macro climate system. On the other hand, despite of the Mediterranean geographical location of Turkey in which climatic conditions are quite temperate, diverse nature of landscape and irregular topography causes significant differences in climatic conditions from one region to the other. Shortly, the coastal areas have mild climates and inner Anatolian parts have extremely hot summers and cold winters with insufficient rainfall, on the contrary, the north region of Turkey, the Black Sea Region, receives rainfall throughout the year. Average rainfall nationwide is about 650 mm [4].

Table 1
Amount of primary energy sources in Turkey [6]

Sources	Apparent	Probably	Possible	Total
Hard coal (million tons)	428	449	249	1126
Lignite (million tons)	7339	626	110	8075
Asphaltite (million tons)	45	29	8	82
Oil shale (million tons)	555	1086	269	1641
Hydropower (MW)	34 736	—	—	34 736
Oil (million tons)	36	—	—	36
Natural gas (million tons)	8	—	—	8
Nuclear (tons)				
Uranium	9129	—	—	9129
Thorium	380 000	—	—	380 000
Geothermal (MW)				
Electric	200	—	4300	4500
Thermal	2250	—	28 850	31 100
Solar (Mtoe/y)				
Electric	—	—	—	8.8
Heat	—	—	—	26.4
Wood	1550	150	25	1725
Dung	175	30	13	218

Turkey's primary energy sources are hard coal, lignite, asphaltite, oil shale, hydropower, oil, natural gas, geothermal, solar, wood, and animal and plant wastes. Table 1 shows the amounts of these primary sources [5].

The primary energy production and consumption statistics are given in Table 2. It is clearly seen that on the average approximately half of the primary fuel used was imported between 1990 and 2003, if hard coal, natural gas and oil are considered separately. This picture becomes more dramatic as the import of these fuels varies between 80% and 90% and reaches up to 92% in 2003.

Due to the high economic development and the increase of population in Turkey, it is expected that between 2000 and 2010 the energy demand of Turkey will be doubled and in 2030, it will be almost fivefold, Table 3 summarizes the sectoral distribution of general energy demand.

The distribution of the consumption of energy sources of Turkey by the year 2005 is given in Fig. 1. It is clearly seen that only a total of 12% of the energy need correspond to the renewable sources.

Other significant aspects about the use of biomass sources can be shown by the recent energy production and consumption values [6]; Table 4 shows the projected values for total primary energy production and consumption and the share of biomass sources and Fig. 2 summarizes the values presented in Table 4. It is obvious that the amount of primary energy consumption increases exponentially, while the production values significantly stay behind these values and in spite of that, use of biomass as a primary energy source decreases each year.

From the tables and the figures above, it is clear that Turkey needs to start to use its sustainable energy sources immediately as previously stated. Among the various sustainable sources available in Turkey, biomass could play an important role. However,

Table 2
Primary energy production and consumption in Turkey between 1990 and 2003 (values in parenthesis represents the consumption values) [6]

	Units	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Hard coal	kton	2745	2762	2830	2789	2839	2248	2441	2513	2156	1990	2259	2357	2245	2011
		(8191)	(8824)	(8841)	(8844)	(8192)	(8548)	(10 892)	(12 537)	(13 146)	(11 362)	(15 393)	(11 039)	(13 756)	(17 487)
Lignite	kton	44 407	43 207	48 388	45 685	51 553	52 758	53 888	57 387	65 204	65 019	60 854	59 572	51 660	46 168
		(45 891)	(45 851)	(50 659)	(46 086)	(51 178)	(52 405)	(54 961)	(59 474)	(64 504)	(64 049)	(64 394)	(61 010)	(52 039)	(46 051)
Asphaltite	kton	276	139	213	86	—	67	34	29	23	29	22	31	5	—
		(287)	(139)	(197)	(102)		(66)	(34)	(29)	(23)	(29)	(22)	(31)	(5)	
Natural gas	Mm^3	212	203	198	200	200	182	206	253	565	731	639	312	378	561
		(3418)	(4205)	(4612)	(5088)	(5408)	(6937)	(8114)	(10 072)	(10 648)	(12 902)	(15 086)	(16 339)	(17 694)	(21 374)
Oil	kton	3717	4451	4281	3892	3687	3516	3500	3457	3224	2940	2749	2551	2420	2375
		(22 700)	(22 683)	(23 660)	(27 074)	(25 589)	(27 918)	(29 601)	(29 176)	(29 022)	(28 862)	(31 072)	(29 661)	(29 776)	(30 669)
Hydropower	GWh	23 148	22 683	26 568	33 951	30 586	35 541	40 475	39 816	42 229	34 678	30 879	24 010	33 684	35 330
		(23 148)	(22 683)	(26 568)	(33 951)	(30 586)	(35 541)	(40 475)	(39 816)	(42 229)	(34 678)	(30 879)	(24 010)	(33 684)	(35 330)
Wind & geoth (electricity)	GWh	80	81	70	78	79	86	84	83	85	81	76	90	105	89
		(80)	(81)	(70)	(78)	(79)	(86)	(84)	(83)	(85)	(81)	(76)	(90)	(105)	(89)
Wind & geoth (heat)	kTOE	364	365	388	400	415	437	471	531	582	618	648	687	730	784
		(364)	(365)	(388)	(400)	(415)	(437)	(471)	(531)	(582)	(618)	(648)	(687)	(730)	(784)
Wood	kton	17 870	17 970	18 070	18 171	18 272	18 374	18 374	18 374	18 374	17 642	13 938	16 263	15 614	14 991
		(17 870)	(17 970)	(18 070)	(18 171)	(18 272)	(18 374)	(18 374)	(18 374)	(18 374)	(17 642)	(16 938)	(16 263)	(15 614)	(14 991)
Animal and plant residues	kton	8030	7918	7772	7377	7074	6765	6666	6575	6396	6184	5981	5790	5609	5439
		(8030)	(7918)	(7772)	(7377)	(7074)	(6765)	(6666)	(6575)	(6396)	(6194)	(5981)	(5790)	(5609)	(5439)
Solar	kTOE	26	41	60	88	129	143	159	179	210	236	262	287	318	350
		(28)	(41)	(60)	(88)	(129)	(143)	(159)	(179)	(210)	(236)	(262)	(287)	(318)	(350)
Total	kTOE	25 478	25 501	26 794	26 441	26 511	26 719	27 386	28 209	29 324	27 659	26 855	25 173	24 727	23 812
		(52 987)	(52 278)	(56 684)	(60 265)	(59 127)	(63 679)	(69 862)	(73 779)	(74 709)	(74 274)	(81 221)	(75 952)	(78 711)	(83 804)

Table 3
Sectoral distribution of the general energy demand (1000 tons of oil equivalents) [7]

Year	Industry	Household	Transportation	Agriculture	Other	Total
1995	18 181	17 475	10 827	2790	1514	50 787
1997	22 779	21 374	12 209	3120	1558	61 040
1999	26 576	23 021	13 521	3483	1604	68 205
2001	30 815	24 708	14 842	3868	1651	75 883
2003	35 491	26 414	16 146	4273	1699	84 024
2005	40 764	28 239	17 564	4721	1749	93 037
2007	46 863	30 125	19 122	5148	1800	103 068
2010	57 493	33 193	21 722	5862	1880	120 174
2020	121 179	50 675	33 049	11 016	4407	200 325
2030	203 700	63 447	36 733	20 036	10 018	333 934

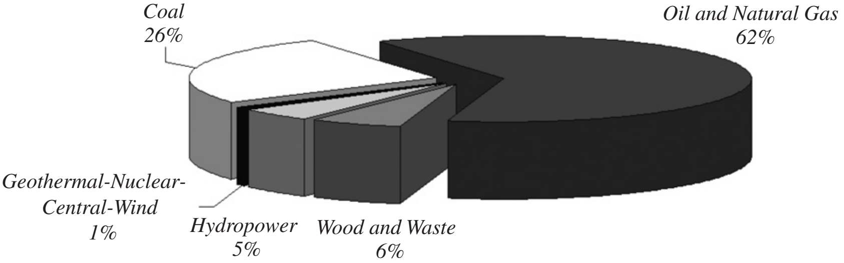

Fig. 1. Distribution of the energy sources according to their contribution to the total energy consumption in Turkey by the year 2005.

experience has shown that the availability of biomass could be a serious obstacle for its extensive use for energy. Thus, a detailed analysis of the characteristics, logistic aspects, environmental aspects, economical, legal and technical aspects needs to be undertaken in order to show that the possible biomass co-firing could be very important for the construction of economic, sustainable and environmental friendly energy systems. In this study, we investigated the opportunities to use the biomass energy sources from co-firing point of view.

3. Biomass species and non-toxic waste materials

Biomass is a type of energy source with high carbon content. In fact, biomass is the only energy source that contains carbon within the renewable energy systems. Biomass can be either obtained directly from plants or indirectly from industrial, domestic, agricultural and animal wastes. The examples of biomass energy sources include wood and wood wastes, agricultural crops and their waste byproducts, municipal solid waste, animal wastes, waste from food processing, and aquatic plants, algae, energy crops such as trees and sugarcane that can be grown specifically for conversion to energy [8]. To contribute to the energy demand of the country by using the national sources and to overcome the environmental problems, renewable energy sources should be considered as important

Table 4
Primary energy production and consumption of Turkey between 2000 and 2030, Mtoe (values in parenthesis are the consumption values) [7]

Energy source	2000	2005	2010	2015	2020	2025	2030
Coal (Hard coal + Lignite)	17 202 (20 256)	21 259 (30 474)	28 522 (50 311)	31 820 (83 258)	39 385 (129 106)	45 944 (296 997)	59 765 (363 210)
Oil and Natural gas	3408 (59 250)	2127 (73 256)	1735 (92 637)	1516 (112 993)	1604 (136 365)	1455 (179 765)	1893 (227 518)
Wood and waste	6963 (6963)	6760 (6760)	6446 (6446)	6029 (6029)	5681 (5681)	5393 (5393)	7015 (7015)
Hydropower	3763 (3763)	5845 (5845)	7520 (7520)	8873 (8873)	9454 (9454)	10 445 (10 445)	3587 (3587)
Geothermal	432 (432)	1380 (1380)	3760 (3760)	4860 (4860)	4860 (4860)	5400 (5400)	7024 (7024)
Nuclear	0.0 (0.0)	0.0 (0.0)	3657 (3657)	9143 (9143)	18 286 (18 286)	29 200 (29 200)	37 984 (37 984)
Solar	204 (204)	459 (459)	907 (907)	1508 (1508)	2294 (2294)	3248 (3248)	4225 (4225)
Central heating	253 (253)	495 (495)	884 (884)	1336 (1336)	2018 (2018)	2748 (2748)	3575 (3575)
Wind	55 (55)	250 (250)	620 (620)	980 (980)	1440 (1440)	2134 (2134)	2776 (776)

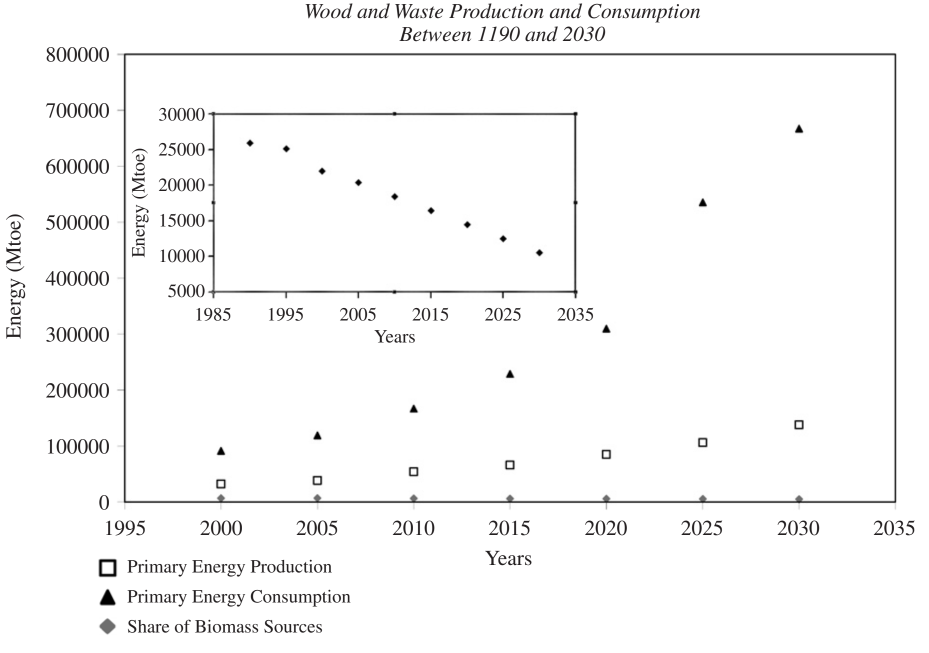

Fig. 2. Projection for total primary energy production and consumption.

inputs. Because biomass offers considerable flexibility in fuel supply in Turkey, due to the range and diversity of the fuels that can be produced, it should be considered as a renewable energy equivalent to fossil fuels. Biomass can be either used by direct combustion or mixed with an appropriate fossil fuel and be combusted or it can be converted into solid, liquid and gaseous fuels using conversion technologies such as fermentation to produce alcohols, bacterial digestion to produce biogas and gasification to produce a natural gas substitute. Biomass has so far been utilized either as a base fuel in fairly small boilers or as a co-fuel in larger, mostly coal-based units. There is a possibility of rendering the use of biomass more viable by blending it with non-toxic waste materials, which are economically unattractive for recycling and are expensive to dispose of in landfills. The use of these wastes for energy is promising provided that they combine well with other fuels during the conversion process for energy and have no negative effect on the environment. It is, therefore, imperative that there is a satisfactory synergy between coal, biomass and wastes so that the impact of multi-fuel co-firing minimizes any negative aspect of any fuel when used separately [9]. The proposed study aims at determining the limits of the optimized operation that could be beneficial in getting rid of waste and promoting biomass for environmentally acceptable energy generation. Fluidized bed systems are particularly well suited for such a co-firing operation because of their versatility with regard to fuel.

Worldwide, biomass is in the fourth place as an energy source and provides about 14% of the world's energy needs [10]. Furthermore, biomass is a clean and renewable energy source; for example, if biomass is utilized in a closed-loop process, the entire process, planting, harvesting, transportation, conversion to electricity via combustion then release into the atmosphere, can be considered as there is no net gain of carbon dioxide in the atmosphere [11–13].

In future, biomass has the potential to provide a cost-effective, environmental friendly and sustainable supply of energy [1]. By the year 2050, it is estimated that 90% of the world population will live in developing countries. It is critical, therefore, that the biomass processes used in these countries should be sustainable. The modernization of biomass technologies, leading to more efficient biomass production and conversion is one possible direction for biomass use in developing countries. Besides the ability of biomass providing a clean, renewable energy source that could dramatically improve our environment, economy and energy security, it can also create thousands of jobs and helps revitalize rural communities.

Biomass offers important advantages as a combustion feedstock due to its high volatility and the high reactivity, both of the fuel and the resulting char. On the other hand, biomass should be separated from coal to another category in term of its organic, inorganic, energy content and physical properties. If compared with coal, biomass generally has less carbon, more oxygen, more silica and potassium, less aluminum and iron, lower heating value, higher moisture content and lower density and friability [14–17]. Also, the chlorine content is considerably high in comparison with coal, which results with corrosion [16–18]. Additionally, the high moisture and ash contents in biomass fuels can cause ignition and combustion problems. Also the melting point of the dissolved ash is generally low, which causes fouling and slugging problems. Because of the low-heating values, use of biomass can cause flame stability problems. A bright solution to these problems can be blending biomass with higher quality coal, which will reduce the flame stability problems, as well as minimize the corrosion effects [19].

3.1. Agricultural biomass residues

Agricultural wastes are the wastes of agricultural activities without posterior use in the proper exploration. Crops and livestock account for 90% of the agricultural sector in Turkey. The type and quantity of crops that form the basis of the agricultural sector (wheat, barley, tobacco, cotton, rice, etc) give rise to huge amounts of agricultural residues. These are generally treated in an uncontrolled manner, and either burned in open-air fires or allowed to decay. In either case, they result in significant environmental impacts while at the same wasted.

The main agricultural products of Turkey are grain, cotton, tobacco, grapes, sunflower, pulses (chickpeas and lentils), dried fruit (hazelnuts, seedless raisins, figs and apricots), fresh fruits (apples and citrus), tomatoes, tea and small ruminants (sheep, goats). Cereal production occupies 75% of Turkey's crop land. Turkey is one of the world's biggest wheat and barley producers; the annual wheat production was 19 million tons in 2003 and barley production was 8.1 million tons in 2003. Other important products are cotton seed, which has an annual production of 1.3 million tons (2003), and sugar beet with 12.6 million tons of annual production by the year 2003 [20].

Turkish agriculture is heavily dependent on seasonal rainfall. Among the total 8.5 million hectares of land under potential perennial irrigation, only 4.5 million hectares, has been equipped with requisite irrigation infrastructure. On the other hand, the expansion of irrigated lands helps to improve production, create rural employment and alleviate migration from rural to urban areas. For this reason, it is planned that by the year 2015, 1.7 million hectares of land will be added to the irrigated land by the Southeastern Anatolian Project [21].

Small farm size is a characteristic of Turkish agriculture. Distribution of the 4 million farm households is in such a way that 67% of these farms is between 0.1 and 5 ha and only 33% of households own more than 5 ha. Unfortunately, this distribution causes the farm output to be low in comparison to the country's enormous potential.

In 1999, Turkey has been faced with a serious economic crisis, and the debt of public sector has reached to very high limits. During 1990s the ratio of public debit to national income was below 30%, at the end of 2000 this ratio has reached to 60% and at the end of 2001 it was 70%. Up to that time government was able to get into debts at high real interest, but after that time this was not acceptable anymore.

By the IMF Letter of Intent and Reconstruction Program in 1999, the agricultural policy of Turkey has changed; the subsidizing policies has been stopped and shifted into a direct income support system [22].

The improvement in the agricultural sector had targeted as 2.9–3.7% for the VIIth planning period but realization of the target was as 1.7%. On the other hand, in the 8th five year development plan (2001–2006), the improvement in the agricultural sector had targeted as 2.1% [23].

The following Table 5 presents the agricultural residues and the energy content of the available biomasses in Turkey. The most important representative example of biomass family is wood, which is a naturally occurring material, which consists of cellulose, hemicellulose and lignin. The following Table 6 is representing the proximate, ultimate and elemental analysis results of selected agricultural biomass sources and Turkish lignocellulosic biomass sources. Wood is one of the major sources of energy in rural Turkey. An average of 0.75 m^3 of fuelwood is burnt annually by each fuelwood consumer.

Table 5
Evaluation of plant based biomasses available in Turkey [17,25]

Product	Annual production (tons)	Energy content (MJ/kg)
Wheat residues	30 000–40 000	18.40
Barley residues	12 000–16 000	17.10
Oats residues	400–600	17.70
Rye residues	350–450	17.60
Rice residues	250–350	15.40
Maize residues	4000–5000	16.80
Sun flower residues	2500–3000	14.28
Cotton seed residues	2600–3100	17.07
Sugar beet residues	1500–2000	16.72
Hazelnut shell	350 000	1.9 kWh
Walnut shell	150 000	20.18
Olive waste	450 000 tons/1 million tons of olive	12.5–21.0
Cocoon shell	10 00 000	5.3 kWh
Wood and woody materials	12 000 000	62.3 kWh

Table 6
Chemical and structural analyses of biomass samples (wt% dry and extractive free basis) [17,26]

Sample	C%	H%	O%	N%	Ash	Moisture	HHV (Mj/kg)	Hemicellulose	Cellulose	Lignin
Hazelnut shell	52.9	5.6	42.7	1.4	1.3	9.0	19.3	29.9	25.9	42.5
Hazelnut seedcoat	51.0	5.4	42.3	1.3	1.4	6.8	19.3	15.7	29.6	53.0
Softwood (av.)	52.1	6.1	41.0	0.2	1.7	8.8	20.0	24.4	45.8	28.0
Hardwood (av.)	48.6	6.2	41.1	0.4	2.7	7.8	18.8	31.3	45.2	21.7
Waste material	48.3	5.7	45.3	0.7	4.5	11.0	17.1	29.2	50.6	24.7
Walnut shell	49.9	5.7	43.4	0.2	0.6	—	20.2			
Tea waste	48.6	5.5	39.5	0.5	3.4	6.5	17.1	19.9	30.2	40.0
Wood bark	53.1	6.1	40.6	0.2	1.6	8.8	20.5	29.8	24.8	43.8
Wheat straw	45.5	5.1	34.1	1.8	13.5	8.5	17.0	39.1	28.8	18.6
Corncob	49.0	5.4	44.6	0.4	1.0	12.1	17.0	32.0	52.0	15.0
Corn stover	—	—	—	—	3.7	10.6	17.8	30.7	51.2	14.4
Tobacco stalk	—	—	—	—	2.4	8.9	17.7	28.2	42.4	27.0
Tobacco leaf	—	—	—	—	17.2	8.4	15.0	34.4	36.3	12.1
Olive husk	50.0	6.2	42.2	1.6	4.0	9.2	19	23.6	24.0	48.4
Spruce wood	51.9	6.1	40.9	0.3	0.5	7.6	20.1	21.2	50.8	27.5
Beech wood	49.5	6.2	41.2	0.4	0.4	7.4	19.2	31.8	45.8	21.9
Ailanthus wood	49.5	6.2	41.0	0.3	0.5	8.1	19.0	26.6	46.7	26.2

Forest sources of Turkey shows an exponential declining due to insufficient forestry plantation and regeneration. Turkish forest area occupies about 26.6% (20.7 million hectares) of entire land area, of which 48% is productive. Productive high forests cover about 39.4% of total forest area and 10.5% of total land area [24].

Main tree species in Turkey are, coniferous, which makes up about 54% and broadleaved 46% of designated forest area. Most abundant species in Turkey are namely coniferous, pine, fir, spruce and cedar and among hardwoods beech, oak, chestnut, hornbeam and alder.

Estimated total annual wood increment in Turkish forests is about 34 million m^3. Annual total wood production including private is about 28 million m^3, of which 63% is consumed as fire wood [24].

In Turkey, 5.9% of entire country (17.5% of forest areas) has been set aside for conserving natural values, especially biological diversity, and for preventing soil erosion and land slides. The areas set aside for protecting biological diversity alone, constitute 0.9% of total land area and 1.8% of total forest area. Table 7 shows a summary of forest potential of Turkey and main tree species that can be found in Turkey are presented in Table 8.

When the biological species are considered, Turkey would be one of the richest countries in the world which means, non-wood products and services play very important role in the life of people, especially that of rural poor regions [27]. Turkey is the largest producer and exporter of agricultural products in the near East and North African region. Despite the overall trade deficit of Turkey, the agricultural trade balance is significantly positive, providing some relief to external accounts. Trade liberalization and rising demand in the region resulted in agricultural product exports (excluding agro-industry) rising to a value of approximately US$ 2.5 billion in 2003 and accounts for 5.3% of Turkey's total export earnings [28].

According to the Turkish Forestry Inventory, the Turkish forestry treasure is 1.2 billion m^3, and the growth of this on the year basis is 34 million m^3, on the other hand, the amount among these forest area which is available for woodcutting is 18 million m^3 [29]. Turkish wood demand per year will be 43 million m^3 by the year 2020. And if the difference between wood production and consumption will be supplied by import, government should have to pay 6.4 billions USD. In order to meet this deficiency, government should build up modern energy forests itself and citizens should be stimulated

Table 7
Forest potential of Turkey [24]

	Quality						Grand total (ha)
	High forest			Coppice			
	Coniferous	Broadleaved	Total	Coniferous	Broadleaved	Total	
Area							
Productive forest	64 88 725	16 72 455	81 61 180	3414	17 89 268	17 92 682	99 53 862
Degraded forest	45 86 869	15 35 262	61 22 131	30 087	46 06 814	46 36 901	10 759 032
Total	11 075 594	32 07 717	14 283 311	33 501	63 96 082	64 29 583	20 712 894
Growing stock (000 m^3)							
Productive forest	742 224	276 358	10 18 582	87	80 786	80 873	10 99 455
Degraded forest	44 884	18 754	63 638	143	23 192	23 335	86 973
Total	787 108	295 112	10 82 220	230	103 978	104 208	11 86 428
Annual increment (000 m^3)							
Productive forest	19 686	6674	26 360	29	4641	4670	31 030
Degraded forest	1009	588	1597	3	1369	1372	2969
Total	20 695	7262	27 957	32	6010	6042	33 999
Annual allowable cut							
Selection methods	417	40	457				
Regeneration methods	6402	2145	8548				
Tending methods	2229	980	3209				
Total	9048	3165	12 214			5884	

Table 8
Main tree species in Turkish forests [24]

Species		High forests		Total forest area	
Family of species	# of species	Area (ha)	%	Area (ha)	%
Coniferous					
Pine–Pinus	7	55 41 722	67.90	86 01 681	41.53
Fir–Abies	4	457 778	5.61	61 9791	3.00
Spruce–Picea	1	185 138	2.26	286 658	1.38
Cedar–Cedrus	1	219 369	2.68	336 342	1.62
Juniper–Juniperus	6	78 583	0.96	12 34 162	5.96
Cypress–Cupressus	1	666	0.01	1 347	0.01
Douglas–Pseudotsuga	1	280	—	280	—
Others		5191	0.06	28 835	0.14
Sub total		6 488 727	79.48	11 109 096	53.64
Broadleaved					
Beech–Fagus	1	10 60 822	13.00	13 35 786	6.45
Oak–Quercus	34	349 259	4.28	60 89 327	29.40
Chestnut–Castanea	1	56 886	0.70	99 434	0.48
Hornbeam–Carpinus	2	57 550	0.70	99 309	0.48
Alder–Alnus	2	57 815	0.70	109 502	0.53
Ash–Fraxinus	3	8096	0.10	11 669	0.06
Poplar–Populus	6	10 289	0.12	20 548	0.10
Maple–Acer	10	1579	0.02	2953	0.01
Lime–Tilia	4	4944	0.06	5424	0.03
Acacia–Acacia	1	1022	0.01	3075	0.02
Sweet Gum–Liquidambar	1	1930	0.02	3191	0.02
Plane–Platanus	2	817	0.01	1470	0.01
Eucalypt–Eucalyptus	1	771	0.01	6655	0.03
Tree of Heaven–Ailanthus	3	802	0.01	802	—
Hop Honbeam–Ostrya	1	646	0.01	2066	0.01
Elm–Ulmus	3	459	0.01	519	—
False Acacia–Robinia	1	234	—	234	—
Walnut–Juglan	1	176	—	176	—
Willow–Salix	19	160	—	2194	0.01
Birch–Betula	3	11	—	596	—
Laurel–Laurus	1	—	—	409	—
Others		58 186	0.71	18 08 460	8.72
Sub total		16 72 454	20.52	96 03 799	46.36
Grand total		81 61 181	100.00	20 712 895	100.00

for energy afforestation by government also. General Management of Forestry has started energy forestry in 1978, and the afforested area under this project was 535,000 ha at the end of 2001. Efficiency of the energy forestry in Turkey from wood product per unit area point of view is well below than the countries, which are the leaders in this subject [30].

3.2. Animal based biomass samples available in Turkey

Animal husbandry is one of the main means of living. Thus a significant amount of animal wastes are produced each year. In Turkey, most of the animal based biomass studies have been done in the area of biogas research and development projects since the

1960s. In addition to feasibility studies on biogas utilization, many digesters have been constructed at different places in the country. The representative animal-based residues and their total energy potential is given in Table 9.

3.3. Non-toxic solid wastes

The solid wastes have been recording by Government Statistics Institute since 1994. By the end of 2002, among 3215 municipalities, 2984 have solid waste removal service. The solid waste removal situation by the municipalities is presented in Fig. 3.

The first power generation attempts based on biogas applications had been started in 1957 and continued until 1987. Recently, power generation by using biomass and waste attempts have been restarted on small scale by using municipal solid wastes (MSW) [32]. The Ministry of Energy and Natural Resources has planned to increase the production of biomass energy, which uses up animal and plant waste, to 7530 thousand tons of oil equivalent (Ttoe) by 2020. Modern biomass energy production, however, has not been foreseen at all. In fact, classical biomass energy production with no commercial value should be decreased and modern biomass energy production should start and be increased.

Table 9
Total and recoverable bioenergy potential of animal wastes in Turkey [31]

Kind of animal	Total number of animals (thousand head)	Coefficient of conversion (ktoe per thousand animals)	Total energy potential (ktoe)	Recoverable energy potential (ktoe)
Sheep and goats	75 095	0.048	3604	1081
Donkey, horse, mule and camel	1370	0.235	322	97
Poultry	311 500	0.003	935	281
Cattle and water buffalo	12 121	0.245	2970	891

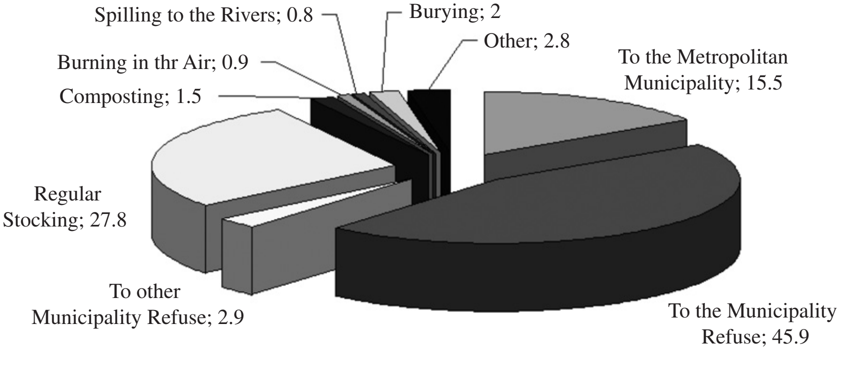

Fig. 3. Solid wastes in Turkey according to the Removal Type [34].

Table 10
Waste power plants in Turkey [33]

Waste plant	Power (MW)	Net energy production (million kWh/y)
Adana waste plant	45	302
Mamak waste gas plant	10	76.8
Bursa waste gas plant	14	Auto-producer
İzmit waste gas plant	72	Auto-producer
Mersin waste plant	18.8	On construction
Tarsus waste plant	12.5	On construction

On the other hand, there have been initiatives to build waste power plants in Turkey. These initiatives are continuing under the Build Operate and Transfer (BOT) model. Among them, a contract has been signed for Adana Waste Plant with a power of 45 MW and 302 million KWh/year net energy production. The waste plants including Adana are presented in Table 10. Antalya, Diyarbakır, Eskişehir, Konya and Sakarya should also be added among cities where waste plants are going to be built [33].

Besides the government's plants, private companies have attempted on building biomass and waste power plants; Turkish company Selcuk Gida is planning to apply to the Ministry of Energy to get permission to produce energy from oil cake. This kind of energy production would be the first in Turkey. Sel Energy AS will produce energy from oil cake material, which is an environmentally safe waste product made from olive oil. The power plant will be established in Aydin's Germencik district and will cost about 20 million USD.

Sludge resulting from municipal and/or industrial wastewater treatment plants is another important waste. In Turkey, only 13% of the population is connected to sewage collection systems. The number of waste water treatment plants operated by municipalities is 69 and domestic wastewater treatment systems produce about 500,000 tons of sludge per year. On the other hand, State Institute of Statistics (SIS) has stated that treatment plants in the manufacturing industry releases 3.6 million tons of treatment sludge, of which 8% is spread on agricultural land, 12% is disposed to seas, 34% is dumped in filling sites, 20% is disposed to municipal landfill areas, and 1% is burned, and the rest is treated by other methods. Moreover, in Organized Industrial Estates (OIEs), there are currently 11 plants for treatment of industrial and domestic wastewaters, which are having an amount of the sludge cake production approximately 300,000 tons per year. Also, there are nine plants in the planning and 12 plants in the construction stage. The total amount of sludge produced from already operating plants and from the plants in the construction stage is expacted to reach about 750,000 tons per year in a reasonable period of time. Sludge production increases annually and methods of disposal of sludge are becoming more important in Turkey. The heating value of sewage sludge on dry basis is about 12–24 MJ/kg and it is possible to burn the sludge in fluidized bed combustors (FBCs), which will be a definite solution for disposal [35].

3.4. Industrial wastes

All industries, businesses and consumers produce waste. Industrial waste term encloses all types of solid wastes and semi-solid wastes which result from industrial processes and manufacturing operations, while commercial solid wastes include all types of solid wastes

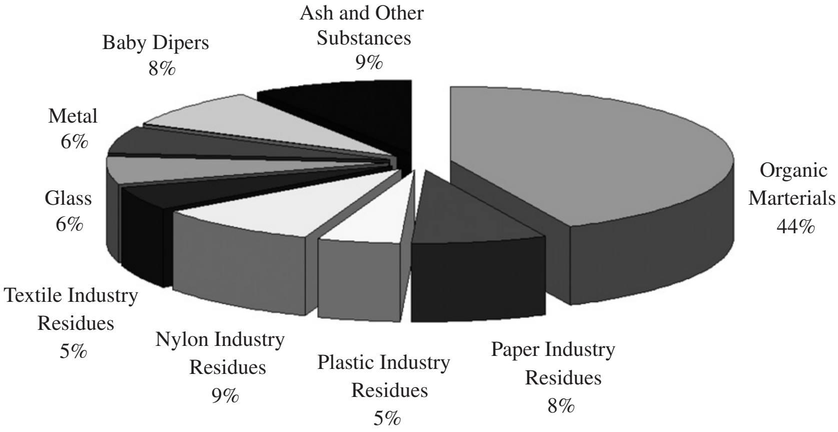

Fig. 4. Main constituents of industrial residues in Istanbul [36].

generated by stores, offices and other commercial sources, excluding residences, and excluding industrial wastes. Some part of those industrial and commercial wastes are biodegradable, such as paper fines and industrial biosludge, into mixed alcohol fuels (e.g. isopropanol, isobutanol, isopentanol) [10]. The types of industrial wastes and the comparative amounts are given in Fig. 4.

4. Co-firing aspects

Biomass can be converted into useful forms of energy using number of different processes. Conversion process is selected according to the type and quantity of biomass feedstock, the desired form of the energy, environmental standards expectations, economic conditions and designing factors. Conversion of biomass to energy is undertaken using two main processing technologies: first category is thermo-chemical processes, which include combustion, pyrolysis, gasification and liquefaction and bio-chemical/biological processes consist of digestion (production of biogas, a mixture of mainly methane and carbon dioxide) and fermentation (production of ethanol) [8,37]. Co-combustion of biomass with other fuels can be advantageous with regard to cost, efficiency and emissions. Processing costs can be lowered and higher efficiencies of large plants can be utilized for biomass and emissions of CO_2, SO_x and NO_x can be reduced by co-firing process. The use of biomass in the existing boilers, which are designed for coal combustion is much cheaper than building new biomass plants [14]. Fluidized bed systems are particularly well suited for such a co-firing operation because of their versatility with regard to fuel [38,39]. While using biomass, care has to be taken if high chlorine and high alkaline, which are known to be negative effects on operation like corrosion or slagging of the heat transfer surfaces [40,41]. In a generalized sense, the co-firing processes can be categorized as following:

(a) Co-combustion or direct co-firing: the biomass is directly fed to the boiler furnace of any type (fluidized bed, grate or pulverized combustion), if needed, physical preprocessing is applied to the biomass and coal such as drying, grinding or metal removal.

(b) Indirect co-firing: the biomass is gasified and the product gas is fed to a boiler furnace, thus a combination of gasification and combustion is applied.
(c) Parallel combustion: in this process, biomass is burnt in a separate boiler for steam generation. The steam is used in a power plant together with the main fuel, coal [42].

Co-firing of biomass and coal has been investigated by many groups and it is concluded that utility of biomass has some disadvantages also. Main barriers of co-firing are:

(a) Supply of the biomass in long period of time.
(b) Ash characteristics of biomass, which brings corrosion problems to the system.
(c) Addition of biomass to coal has negative effects on the fly ash characteristics, which is the by product of combustion and this by product has been readily selling to the cement and concrete industry.
(d) Balance between the gain from emission and fuel cost point of view and boiler efficiency and power plant net heat rate.
(e) Economic competiveness of using biomass is still a subject [43].

Since we are investigating the biomass-coal co-firing in fluidized bed combustor, properties of the coal are important also. The regional distribution and the average properties of Turkish lignite coal is given in Table 11 [23].

Knowing the combustion conditions is very important from the selection and preparation of the biofuel. The power stations of Turkey, their capacities and the type of fuel they use are given in Table 12 [32]. There is only one fluidized bed reactor system in Turkey, which is located in Çan-Çanakkale (upper-west region of Turkey).

Table 11
Regional distribution and average chemical composition of the lignite coal in Turkey [23]

Geographical region	Reserve ($\times 10^3$ tons)	Ultimate analysis			Lower heating value	
		Moist%	Ash%	Sulfur%	Kcal/kg	KJ/kg
Edirne–Demirhanli	55 000	40.00	11.65	NA	2700	11 290
Tekirdag–Malkara–Haskoy	35 000	29.78	25.70	1.53	2490	10 410
Istanbul–Eyup–Agacli	60 000	38.02	17.52	2.02	2500	10 450
Bursa–Civili–Sagirlar	57 900	31.73	21.03	1.70	2694	11 290
Canakkale–Can	143 300	23.34	23.18	3.18	3254	13 600
Bolu–Gerede–Mengen	20 500	17.35	10.85	7.60	4800	20 065
Manisa–Soma–Eynes	144 000	18.00	20.00	1.03	4200	17 555
Mugla–Yatagan–Eskihisar	131 000	34.93	20.75	0.99	2782	11 630
Kutahya–Seyitomer	229 000	33.54	19.10	1.36	2750	11 495
Tavsanli–Tuncbilek	252 000	15.00	10.10	1.50	4000	16 720
Ankara–Beypazari	153 000	10.00	23.10	4.70	3144	13 140
Samsun–Havza	40 000	44.00	20.00	1.01	1600	6690
Cankiri–Orta	100 000	51.50	23.50	0.57	800	3345
Sivas–Kangal	142 400	47.88	21.64	NA	1342	5610
Bingol–Kozkova	45 000	44.04	24.81	0.60	2060	8610

Table 12
Powerstations in Turkey [32]

	Name of powerplant	Type of fuel	City	Capacity (MW)
1	Afşin-Elbistan A	Lignite	K. Maraş	1360
2	Aliağa GT + KÇ	Motorin	İzmir	180
3	Ambarlı	Fuel–Oil	İstanbul	630
4	Ambarlı KÇ*	Natural gas	İstanbul	1350
5	Bursa NG	Natural gas	Bursa	1432
6	Çan Onsekizmart	Lignite	Çanakkale	320
7	Çatalağzı B	Hard coal	Zonguldak	300
8	Denizli	Vapor	Denizli	17.5
9	Esenyurt I, II, III, IV	Natural gas	İstanbul	188.5
10	Enron (Trakya Elek)	Natural gas	Tekirdağ	498
11	Engil GT	Motorin	Van	15
12	Hakkari	Fuel–Oil	Hakkari	11
13	Hamitabat KÇ	Natural gas	Kırklareli	1200
14	Hopa	Fuel–Oil	Artvin	50
15	Kangal 1, 2, 3**	Lignite	Sivas	457
16	Kemerköy 1, 2, 3	Lignite	Muğla	630
17	Orhaneli	Lignite	Bursa	210
18	Oya elektrik	Natural gas	Kocaeli	258
19	Park Termik	Lignite	Ankara	620
20	PS3-Silopi	Fuel–Oil	Ş.Urfa	44
21	PS3A-İdil	Fuel–Oil	Mardin	11.4
22	Seyitömer	Lignite	Kütahya	600
23	Soma A	Lignite	Manisa	44
24	Soma B	Lignite	Manisa	990
25	Tunçbilek A + B	Lignite	Kütahya	429
26	Unimar	Natural gas	Tekirdağ	504
27	Van	Fuel–Oil	Van	24
28	Yatağan	Lignite	Muğla	630
29	Yeniköy	Lignite	Muğla	420

5. Logistic aspects

The more available the biomass the more practical it becomes as a fuel. Thus, determination of the regional availability and transport possibilities of the biomass is very important. Additionally, the existing power plants are going to be considered according to their closeness to the biomass sources. The below Fig. 5 summarizes the energy sector in Turkey. In the figure the black labels show the power stations, blue labels are the coal mines and the red labels represent the coal mines on investment stage.

Distribution of the biomass is another factor for biomass evaluation. In the following Fig. 4 the simple demonstration of the highways in Turkey are shown, in fact, the real network is more advanced and Fig. 5 represents the rail roads for transportation. Besides the ability of reaching the area desired of the selected route, its economy is another important point of decision. Basically transportation by railroads is much cheaper than the main roads, but, as it can be seen from the following figures; main roads have much more opportunities for the distribution of the fuel. Railroads can be selected for the destinations where available, or railroad transferred by main road option can be considered also.

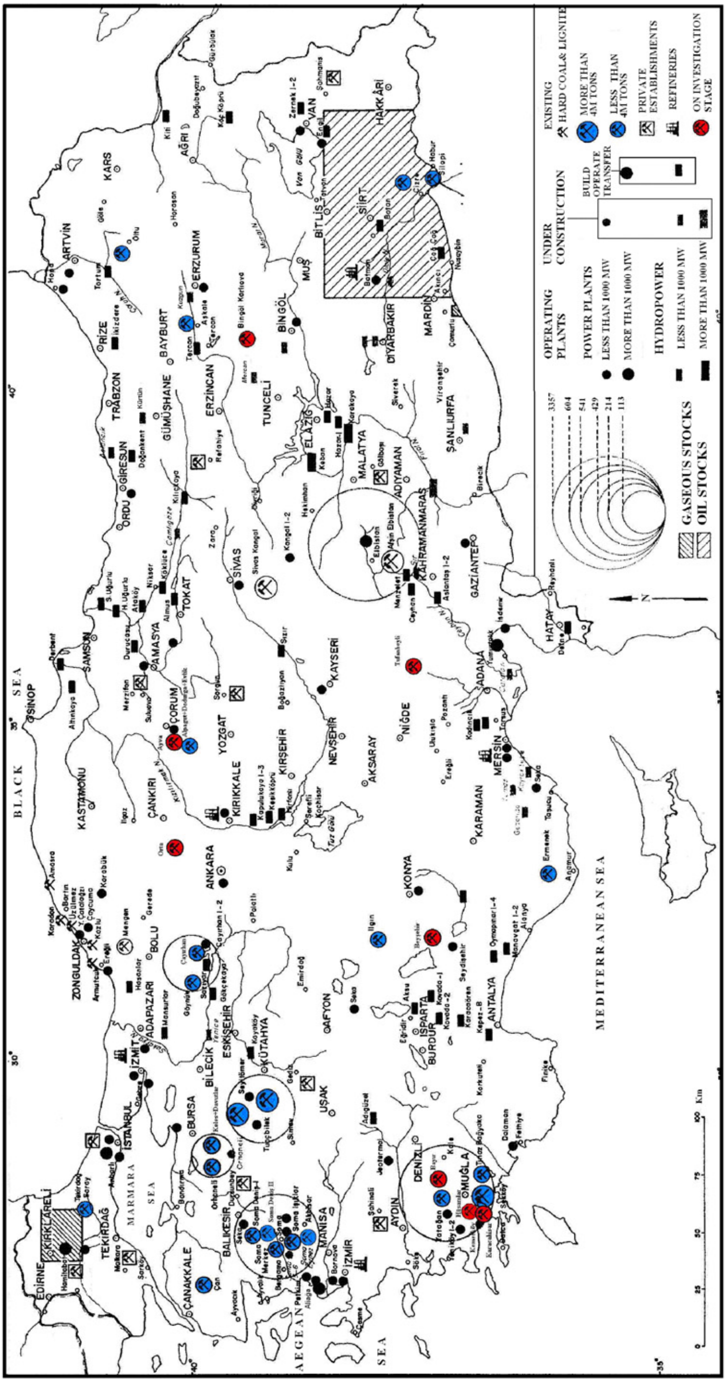

Fig. 5. Energy sector in Turkey [44].

6. Technological aspects

6.1. Collected methodologies

In Turkey there is no such an organizational collected methodology developed for biomass energy sources. The responsible authorities for solid waste management in Turkey are the Ministries of Environment, Industry and Trade, Interior Affairs, Public Works and Settlement, municipalities, the chambers of trade and industry; and the Turkish Standards Institute. Among the biomass consumers wood-derived industries and household users consume the main portion biomass energy. Lumber, pulp and paper industries burn their own wood wastes in large furnaces and boilers to supply 60% of the energy needed to run factories. In terms of household burning, wood is usually burnt in stoves and approximately 6.5 million homes in Turkey use biomass as their primary heating fuel. Agricultural and municipal solid wastes can be used as energy sources economically in Turkey also (Figs. 6 and 7).

6.2. Plantation and production methodologies

Biomass plantation is an energy forests and energy crops based issue. The aim of the biomass plantation is to obtain modern biofuels. The basis of the biomass plantation is photosynthesis, and the plants which can make faster photosynthesis and grow quickly are preferred.

According to the present tree types, only 7 t/ha amount of wood is possible to be produced per year, which means the power of the wood plantation is about 2.8 kW/ha. On the other hand, depending on the efficiency of utilization, specific power value declines, thus, in order to obtain 1 kW of power with a wood boiler we need 1.43 ha of planted forest. The efficiency of energy forests should be higher that the natural forestration. The efficiency of an energy forest is between 15 and 35 t/ha and the plantation period is about 4–8 years. Recently, the most preferred tree types for energy forestry are black poplar, balsam poplar, trembling poplar, willow and eucalyptus [47].

Energy plantation is done with C4 type of plants for 1 year period or several years period of time. Sweet sorghum, miscanthus, sugar cane and corn are in the class of C4 type plants and from these plants, it is possible to produce ethanol, synthetic petroleum, biogas and solid biofuels. C3 plants such as, wheat, barley, rye, sugar beet have a production rate of 10–30 tons/ha/year and their dry matter production per unit leaf is 50–200 g/m^2 leaf/day. On the other hand, C4 type plants have a production rate of 60–80 tons/ha/year and their dry matter production per unit leaf is 400–500 g/m^2 leaf/day [48].

In Turkey, energy plantation and forestry are the emerging subjects to be developed. For this reason in the scope of energy planning for the area allocated for energy, forestry and plantation, a strict agricultural and afforestration production planning should be made.

6.3. Densification to transport and preparation of the fuel

Wood can be either chipped or briquetted prior to use. These chips or briquettes are supposed to be utilized in the co-combustion with coal in the power plants. There are no such biomass preparation application present in Turkey, the dried and compressed animal wastes, which are used as household fuel in rural areas. Biomass species can be either

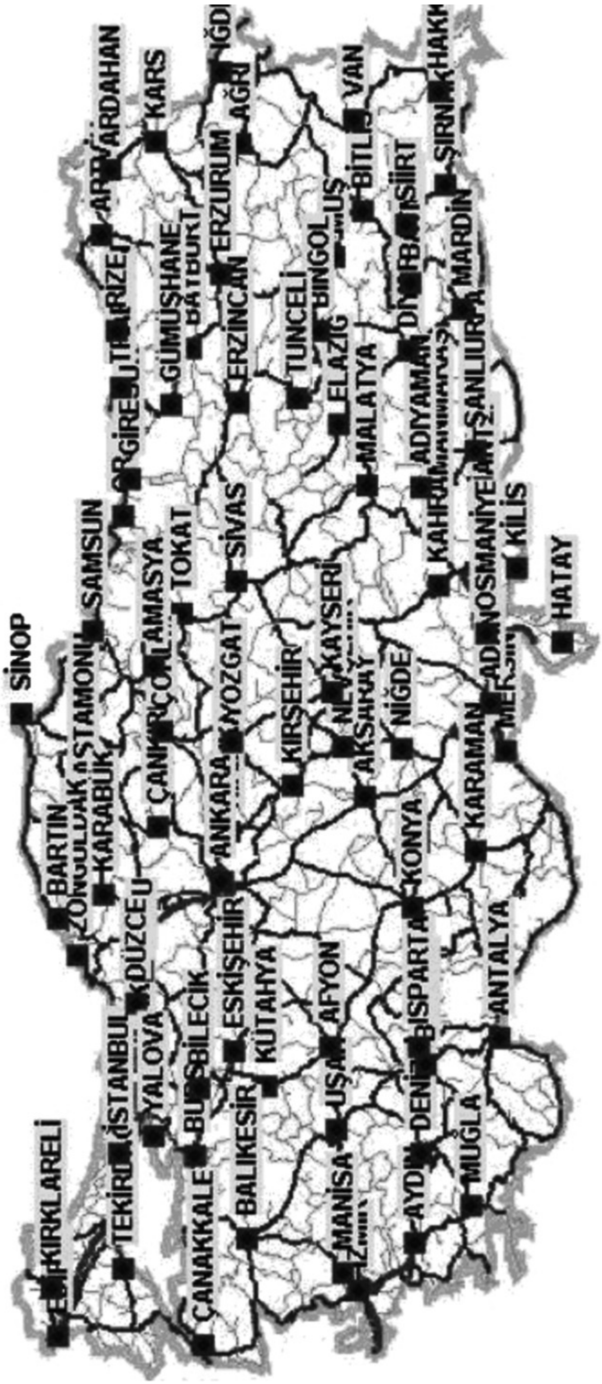

Fig. 6. Main roads in Turkey, adapted from [45].

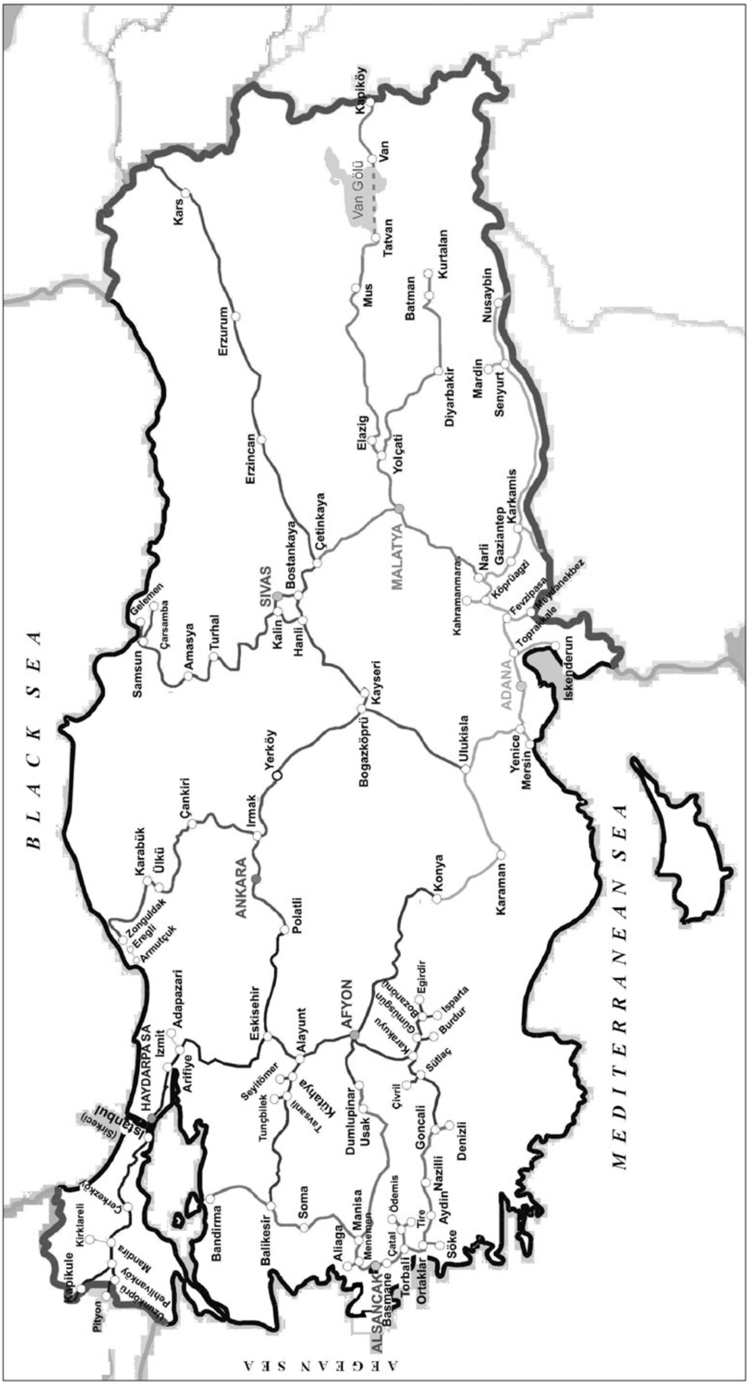

Fig. 7. Rail roads in Turkey, adapted from [46].

chipped or briquetted prior to use. Since there are no such attempts of co-combustion of biomass with coal, there is no fuel preparation methods described yet in Turkish Standards.

7. Environmental aspects

The environmental considerations include the emissions and solid wastes after using biomass as an energy source. By means of emissions, although biomass can be directly burnt in conventional boilers. There are advantages of co-firing biomass and coal, such as co-firing biomass with coal, which in comparison with single coal firing, helps to reduce the total emissions. Co-firing biomass with coal reduces both NO_x and SO_x emissions from existing pulverized coal-fired power plants [49]. Co-firing may be preffered for the purpose of reducing the costs, minimize waste and reduce soil and water pollution, depending upon the chemical composition of the biomass used.

Due to its low sulfur content, biomass reduces the SO_x emissions [15]. NO_x emissions are reported to be reduced by the use of biomass in a range of 10–40% depending on the type and amount of the biomass used. On the other hand, biomass emits CO_2, but the amount of CO_2 is the same that biomass consumes from the atmosphere during its growth. Thus in a short term cycle, biomass can be considered as a CO_2 neutral fuel [18]. Biomass also emits CO, N_2O, CH_4 other hydrocarbons and particulate matter, and trace element emissions reduce as well [15]. Inspite of the presence of some uncertainties at the moment, SO_2, CO_2 and ash production will be typically far lower for biomass power systems than for coal combustion and conversion systems [50–52].

The amount of ash deposition from biomass can either be greater or considerably less than that from coal. Trace elements comes from biomass' nature transfers to the ash content. The amounts of trace element levels are related to species of biomass, growing site of the sample, age of plant, and distance the source of pollution [50]. The utilization of biomass and waste as fuels has an environmental benefit. On the other hand, using biomass can introduce environmental risks due to the content of heavy metals, especially Cd in the combustion residues. In addition, the potassium (K), sodium (Na), chlorine (Cl) and sulfur (S) content of the biomass fly ash as well as in the boiler fly ash is great, which may cause undesirable reactions that can take place in the boiler section results with fouling and corrosion [53].

The main problem concerning waste plants are the emissions to the air while burning. Necessary controls should be taken over by the Ministry of Environment for these emissions to be under standards foreseen by the European Union and no facility should be given license, if it has no Energy Information Administration.

Recently, environmental problems resulting caused by energy production, conversion and utilization take a great attention from public, industry and government [54]. Turkey made great progress over the last 15 years in terms of its environmental problems: the 1982 Constitution recognizes the right of citizens to live in a healthy and balanced environment; an Environment Act was passed in 1983; the Ministry of Environment was established in 1991; public awareness and demand for a clean environment are growing; and active non-governmental environmental organizations are emerging. Despite these positive developments, there are still economic and social decisions need to be taken in order to incorporate the environmental issues adequately [19].

8. Economic aspects

In future, it is expected that biomass will provide a cost-effective, sustainable and environmental friendly supply of energy.

Turkish energy policy needs to meet fast growing demand in a reasonable period of time, which means large investments has to be made. On the other hand, private sector has relatively limited financial capacity. Thus in order to be more efficient and effective, the private sector has to be mobilized.

The energy prices should be determined in such a way that the balance between demand and supply to be established without undervaluing the rest of the economy and environment. Additionally, energy prices must reflect the cost imposed by the specific consumer category on the economy. Another important point about energy pricing policy is it should not be employed as an anti-inflationary instrument. It should be applied in such a way that it does not create cross subsidies between classes of consumers [55,56].

Another important consideration of using biomass is the tariff of using biomass energy as well as its production cost. According to the 'Law of Priority for Renewable Energy Sources' accepted by Parliament of Federal Germany in 1999, which is accepted as a groundbreaking development for renewable energy sector, this law was specifying the actual prices that would be paid for generation from each of several different renewable technologies independent of the retail price for electricity and this is expected to be a model for overall Europe [57]. Since the European Membership negotiations of Turkey has started on 3 October 2005, a very similar regulation will be used in Turkey. According to 'Law of Priority for Renewable Energy Sources', tariff regulations for the electricty obtained from biomass sources are as the following:

1. For the plants with a capacity lower than 500 kWatts, at least 10.23 cents/kWatt.
2. For the plants with a capacity lower than 5 MWatts, at least 9.2 cents/kWatt.
3. For the plants with a capacity lower than 500 MWatts, at least 8.69 cents/kWatt [58].

9. Conclusions

Turkey has most of the energy sources, but unfortunately, Turkey is an energy importing country. In order to be less dependent on other countries, Turkey needs to use its sustainable sources. For this point of view, biomass is a very attractive choice, since it is economical, sustainable, environmental friendly and a familiar energy source for Turkey. Additionally, Turkey has several advantages for the use of biomass sources in terms of its climate.

In this paper, we investigated the use of biomass for co-firing with coal. Thus, we searched for the characteristics of the fuel, logistic aspacts, environmental aspects, technical and economical aspects of using biomass with coal.

Worldwide, biomass is in the fourth place as an energy source and provides about 14% of the world's energy needed. Turkey is one of the world's biggest wheat and barley producers, and Turkey is a very rich country in terms of biological diversity. Also, Turkey has a significant amount of agricultural wastes, which needs to be utilized. On the other hand, according to the Turkish Forestry Inventory the Turkish forestry treasure is 1.2 billion m^3, and the growth of this, on the year basis is 34 million m^3. Another source of biomass sources is coming from animal husbandry, which is one of the main means of living, means a significant amount of animal wastes are produced each year.

There are initiative studies about evaluating the non-toxic solid wastes, which are needed to be spread, such as from Adana and Mamak waste plants. Another non-toxic solid waste is sludge which has a big potential, i.e. 500,000 tons per year for use as fuel.

Biomass can be converted into useful forms of energy using a number of different processes. Fluidized bed systems are particularly well suited for such a co-firing operation because of their versatility with regard to fuel. Although emissions of CO_2, SO_x and NO_x can be reduced by co-firing process, care has to be taken of high chlorine and high alkaline, which are known to be negative effects on operation like corrosion or slagging of the heat transfer surfaces.

The more available the biomass, the more practical it becomes as a fuel. Thus, we investigated the logistic distribution of the power plants and transport possibilities. In fact, Turkey has a chance to grow biomass species throughout the country depending on the annual rainfalls, but transport possibilities are also important. In one hand, we have railroad transportation which is cheap, on the other hand, we have main roads which are well distributed.

In terms of technological issues there is no organizationally collected methodology developed for biomass energy sources, but the biomass plantation and production methodologies are well described although it is not applicable yet.

The energy pricing of the biomass sources are not regulated by the Turkish government yet, but the prior considerations are made. Basically, the energy prices should be determined in such a way that the balance between demand and supply is established.

Acknowledgement

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