Energy Policy 39 (2011) 6120–6135

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Carbon dioxide emission from the Turkish electricity sector and its mitigation options

Izzet Ari [a], Merih Aydinalp Koksal [b,*]

[a] State Planning Organization, General Directorate of Social Sectors and Coordination, Necatibey Cad. No. 108, Yucetepe, Cankaya, 06100 Ankara, Turkey
[b] Hacettepe University, Department of Environmental Engineering, Beytepe, 06800 Ankara, Turkey

ARTICLE INFO

Article history:
Received 7 March 2011
Accepted 6 July 2011
Available online 5 August 2011

Keywords:
Electricity generation-associated CO_2 emission
Mitigation of CO_2 emission
Fuel-specific emission factors

ABSTRACT

In this study, electricity generation associated CO_2 emissions and fuel-specific CO_2 emission factors are calculated based on the IPCC methodology using the data of fossil-fueled power plants that ran between 2001 and 2008 in Turkey. The estimated CO_2 emissions from fossil-fueled power plants between 2009 and 2019 are also calculated using the fuel-specific CO_2 emission factors and data on the projected generation capacity of the power plants that are planned to be built during this period. Given that the total electricity supply (planned+existing) will not be sufficient to provide the estimated demand between 2011 and 2019, four scenarios based on using different fuel mixtures are developed to overcome this deficiency. The results from these scenarios show that a significant decrease in the amount of CO_2 emissions from electricity generation can be achieved if the share of the fossil-fueled power plants is lowered. The *Renewable Energy Scenario* is found to result in the lowest CO_2 emissions between 2009 and 2019. The associated CO_2 emissions calculated based on this scenario are approximately 192 million tons lower than that of the *Business As Usual Scenario* for the estimation period.

1. Introduction

Industrialization, high population growth, and urbanization cause the depletion of natural resources and numerous environmental problems. Fossil fuel consumption, as a depletion of natural resources, results in the increase of greenhouse gas (GHG) emissions in the atmosphere. The concentration of atmospheric CO_2, which is the major GHG, has increased from a pre-industrial value of approximately 280–379 ppm as of 2005 (IPCC, 2007). Changes in sea level, snow cover, ice sheets, and rainfall are results of global climate change, and all these disasters affect ecosystems in many parts of the world (UNFCCC, 2006).

Because the climate change problem threatens all living beings, the solution to this problem needs to be dealt with globally. Thus, the United Nations took a step to handle this global problem at the United Nations Framework Convention on Climate Change (UNFCCC). The ultimate objective of the UNFCCC is to stabilize the GHG concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. To accomplish this task, significant GHG emission reduction is required (IEA, 2009).

As a party to UNFCCC and Kyoto Protocol, Turkey has been keeping track of her GHG emissions since 2006. According to the national GHG emission inventory of Turkey, GHG (CO_2, CH_4, N_2O, HFC, PFC, and SF_6) emissions have increased 95% from 187 to 366.5 million tons CO_2 eqv. between 1990 and 2008. The CO_2 emissions for the same period increased from 141 to 297 million tons. In addition, the CO_2 emissions from electricity generation increased 234% from 30.3 to 101.5 million tons for the same period, covering, on average, approximately 30% of the total CO_2 emissions in Turkey. Consequently, the electricity generation between 1990 and 2008 in Turkey increased 244% from 57,543

Abbreviations: Avg, average; BAU, business as usual; EFT, Environment Foundation of Turkey; EGIC, Electricity Generation Incorporated Company [EUAS in Turkish]; EMRA, Energy Market Regulatory Authority [EPDK in Turkish]; EPSA, Electrical Power Survey and Administration [EIE in Turkish]; Geo, geothermal; GHG, greenhouse gas; GNAT, The Grant National Assembly of Turkey [TBMM in Turkish]; GWh, gigawatt hour; IEA, International Energy Agency; IPCC, Intergovernmental Panel on Climate Change; kWh, kilowatt hour; LHV, low heating value; LPG, liquefied petroleum gas; MENR, ministry of Energy and Natural Resources [ETKB in Turkish]; MoEF, Ministry of Environment and Forestry [ÇOB in Turkish]; MW, megawatt; MWG, municipal waste gas; MWh, megawatt hour; NG, natural gas; NIR, National Inventory Report; NLDC, National Load Distribution Center; OECD, Organization for Economic Cooperation and Development; ppm, parts per million; SEF, specific emission factor; SHW, state hydraulic works [DSI in Turkish]; SPO, State Planning Organization [DPT in Turkish]; TETC, Turkish Electricity Transmission Corporation [TEIAS in Turkish]; TURKSTAT, Turkish Statistical Institute [TUIK in Turkish]; UNFCCC, United Nations Framework Conventions on Climate Change

* Corresponding author. Tel.: +90 312 2977800; fax: +90 312 2992053.
E-mail address: aydinalp@hacettepe.edu.tr (M. Aydinalp Koksal).

0301-4215/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2011.07.012

to 197,839 GWh (UNFCCC, 2010). A reduction in electricity generation-associated CO_2 emissions can be achieved by increasing the usage of renewable energy sources, such as wind, geothermal, hydro, and biomass, for power generation.

There are currently only a few studies on the relationship between electricity generation and the associated CO_2 emissions in Turkey. These studies are generally national reports, such as the *National Inventory Report* (NIR) and the *First National Communication* submitted to the UNFCCC secretary due to certain responsibilities of Turkey. The methodology of calculating the GHG emissions in these reports depends on the Intergovernmental Panel on Climate Change (IPCC) approach, which is a top–down approach that does not differentiate IPCC default emission factors according to the low heating value (LHV) of each type of fuel.

The major objective of this study is to investigate the mitigation potential of CO_2 emissions from electricity generation using renewable energy sources over the next decade. To achieve this objective, CO_2 emissions from fossil-fueled power plants that ran between 2001 and 2008 are calculated, and then using these results, the country-specific emission factors for each fuel type are calculated. To the authors' knowledge, this is the first study that is based on calculating the total electricity generation-associated CO_2 emissions using data that cover all currently running power plants and that presents country-specific emission factors for Turkey for each fuel type based on current power plant data. These fuel-specific emission factors and the estimated amount of electricity that will be generated by the planned power plants are used to determine the electricity generation-associated CO_2 emissions in the next decade.

To date, efforts to investigate future electricity generation and the associated CO_2 emissions in Turkey have been limited. Studies conducted by the Ministry of Environment and Forestry (MoEF) (2006), Greenpeace (2009), and Turker (2008) are among those on the developing future electricity demand and the associated CO_2 emissions for Turkey. Different alternatives are used to supply the needed electricity demand and the associated CO_2 emissions in these studies; however, the official licensed and planned power plant data were not considered for calculating the supply side of the electricity demand and its associated CO_2 emissions, as is done in this study.

The power plant data used in this study are gathered from the National Load Distribution Center (NLDC) in Turkey (NLDC, 2009). The default emission factors and the calculation of the CO_2 emission methodology are based on IPCC Guidelines (IPCC, 2006). The low heating value of each fossil fuel and the thermal efficiency data of the fossil-fueled power plants in Turkey are obtained from various sources in the open literature. The estimated electricity demand between 2009 and 2018 is obtained from the Turkish Electricity Transmission Company (TETC, 2009). The planned and licensed power plant data with information on their completion are obtained from the Energy Market Regulatory Authority (EMRA, 2009).

2. Previous studies

Previous studies on determining the CO_2 emissions from the electricity sector, the fuel-specific emission factors, and a projection of the electricity generation-associated CO_2 emissions in Turkey are presented in this section.

One of the earlier studies on CO_2 emission inventory for Turkey was the "*Eighth Five Year Development Plan-Special Experts Report on Climate Change*" (SPO, 2000), in which a CO_2 emission inventory between 1970 and 2005 was calculated using the IPCC Tier-1 approach. A similar approach was used by Can (2006) to determine CO_2 emissions from publicly owned fossil-fueled power plants. Another well-known study on CO_2 emissions is the "*National Inventory Report of Turkey GHG 1990–2007*" (TURKSTAT, 2009). The IPCC approach was again used in this report to calculate CO_2 emissions from the electricity sector.

In the studies mentioned above, the IPCC default emission factors were used without any adjustments for the fossil fuels used in Turkey to calculate electricity generation-associated CO_2 emissions. Because the quality of the fossil fuels, especially Turkish lignite, is not same as those used in other countries, CO_2 emissions calculated using these factors cannot wholly represent emissions from Turkey's fossil-fueled power plants.

To the authors' knowledge, there is only one study available on fuel-specific emission factors for Turkey, which was conducted by the IEA (2010). This study presents country-specific emission factors for coal, oil, and natural gas between 1990 and 2008 for Turkey and some other countries. There are other studies on emission factors in the literature, but they are not country specific and are not in time series.

The studies on the projection of CO_2 emissions from electricity generation in Turkey are also very limited. One of the first studies on CO_2 projection was the Ministry of Energy and Natural Resources' report (MENR, 2005), which included the results of the associated GHG emission projections based on four scenarios: a reference case, low growth, demand side management, and cogeneration. The estimation approach of calculating the associated CO_2 emissions is similar to that of the NIR (TURKSTAT, 2009). The pathway of these scenarios was policy oriented, not plan and program oriented. In addition, the planned and licensed power plants' data were not considered in these scenarios.

Another study is a report published by Greenpeace Turkey (2009), as given in Table 1. This study included the results of two scenarios on the projection of Turkey's electricity generation-associated CO_2 emissions. One of the scenarios of this study, the "Energy [R]Evolution" scenario, is based on the potential of using renewable energy for electricity generation. However, only the technical potential of renewable sources is considered in this scenario.

Another study on CO_2 emissions projection was conducted by Say and Yucel (2006). These authors determined the relationship between the total energy consumption and total CO_2 emission in Turkey, and they estimated the total CO_2 emission using this relationship. A regression analysis was performed, and a strong relationship between total energy consumption and total CO_2 emission was found. While this study did include the total CO_2 emissions from the energy sector, it did not specifically deal with the electricity sector.

As stated above, to the authors' knowledge, there is no study that takes into consideration data of the licensed and planned power plants to estimate the associated CO_2 emissions from electricity generation for Turkey.

In this study, the electricity generation-associated CO_2 emissions up to 2019 are estimated by taking into account the current

Table 1
CO_2 emissions from electricity generation projections, million tons.

Scenario name	2010	2015	2020
MENR (2005) and MoEF (2006)			
Reference	117	152	222
Demand side management	110	140	185
Low growth	107	137	163
Cogeneration	122	167	248
Greenpeace Turkey (2009)			
Reference	87		161
Energy [R]evolution	82		100

and planned power plants and the economically feasible renewable energy potential of Turkey.

3. Turkey's electricity outlook

This section summarizes the changes that have taken place in the electricity sector of Turkey in terms of policies, demand, and generation capabilities, and it presents a brief overview of the liberalization of the electricity sector that took place in the last decade.

Since the 1970s, electricity generation has been increasing sharply in Turkey, reaching 197,389 GWh as of 2008. The generated electricity based on fuel type is shown in Fig. 1.

As seen here, lignite, hard coal, hydro power, and natural gas are the primary energy sources used to generate electricity in Turkey. The amounts of non-hydro renewable and oil derivatives (naphtha, LPG, and diesel) are almost negligible. Another interesting point is the rapid increase in the share of natural gas, which has been increasing since the mid-1980s and reached the highest share of almost 50% in 2008.

In last 5 years in particular, high economic and population growth has led to an increase in electricity demand in Turkey. Over these years, the primary energy and electricity consumption has increased 35% and 43%, respectively (SPO, 2009). Although the global financial crisis of 2008 caused a drop in the electricity demand of Turkey in 2009, the projected electricity demand trends show that new and additional power plants should still be installed in Turkey.

In Turkey, the majority of the electricity is generated from fossil-fueled and hydro power plants. The share of hydro power plants increased above 50% in years with high precipitation (SPO, 1988, 1989). However, as of 2008, more than 80% of the electricity generated in Turkey originates from fossil-fueled power plants.

The installed capacity of electricity generation in Turkey between 2001 and 2008 is given in Table 2. As seen here, the share of fossil-fueled power plant capacity has increased from 59% to 66% between 2001 and 2008, whereas the share of hydro power plant capacity has decreased from 41% to 33% for the same period. The share of geothermal and wind power plant capacities is small compared with those of the fossil-fueled and hydro power plants. A new law called "*Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy*" has started to produce positive results, resulting in threefold increases in the installed capacity of wind and twofold increases in the installed capacity of geothermal power plants in 2008 compared with previous years (EPSA, 2009).

Due to the high electricity demand of Turkey, new electricity supply facilities are essential. Public and private initiatives are aware of this issue, and they act to solve this deficiency by submitting power plant project proposals to EMRA (2009).

4. Data

In this section, the data used for determining the current and future electricity-associated CO_2 emissions from fossil-fueled power plants are presented.

4.1. Current power plant data

In this study, daily fossil-fueled power plant data between 2001 and 2008 were obtained from the National Load Distribution Center (NLDC) of TETC (NLDC, 2009). The daily data contain information on the amount of fuel consumed and the electricity generated at public fossil-fueled power plants, electricity generated at private fossil-fueled, and public and private geothermal, hydro, and wind power plants. The data also contain Turkey's total generated electricity.

4.2. Planned power plant data

The power plants that are planned to be built in Turkey are required to obtain licenses from the Energy Market Regulatory Agency (EMRA). In this study, the license information of the planned power plants was taken from EMRA (EMRA, 2009). The data include detailed information of the licensed power plants, such as the location of the plant, types of fuel that will be used in

Table 2
Electricity generation installed capacity of Turkey (MW) (TETC, 2010).

Year	Fossil-fueled		Hydro		Geothermal + wind		Total
	MW	%	MW	%	MW	%	MW
2001	16,623	59	11,673	41	36	0.13	28,332
2002	19,569	62	12,240	38	36	0.11	31,846
2003	22,974	65	12,579	35	34	0.10	35,587
2004	24,145	66	12,645	34	34	0.09	36,824
2005	25,902	67	12,906	33	35	0.09	38,844
2006	27,420	68	13,063	32	82	0.20	40,565
2007	27,272	67	13,395	33	169	0.41	40,836
2008	27,595	66	13,829	33	394	0.94	41,817

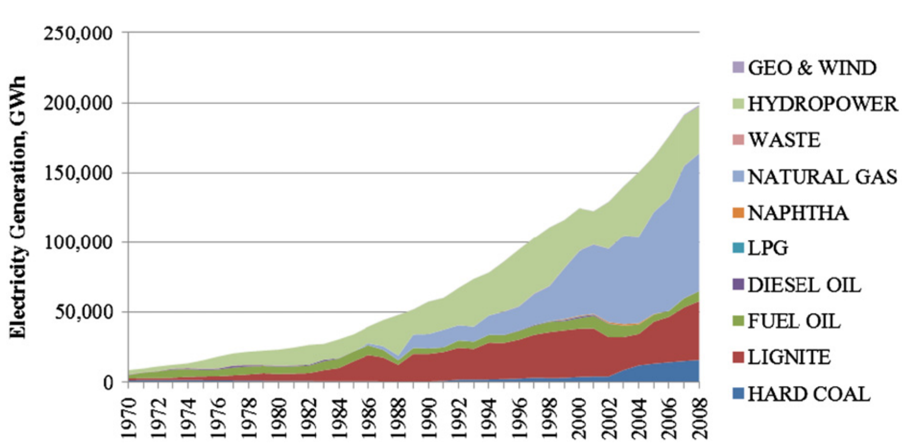


Fig. 1. Amount of generated electricity (GWh) by fuel type 1970–2008 (TETC, 2010).

the plant, licensed capacity (MW), average licensed generation (kWh/year), built capacity (MW) and progress rate (%). As of January 2009, there are 565 licensed power plants included in EMRA's license dataset. The type of fuel, generated amount and progress rate are the most crucial data for this study because they are used specifically for estimating the electricity supply and the associated CO_2 emissions.

Table 3 presents the number of licensed power plants, their installed capacities and their average electricity generation. According to this table, the hydro, coal, natural gas, and wind power plants have higher projected installed capacities than the other types of power plants. In terms of the number of plants, the leading type is the hydro plants, with 408 plants out of the total 565.

4.3. Renewable energy potential of Turkey

The third type of data used in this study is the renewable energy potential of Turkey. The use of renewable energy sources is a vital step in the mitigation of CO_2 emissions from the electricity sector. The best available potential estimates were obtained from relevant government organizations. The overall economically utilizable renewable energy potential of Turkey is given in Table 4. As seen here, hydro owns the greatest share, followed by wind power.

Due to its geographic location, Turkey is a country with high solar potential. In this study, however, electricity generation from solar energy is not included, mainly due to its high capital cost. In addition, the selling price of electricity from solar power plants in Turkey is still so low that no private company has yet applied for a license for a solar power plant from EMRA (EMRA, 2011).

4.4. Electricity demand estimates for Turkey

To determine the amount of future electricity generation-associated CO_2 emissions, electricity demand estimates for Turkey between 2009 and 2018 were obtained from a report published by the Turkish Electricity Transmission Company (TETC, 2009). However, the projections presented in this report are only up to 2018. Because one more year was needed for this study, trend analysis was used to calculate the demand in 2019, as seen in Table 5. The main assumption in this analysis is that the growth rate between 2018 and 2019 is the same as that between 2016 and 2018.

Table 3
Features of planned and licensed power plants as of January 2009 (EMRA, 2009).

	Number of planned power plants	Installed capacity (MW)	Avg. generation (GWh)
Asphaltite	1	413	2916
Biogas	6	13	100
Biomass	2	7	49
Landfill gas	2	22	170
Other coal	12	6947	47,694
Other fossil-fueled	2	18	112
Natural gas	33	5207	39,334
Fuel oil	2	87	565
Hydro	408	11,706	42,196
Geo	3	64	445
Lignite	9	1460	7595
Wind	83	3104	10,978
Hard coal	2	1168	8050
Total	565	30,216	160,204

Table 4
Overall economically utilizable renewable energy potential of Turkey (GWh).

Renewable energy form	Potential (GWh)	References
Hydro	127,381	SHW (2008)
Geothermal	16,000	MENR (2005)
Wind	26,000	MENR (2005)
Biomass	11,575	Ari (2010)

5. Methodology

In this section, three steps implemented to calculate CO_2 emissions from electricity generation and the approach used to determine specific emission factors for each fuel type are presented. The methodology used for determining the amount of CO_2 emissions from fossil-fueled power plants is based on the IPCC approach (IPCC, 2006), which can be simply presented by the equation given below:

$$E = \mathrm{FC} \times \mathrm{EF} \quad (1)$$

where E is the CO_2 emission (kg), FC is the fuel consumption (TJ), and EF is the Emission factor (kg/TJ).

5.1. Calculation of fuel consumption

To determine electricity generation-associated CO_2 emissions, the main data used are the amount and type of fuel consumed at each power plant. These data are available and presented in mass or in volume units in the datasets obtained for this study. Eq. (2) is used to calculate the amount of energy released from the combustion of fuels in solid, liquid, and gas forms using the LHV of each fuel type. The LHV of the fuels used in public fossil-fueled power plants are obtained from various sources:

$$\mathrm{FC} = \mathrm{LHV} \times \mathrm{FA} \times 10^9 \quad (2)$$

where LHV is the fuel low heating value (kJ/kg for solid and liquid fuels and kJ/m^3 for gas fuels), and FA is the fuel amount (kg for solid and liquid fuels and m^3 for gas fuels).

To check the accuracy of the fuel consumption data obtained for each of the public fossil-fueled power plants, the thermal efficiency of each plant is first calculated using the data between 2001 and 2008. The thermal efficiency is the ratio of generated electricity to the amount of fuel used, as presented in Eq. (3):

$$\eta_{th} = \frac{\mathrm{EG} \times 0.0036}{\mathrm{FC}} \quad (3)$$

where η_{th} is the thermal efficiency (%) and EG is the amount of electricity generated (MWh).

The efficiency values are then compared with the thermal efficiency data of public fossil-fueled power plants obtained from various sources (Oktay, 2009; Kincay and Ozturk, 2003; Keskinel,

Table 5
Estimated electricity demand of Turkey (TETC, 2009).

Year	Demand (GWh)	Annual change (%)
2009	194,000	
2010	202,730	4.5
2011	215,907	6.5
2012	232,101	7.5
2013	249,508	7.5
2014	268,221	7.5
2015	288,338	7.5
2016	309,675	7.4
2017	332,591	7.4
2018	357,202	7.4
2019	383,635	7.4

2006). The comparative assessment is performed in the following way. When the calculated thermal efficiency and efficiency values obtained from the literature are close to each other, the fuel consumption data of the plant are accepted as correct. When this difference is greater than 10%, however, the amount of fuel consumption of these plants is readjusted such that the new calculated thermal efficiency values are close to the values obtained from literature.

The data on private power plants in these datasets include only the amount of generated electricity and not on the type or amount of fuel used in private power plants (NLDC, 2009). Thus, the first type of fuel used by each private fossil-fueled power plant was determined from various sources. Then the amount of fuel used by each private fossil-fueled power plant was estimated using the average thermal efficiency data obtained from public power plants using the same fuel.

5.2. Adjusting the IPCC's default emission factors

In the second step of the methodology, the emission factors for each fuel type used in the fossil-fueled power plants in Turkey are obtained from the IPCC's guidelines for stationary combustion in the energy industries (IPCC, 2006). This document lists the upper, lower, and average default emission factors for the various types of fuels used in the energy industries.

As stated previously, lignite is widely used by fossil-fueled power plants in Turkey. The LHV range of the lignite used in fossil-fueled power plants is wide, from 950 kcal/kg, such as that used in the *Afsin Elbistan* power plant, to 2800 kcal/kg, such as that used in the *Park Termik* power plant. However, in the IPCC's guidelines, the default emission factor for lignite is given as 115,000 kg CO_2/TJ for the upper value and 90,900 kg CO_2/TJ for the lower value (IPCC, 2006). Thus, the emission factors of the lignite used in plants are assigned based the range of the LHVs, which means that the emissions of the power plant using lignite with the lowest LHV was calculated using the emission factor with the highest values and vise versa. For instance, the emission factor used for the lignite combusted at the *Afsin Elbistan* power plant is taken as 115,000 kg CO_2/TJ, and that of the *Park Termik* power plant is taken as 90,900 kg CO_2/TJ.

Similar adjustments are not applied to natural gas, oil, and other forms of coal because the LHVs of these fuels used in fossil-fueled power plants vary only slightly.

5.3. Calculation of CO_2 emissions

In the third and final step of the methodology for calculating electricity generation-associated CO_2 emissions, fuel consumption is multiplied with the emissions factor for each fuel type and is summed to determine the total CO_2 emissions from each plant, as given in Eq. (4):

$$E_T = \sum_{i=1}^{n} E_i = \sum_{i=1}^{n} (FC_i \times EF_i) \tag{4}$$

where E_T is the total CO_2 emission (kg), i is the fuel type, and n is the number of fuel types.

Another method for calculating electricity generation-associated CO_2 emission is to develop a mass balance for the combustion reaction using elemental analysis of the coal. To apply this method, elemental analyses of the lignite/hard coal used in publicly owned fossil-fueled power plants are obtained from the Electricity Generation Incorporated Company (EGIC) between 2005 and 2007 (EGIC, 2009a,b). In this method, the crucial factor is the carbon content of the fuel used in the power plants. Eq. (5) presents the calculation of CO_2 emissions of a fossil-fueled power plant using an elemental analysis method:

$$E = \mathrm{FA} \times \mathrm{WtC} \times \frac{\mathrm{MW}_{CO_2}}{\mathrm{MW}_C} \times \eta_C \tag{5}$$

where WtC is the weight percentage of carbon in the fuel; MW_{CO_2} is the molar weight of CO_2 (g)—taken as 44 g, MW_C is the molar weight of carbon (g)—taken as 12 g, and η_C is the combustion efficiency—taken as 80%.

The CO_2 emissions from each fossil-fueled power plant calculated using elemental analysis data were compared with that calculated using the IPCC approach. The difference between the elemental analysis and the IPCC approach came to be less than $\pm 20\%$, which shows that the results obtained from the IPCC and from the elemental analysis approaches are close to each other.

5.4. Determination of specific emission factors

Specific emission factors, i.e., the amount of CO_2 emissions per MWh of electricity generated for each fuel type, are necessary to estimate the associated CO_2 emissions from planned electricity generation facilities. In Turkey, there are various fossil-fueled power plants using fuel with different low heating values; thus, thermal efficiencies and associated CO_2 emissions per MWh of electricity vary from plant to plant. For these reasons, determining emission factors for each fuel type is a crucial issue in calculating the associated CO_2 emissions. The specific emission factor (SEF) for each fuel type is calculated by dividing the amount of associated CO_2 emissions by the amount of electricity generated, as given by Eq. (6):

$$\mathrm{SEF}_i = \frac{E_i}{\mathrm{EG}_i} \tag{6}$$

where SEF is the specific emission factor (kg/MWh).

6. Results

The results on the amount of electricity generated and the associated CO_2 emissions based on fuel type between 2001 and 2008 in Turkey and the fuel type-specific emission factors calculated using these results are presented in this section. In addition to these results, the amount of electricity that will be supplied by the planned power plants and generated to supply the total estimated demand, and total associated CO_2 emissions between 2009 and 2019 based on four scenarios are also presented in this section.

6.1. Generated electricity and associated CO_2 emissions between 2001 and 2008

The amount of generated electricity based on fuel type in Turkey between 2001 and 2008 is determined using the data from NLDC (2009), as explained in detail in Section 4.1. The amount of associated CO_2 emissions based on fuel type is calculated using the methodology explained in Section 5.3. The results on the electricity generated and associated CO_2 emissions are given in Table 6. The total amount of electricity generated, the electricity generated specifically from fossil-fueled power plants, and the associated CO_2 emissions increased 62%, 67%, and 56% between 2001 and 2008, respectively.

In 2002, fossil-fueled electricity generation decreased by 3%. However, the decrease in associated CO_2 emissions was 8% due to the 19% decrease in the electricity generated from lignite (the fuel with the highest emission factor) in 2002, having decreased its share to 22% from 28% from previous year. A similar case was observed in 2003, where the fossil-fueled electricity generation

Table 6
Generated electricity and associated CO_2 emissions, 2001–2008.

Year	Total electricity generation (GWh)	Annual change (%)	Fossil-fueled electricity generation (GWh)	Annual change (%)	CO_2 emissions (million tons)	Annual change (%)
2001	122,311		97,850		68.19	
2002	128,619	5	94,807	−3	62.79	−8
2003	139,916	9	104,221	10	64.03	2
2004	150,588	8	104,157	0	64.66	1
2005	162,333	8	122,347	17	78.03	21
2006	176,295	9	131,157	7	83.91	8
2007	190,446	8	154,329	18	98.91	18
2008	197,839	4	163,578	6	106.6	8

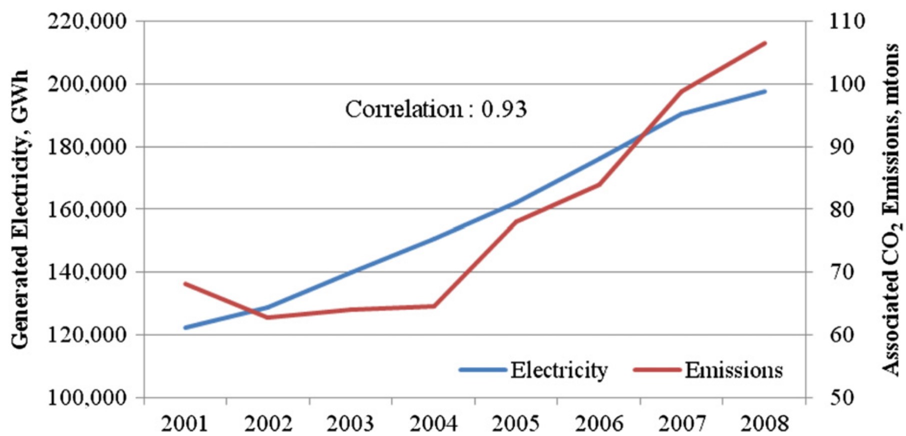


Fig. 2. Total electricity generation and associated CO_2 emissions, 2001–2008.

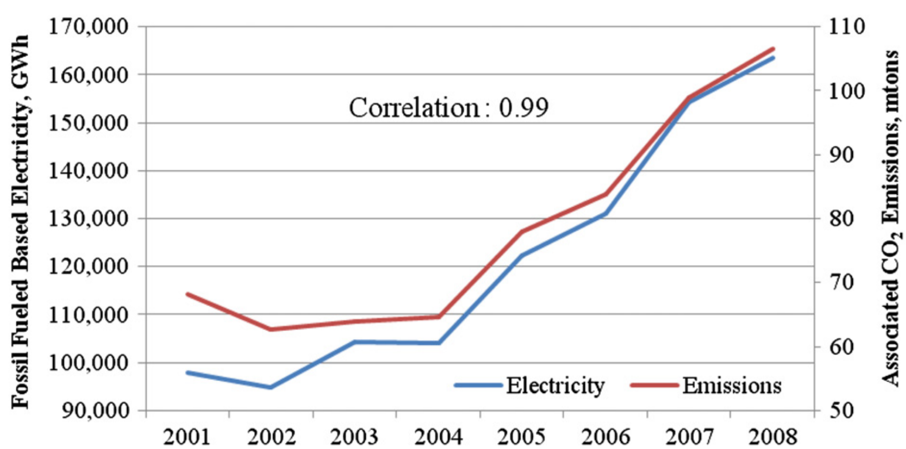


Fig. 3. Fossil fuel-based electricity generation and associated CO_2 emissions, 2001–2008.

increased by 10%, while the associated CO_2 emissions increased by only 2%. The reason for these changes is the 25% increase in the amount of electricity generated from natural gas in 2003, which increased its share to 47% from 41% from previous year. Also, due to the drought experienced in 2005 and 2007, the amount of electricity generated from hydro power plants decreased dramatically, which caused increases in electricity generated from fossil-fueled power plants and, consequently, increases in CO_2 emissions in these years.

Fig. 2 presents the relationship between total electricity generated and the associated CO_2 emissions between 2001 and 2008. As seen in the figure, the correlation between total electricity generated and associated CO_2 emissions is 0.93, indicating that the electricity generation in Turkey is highly dependent on fossil fuel consumption.

Similarly, the amount of electricity generated from fossil-fueled power plants and their associated CO_2 emissions are given in Fig. 3. The correlation between the fossil fueled-based electricity generation and the associated CO_2 emissions is 0.99, as expected. Due to fluctuations in the share of natural gas in fossil fuel usage, as mentioned previously, the emission and electricity generation lines do not regularly follow parallel trends.

The National Inventory Report (NIR) (UNFCCC, 2010) is another study on the amount of CO_2 emissions from the electricity sector in Turkey, as explained in Section 2. The reported CO_2 emissions from this source are listed along with the results of this study for comparison in Table 7. As seen here, the results of this study are in line with most of the NIR (UNFCCC, 2010) numbers.

The generated electricity and associated CO_2 emissions between 2001 and 2008 are categorized based on fuel type and are presented in percentage distributions in Fig. 4. As seen in this figure, natural gas is the dominant fuel used in electricity generation among other fuels, with a share of approximately 45%. The shares of lignite, hydro and hard coal are 20%, 23%, and 6%, respectively. As can also be seen in this figure, lignite power plants contribute the highest share of the associated CO_2 emissions among the other fossil fuels. Although natural gas-fueled power plants generated approximately 45% of the total electricity between 2001 and 2008, their CO_2 emission contribution is approximately 34%, which is lower than that of lignite, which has a share of 44%. This result is due to the emission factor of natural gas being lower than other major fossil fuels. Because renewable energies do not generate any CO_2 emissions during operation, their emissions are zero.

6.2. Fuel-specific CO_2 emission factors

The fuel-specific emission factors for all types of fuel consumed for electricity generation were calculated based on the methodology given in Section 5.4 using the dataset, which included data from more than 300 power plants that generated electricity between 2001 and 2008 using natural gas (NG), fuel oil, lignite, hard coal, naphtha, diesel, liquefied petroleum gas (LPG), and municipal waste gas (MWG). This dataset is analyzed using *SPSS* software (SPSS, 2007). The statistical analysis of each primary fuel type between 2001 and 2008 is given in Table 8. According to these results, lignite and hard coal have much higher CO_2 emission factors than natural gas and municipal waste gas.

The fuel-specific emission factors developed for Turkey are compared with those of the International Energy Agency (IEA, 2010) for the same period. This comparison shows that the specific emission factors developed in this study are close to those of the IEA, as given in Table 9. As seen here, the specific emission factors for all fossil fuel types are developed between 2001 and 2008 for this study. However, the IEA (2010) included specific emission factors only for coal, oil, and natural gas.

6.3. Planned electricity supply and associated CO_2 emissions of Turkey

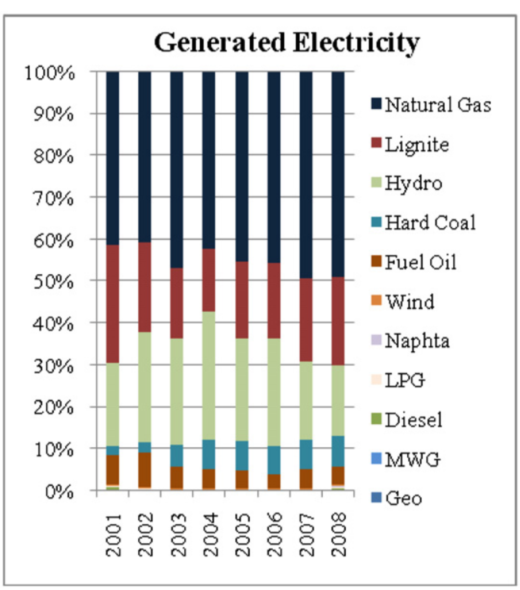
As presented in Section 4.4, the electricity demand of Turkey will increase by approximately 7% annually until 2019. To supply this demand, new power plants need to be built. A dataset that includes information on these planned power plants was obtained from EMRA (2009), as explained in detail in Section 4.3. However, this dataset does not contain information on the exact completion year of these planned power plants. The data only contain information on the "progress rate", which is given in percentage values. This rate provides information on the approximate completion time of the power plant projects. For this reason, an educated guess is made to determine the approximate year when each planned power plant will be completed. To do this, the progress rate data were divided into ten equal increments from

Table 7
Comparison of CO_2 emissions results.

	This study		NIR (UNFCCC, 2010)	
	Emission (million tons)	Annual change (%)	Emission (million tons)	Annual change (%)
2001	68.2		74.5	
2002	62.8	−8	68.8	−8
2003	64.0	2	68.9	0
2004	64.7	1	70.5	2
2005	78.0	21	83.7	19
2006	83.9	8	85.3	2
2007	98.9	18	100.7	18
2008	106.6	8	101.5	1
Avg.		**5**		**4**

Table 8
Fuel-specific CO_2 emission factors (kg CO_2/MWh).

	MWG	NG	Fuel oil	Lignite	LPG	Diesel	Naphtha	Hard coal
Number of data	7	131	28	107	7	6	7	26
Mean	**373**	**374**	**755**	**1,080**	**413**	**805**	**461**	**1018**
Median	357	367	753	1057	413	789	480	1014
Std. deviation	27	20	9	129	0	31	33	28
Minimum	357	356	741	712	413	780	413	919
Maximum	413	456	789	1384	413	860	480	1078



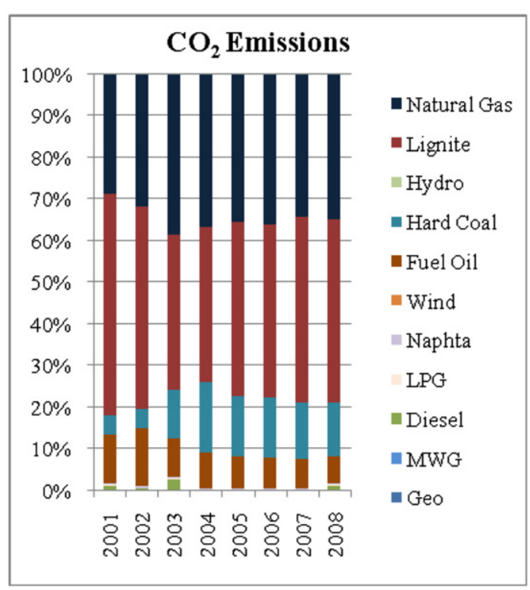


Fig. 4. Average percentage distributions of generated electricity and associated CO_2 emissions based on fuel type, 2001–2008.

Table 9
Comparison of specific emission factors (kg CO_2/MWh).

	2001	2002	2003	2004	2005	2006	2007	2008
Fuel oil	827	821	833	762	754	759	759	604
Hard coal	1035	1009	1022	1021	925	936	1044	844
Lignite	1054	1064	1055	1091	966	988	1043	1018
Natural gas	375	372	375	326	354	330	374	375
Oil (IEA, 2010)	735	672	668	688	654	740	675	714
Coal (IEA, 2010)	1082	1102	1068	1045	916	1015	1037	1037
Natural gas (IEA, 2010)	359	357	347	355	357	341	347	350

Table 10
Estimated completion year of the planned power plants.

Progress rate (%)	Corresponding completion year	Number of planned power plants	Total generation (GWh)
100–90	2009	24	2243
89.9–80	2010	13	2997
79.9–70	2011	6	1079
69.9–60	2012	12	2206
59.9–50	2013	14	6164
49.9–40	2014	18	7785
39.9–30	2015	25	10,501
29.9–20	2016	28	16,724
19.9–10	2017	38	16,177
9.9–0.1	2018	232	60,778
0	2019	155	33,549

Table 11
Total annual electricity supply [existing + planned (GWh)] based on fuel type, 2008–2019.

	Lignite	Coal	Asphaltite	NG	Fuel oil	Hydro	Wind	Geo	Biomass	MWG	Total
2008	41,738	14,216	670	97,399	9089	33,256	843	162	0	466	197,839
2009	41,747	14,342	670	97,603	9654	34,181	924	474	20	466	200,082
2010	41,747	15,407	670	98,103	9654	35,022	1516	474	20	466	203,080
2011	41,747	15,407	670	98,103	9654	35,598	1956	537	20	466	204,158
2012	41,747	15,407	670	99,028	9654	36,702	2135	537	20	466	206,365
2013	41,747	18,323	670	100,882	9654	37,821	2300	537	20	576	212,529
2014	41,747	18,323	670	107,175	9654	39,078	2534	537	20	576	220,314
2015	41,747	18,323	670	116,095	9654	40,145	2988	537	20	636	230,815
2016	41,747	30,658	670	116,095	9654	44,267	3255	537	20	636	247,539
2017	41,747	34,978	670	123,044	9654	48,820	3610	537	20	636	263,716
2018	48,915	59,536	670	125,138	9654	68,748	10,609	537	52	636	324,494
2019	49,445	69,961	3586	136,733	9654	75,452	11,821	607	149	636	358,043

0% to 100%. Each increment of this classification refers to the estimated completion time of the planned power plants, as given in Table 10. This table also presents the total number of planned power plants and electricity generation (GWh) between 2009 and 2019. As seen in Tables 24 and 13 power plants are expected to be completed in 2009 and 2010, respectively. It was found from an EMRA report published in January 2011 that only two of the power plants were not completed by the expected years (EMRA, 2011), which shows that the approach used for determining the estimated completion years based on progress rates are 95% reliable.

The amount of electricity generated by planned power plants based on fuel type and plant completion times are determined using this dataset. The results show that the hard coal-fueled planned power plants have the highest share at 35%, followed by natural gas and hydro power plants with shares of 25% and 26%, respectively. Approximately 40% of the total generation capacity of the planned power plants will be built in 2018, and 25% will be built in 2019.

To calculate the amount of total electricity supply between 2009 and 2019, the generation capacity of the planned power plants is summed with the current electricity capacity in 2008, as given in Table 11. As seen here, the natural gas power plants still have the largest share, followed by similar shares of lignite and hydro power plants.

To estimate the CO_2 emission from the total electricity supply (existing + planned) between 2009 and 2019, the fuel-specific emission factors (kg CO_2/MWh) given in Table 8 are multiplied by the electricity generation data based on fuel type given in Table 11. The results show that the lignite-fueled power plants have the highest share of total CO_2 emissions in this period, even though the amount of electricity that will be generated from lignite power plants is lower than that of natural gas. This result shows again that lignite has the highest emission factor, making it the most polluting fuel among the other power plant fuels.

6.4. Developing electricity demand and supply balance

As stated previously, the electricity demand in Turkey is expected to increase above 7% annually between 2009 and 2019, reaching 383,635 GWh in 2019. However, the annual increase in total electricity supply is lower than that of the demand for this period, which shows that new power plants need to be built to meet this expected demand. The total supply and expected demand of electricity and the differences between these values (surplus/shortfall) are given in Table 12.

As seen in Table 12, the expected demand in 2009 and 2010 is lower than the total supply. Also, the annual increase in demand in these years is lower than the other years due to the effects of the global financial crisis. However, between 2011 and 2019, the total supply (existing + planned) will not be sufficient to provide the estimated demand. The "Surplus/Shortfall" column in Table 12 presents the amount of electricity that needs to be generated by new and additional power plants between 2011 and 2019.

Fig. 5 presents the composition of the total electricity demand estimated between 2009 and 2019 in terms of the electricity generated by the existing, planned, and additional power plants.

To overcome this electricity supply and demand imbalance problem, new, additional and sustainable primary power plants need to be built. In addition, the mitigation of CO_2 emissions from electricity generation is the priority issue to combat climate change and is the main objective of this study. For these reasons, the shortfall amount of the electricity supply between 2011 and 2019 can be provided with renewable energy sources as a key solution for CO_2 emission reduction.

The economically feasible renewable energy potential of Turkey and the existing, planned, and remaining amounts are given in Table 13. The table shows that the deficiency of the electricity supply between 2011 and 2019 can easily be provided using the remaining renewable resources.

As seen here, only 19% of the total economic renewable potential of Turkey is currently used, and 30% is planned to be used in the near future. However, the remaining 51% is not utilized, which could be used to generate electricity to provide the deficient part of the electricity supply.

6.5. *Scenarios for providing electricity for the deficient part of the total supply and the associated CO_2 emissions of Turkey*

This section presents the results of four scenarios developed to overcome the shortfall problem given in Table 12. The first is the *Business as Usual (BAU) Scenario*. As a basic approach, the *BAU Scenario* considers electricity supply security rather than the climate change issue. For this scenario, shares of each primary energy source for the shortfall amount are estimated to have the same shares as of 2008 and be constant between 2009 and 2019.

The second scenario, called the *Renewable Scenario*, is developed considering the economically feasible renewable energy sources of Turkey for the shortfall amount as given in Table 13. The third scenario, the *Fossil Fuel Scenario*, is based on using only fossil fuel sources with the shares from the 2008 generation for the shortfall amount. The fourth and final scenario is the *Natural Gas Scenario*, which is developed based on the assumption that natural gas is the only energy source to generate electricity for the shortfall amount.

The common main assumptions of these scenarios are summarized as follows:

- The total electricity demand will be supplied only by national electricity generation.
- All power plants as of 2008 will be running until 2019.
- All planned power plants will be completed by 2019 based on the timing given in Table 10.
- To obtain the associated CO_2 emissions, the amount of electricity generated by each fuel type is multiplied with its fuel-specific emission factors in Table 8.
- The fuel-specific emission factors of all renewable energy sources are accepted as zero.

Table 12
Electricity supply, demand and surplus/shortfall (GWh), 2009–2019.

Year	Supply (GWh)	Demand (GWh)	Surplus/shortfall (GWh)
2009	200,082	194,000	6082
2010	203,080	202,730	350
2011	204,158	215,907	−11,749
2012	206,365	232,101	−25,736
2013	212,529	249,508	−36,979
2014	220,314	268,221	−47,907
2015	230,815	288,338	−57,523
2016	247,539	309,675	−62,136
2017	263,716	332,591	−68,875
2018	324,494	357,202	−32,708
2019	358,043	383,635	−25,592

Table 13
Overview of the renewable energy sources (GWh).

	Total economic potential (GWh)	**Existing usage as of 2008 (GWh)**	**Planned usage up to 2019 (GWh)**	**Remaining (GWh)**
Hydro	127,381	33,256	42,196	51,929
Geothermal	16,000	162	445	15,393
Wind	26,000	843	10,978	14,179
Biomass	11,575	0	149	11,426
Total	**180,956**	**34,261**	**53,768**	**92,927**

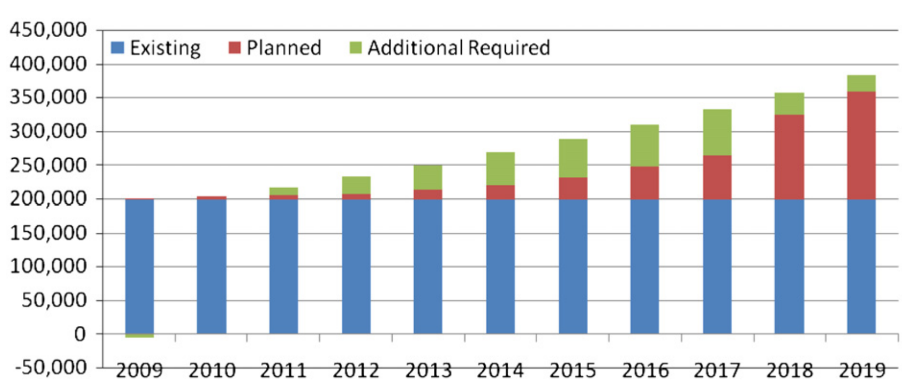


Fig. 5. Expected electricity supply mixture (GWh).

6.5.1. Business As Usual (BAU) scenario

The main assumption of the BAU scenario is to use all primary energy sources to generate electricity to overcome the shortfall between demand and supply as given in Table 12. The shares of the primary energy sources will be those of 2008 and will be kept constant between 2011 and 2019. The allocation of additionally required electricity generation based on fuel type is given in Table 14.

The total amount of electricity generated by fuel type based on the *BAU Scenario* is given in Table 15, which shows that there is a small fluctuation in the percentage of each primary energy source. When the primary energy allocation is compared with that of 2008, the lignite and natural gas shares decrease, while the hydro and coal shares increase between 2009 and 2019. Ina addition, the renewable energy share increases continuously from 18% to 24% in this period.

The associated CO_2 emissions of the total electricity generated based on the *BAU Scenario* by fuel type are given in Table 16. The CO_2 emissions in 2019 are calculated to be a little more than 198 million tons, which is almost twice the value in 2008. There is a sharp increase in the amount of electricity generated by the planned coal power plants in 2016 and 2018. This increase in coal power plants results in a sharp increase in the amount of associated CO_2 emissions in these years, as seen in Table 16.

6.5.2. Renewable scenario

The main assumption of this scenario is to use the remaining economically feasible renewable energy potential of Turkey, as given in Table 13, to overcome the shortfall amount between demand and supply, as given in Table 12.

The contributions of renewable energy sources are prioritized according to their investment costs, as given in Table 17. Those with lower investment costs per kW are expected to be built sooner than the others.

The allocation of the shortfall amount based on fuel type between 2011 and 2019 is given in Table 18.

The total amount of electricity generated by fuel type based on the *Renewable Scenario* is given in Table 19. As seen in this table, the shares of renewable energy sources increased sharply from 18% to 30% between 2009 and 2019. As noted earlier, there is a dramatic increase in the number of planned coal power plants in 2018 and 2019, which decreases the share of renewable energy in these years.

The associated CO_2 emissions of the total electricity generated based on the *Renewable Scenario* by fuel type are given in Table 20.

Table 16
Associated CO_2 emissions of the total electricity generated by fuel type based on the *BAU Scenario*, thousand tons.

	Lignite	**Coal**	**Asphaltite**	**NG**	**Fuel oil**	**MWG**	**Total**
2009	43,701	14,156	299	35,384	7078	168	**100,786**
2010	45,007	15,659	308	36,626	7277	173	**105,050**
2011	47,764	16,544	327	38,854	7696	184	**111,369**
2012	50,951	17,567	349	41,775	8181	196	**119,019**
2013	53,512	21,358	367	44,539	8571	247	**128,594**
2014	56,002	22,157	384	48,904	8950	257	**136,655**
2015	58,193	22,861	399	54,011	9284	288	**145,035**
2016	59,244	35,756	406	54,860	9444	292	**160,002**
2017	60,780	40,646	416	58,700	9678	298	**170,518**
2018	60,280	63,000	360	52,824	8423	266	**185,153**
2019	59,232	73,092	1693	55,850	8176	260	**198,303**

Table 17
The unit of investment cost of renewable energy sources (GNAT, 2008).

	Investment cost (kW^{-1})
Hydro	\$1500–\$5500
Geothermal	\$1700–\$5700
Wind	\$900–\$2500
Biomass	\$1000–\$2500

Table 14
Additionally required electricity between 2011 and 2019 based on fuel type for the *BAU Scenario* (GWh).

	Lignite	Coal	Asphaltite	NG	Fuel oil	Hydro	Wind	Geo	Biomass	MWG	Total
2011	2479	844	40	5784	540	1975	50	10	0	28	11,749
2012	5430	1849	87	12,670	1182	4326	109	22	0	61	25,736
2013	7801	2657	125	18,205	1699	6216	157	31	0	87	36,979
2014	10,107	3442	162	23,585	2201	8053	205	40	0	113	47,907
2015	12,136	4133	195	28,319	2643	9670	245	48	0	135	57,523
2016	13,109	4465	210	30,591	2855	10,444	265	51	0	146	62,136
2017	14,531	4950	233	33,908	3164	11,578	293	57	0	162	68,875
2018	6900	2350	111	16,102	1503	5498	139	27	0	77	32,708
2019	5399	1839	87	12,599	1176	4301	109	21	0	60	25,592

Table 15
Amount of total electricity generated by fuel type based on the *BAU Scenario* (GWh), 2008–2019.

	Lignite	**Coal**	**Asphaltite**	**NG**	**Fuel oil**	**Hydro**	**Wind**	**Geo**	**Biomass**	**MWG**	**Total**
2008	41,738	14216	670	97,399	9089	33,256	843	162	0	466	**197,839**
2009	40,464	13905	649	94,609	9375	33,159	898	469	20	452	**194,000**
2010	41,673	15382	669	97,931	9638	34,964	1515	474	20	465	**202,730**
2011	44,226	16251	710	103,887	10,194	37,573	2006	547	20	494	**215,907**
2012	47,177	17,256	757	111,698	10,836	41,028	2244	559	20	527	**232,101**
2013	49,548	20,980	795	119,087	11,353	44,037	2457	568	20	663	**249,508**
2014	51,854	21,765	832	130,760	11,855	47,131	2739	577	20	689	**268,221**
2015	53,883	22,456	865	144,414	12,297	49,815	3233	585	20	771	**288,338**
2016	54,856	35,123	880	146,686	12,509	54,711	3520	588	20	782	**309,675**
2017	56,278	39,928	903	156,952	12,818	60,398	3903	594	20	798	**332,591**
2018	55,815	61,886	781	141,240	11,157	74,246	10,748	564	52	713	**357,202**
2019	54,844	71,800	3673	149,332	10,830	79,753	11,930	628	149	696	**383,635**

Table 18
Additionally required electricity between 2011 and 2019 based on fuel type for the *Renewable Scenario* (GWh).

	Lignite	Coal	Asphaltite	NG	Fuel oil	Hydro	Wind	Geo	Biomass	MWG	Total
2011	0	0	0	0	0	2350	3877	1997	3525	0	11,749
2012	0	0	0	0	0	5147	8493	4375	7721	0	25,736
2013	0	0	0	0	0	7396	12,203	6286	11,094	0	36,979
2014	0	0	0	0	0	14,157	14,179	8144	11,426	0	47,907
2015	0	0	0	0	0	22,140	14,179	9779	11,426	0	57,524
2016	0	0	0	0	0	25,968	14,179	10,563	11,426	0	62,136
2017	0	0	0	0	0	31,561	14,179	11,709	11,426	0	68,875
2018	0	0	0	0	0	6542	10,794	5560	9812	0	32,708
2019	0	0	0	0	0	5118	8445	4351	7677	0	25,592

Table 19
Amount of total electricity generated by fuel type based on the *Renewable Scenario* (GWh), 2008–2019.

	Lignite	**Coal**	**Asphaltite**	**NG**	**Fuel oil**	**Hydro**	**Wind**	**Geothermal**	**Biomass**	**MWG**	**Total**
2009	40,464	13,905	649	94,609	9375	33,159	898	469	20	452	**194,000**
2010	41,673	15,382	669	97,931	9638	34,964	1515	474	20	465	**202,730**
2011	41,747	15,407	670	98,103	9654	37,925	5834	2591	3510	466	**215,907**
2012	41,747	15,407	670	99,028	9654	41,799	10,630	5035	7666	466	**232,101**
2013	41,747	18,323	670	100,882	9654	45,145	14,506	7000	11,006	576	**249,508**
2014	41,747	18,323	670	107,175	9654	48,566	18,348	8910	14,252	576	**268,221**
2015	41,747	18,323	670	116,095	9654	51,538	21,976	10,590	17,109	636	**288,338**
2016	41,747	30,658	670	116,095	9654	56,573	23,766	11,396	18,480	636	**309,675**
2017	41,747	34,978	670	123,044	9654	62,462	26,345	12,574	20,482	636	**332,591**
2018	48,915	59,536	670	125,138	9654	75,226	21,406	6253	9769	636	**357,202**
2019	49,445	69,961	3586	136,733	9654	80,520	20,269	5080	7752	636	**383,635**

Table 20
Associated CO_2 emissions of the total electricity generated by fuel type based on the *Renewable Scenario*, thousand tons.

	Lignite	**Coal**	**Asphaltite**	**NG**	**Fuel oil**	**MWG**	**Total**
2009	43,701	14,156	299	35,384	7078	168	**100,786**
2010	45,007	15,659	308	36,626	7277	173	**105,050**
2011	45,087	15,684	309	36,691	7289	174	**105,233**
2012	45,087	15,684	309	37,036	7289	174	**105,579**
2013	45,087	18,653	309	37,730	7289	215	**109,281**
2014	45,087	18,653	309	40,083	7289	215	**111,635**
2015	45,087	18,653	309	43,420	7289	237	**114,994**
2016	45,087	31,210	309	43,420	7289	237	**127,551**
2017	45,087	35,608	309	46,018	7289	237	**134,548**
2018	52,828	60,607	309	46,802	7289	237	**168,071**
2019	53,401	71,220	1653	51,138	7289	237	**184,938**

The CO_2 emissions in 2019 are calculated to be nearly 185 million tons, which is lower than that of the *BAU Scenario*. There is a sharp increase in the amount of electricity generated by the planned coal power plants in 2016 and 2018. This increase results in a sharp increase in the amount of associated CO_2 emissions in these years, as seen in Table 20.

6.5.3. Fossil fuel scenario

The main assumption of this scenario is using only fossil fuels as the primary energy source to overcome the shortfall between the demand and supply, as given in Table 12. The shares of each fossil fuel in the total fossil fuel mix of 2008 are used as the fossil fuel shares between 2011 and 2019, and these shares are estimated to be constant in this period. The allocation of the shortfall amount is given in Table 21.

The total amount of electricity generated by fuel type based on the *Fossil Fuel Scenario* is given in Table 22. According to this table, the fossil fuel ratio reaches nearly 85% between 2013 and 2017. Because the deficiency is high for these years, more fossil fuels are required to meet the demand. The decrease in the fossil fuel ratio for 2018 and 2019 is due to the high amount of hydro power plant contributions from the planned electricity supply.

The associated CO_2 emissions of the total electricity generated based on the *Fossil Fuel Scenario* by fuel type are given in Table 23. The CO_2 emission in 2019 is calculated to be more than 201 million tons, which is more than twice the value in 2009 and higher than that of the *BAU* and *Renewable* scenarios. Because the incremental electricity supply is highly dependent on fossil fuels, this scenario has more CO_2 emissions than the previous scenarios.

6.5.4. Natural gas scenario

The main assumption of this scenario is to use only natural gas as the primary energy source to overcome the shortfall amount as given in Table 12 between 2011 and 2019. The allocation of this shortfall amount by fuel type is given in Table 24.

The amount of total electricity generated by fuel type based on the *Natural Gas Scenario* is given in Table 25. As seen in this table, the fossil fuel share is the same as that of the *Fossil Fuel Scenario* seen in Table 22 because natural gas is a fossil fuel. Because the deficiency is high between 2013 and 2017, more fossil fuels are required to meet the demand. The decrease in the fossil fuel ratio in 2018 and 2019 is due to high amount of hydro contribution from the planned electricity supply.

The associated CO_2 emissions of the total electricity generated based on the *Natural Gas Scenario* by fuel type are given in Table 26. The CO_2 emissions in 2019 are calculated to be 194 million tons, which is less than that of the *Fossil Fuel Scenario*, though it is higher than that of the *Renewable Scenario*.

6.5.5. Comparative assessment of the scenarios

The percentage distributions of the electricity generated from fossil fuels and renewable energies based on the four scenarios are given in Table 27. The shares of fossil fuels and renewable energies are very close for the *Fossil Fuel* and *Natural Gas* scenarios. In the *BAU Scenario*, there is a continuous increase in the renewable energy ratio. This increase will be especially

Table 21
Additionally required electricity between 2011 and 2019 based on fuel type for the *Fossil Fuel Scenario* (GWh).

	Lignite	Coal	Asphaltite	NG	Fuel oil	Hydro	Wind	Geo	Biomass	MWG	Total
2011	2998	1021	48	6996	653	0	0	0	0	33	11,749
2012	6567	2236	105	15,324	1430	0	0	0	0	73	25,736
2013	9435	3214	151	22,018	2055	0	0	0	0	105	36,979
2014	12,224	4163	196	28,525	2662	0	0	0	0	136	47,907
2015	14,677	4999	235	34,251	3196	0	0	0	0	164	57,523
2016	15,855	5401	254	36,998	3452	0	0	0	0	177	62,136
2017	17,574	5986	282	41,010	3827	0	0	0	0	196	68,875
2018	8345	2842	134	19,475	1817	0	0	0	0	93	32,708
2019	6530	2224	105	15,238	1422	0	0	0	0	73	25,592

Table 22
Amount of total electricity generated by fuel type based on the *Fossil Fuel Scenario* (GWh), 2008–2019.

	Lignite	**Coal**	**Asphaltite**	**NG**	**Fuel oil**	**Hydro**	**Wind**	**Geo**	**Biomass**	**MWG**	**Total**
2008	41,738	14,216	670	97,399	9089	33,256	843	162	0	466	**197,839**
2009	40,195	13,814	645	93,982	9316	34,181	924	474	20	449	**194,000**
2010	41,658	15,376	668	97,895	9635	35,022	1516	474	20	465	**202,730**
2011	44,745	16,428	718	105,099	10,307	35,598	1956	537	20	499	**215,907**
2012	48,314	17,643	775	114,352	11,084	36,702	2135	537	20	539	**232,101**
2013	51,182	21,537	821	122,900	11,709	37,821	2300	537	20	681	**249,508**
2014	53,971	22,486	866	135,700	12,316	39,078	2534	537	20	712	**268,221**
2015	56,424	23,322	905	150,346	12,850	40,145	2988	537	20	800	**288,338**
2016	57,602	36,059	924	153,093	13,106	44,267	3255	537	20	813	**309,675**
2017	59,321	40,964	952	164,054	13,481	48,820	3610	537	20	832	**332,591**
2018	57,260	62,378	804	144,613	11,471	68,748	10,609	537	52	729	**357,202**
2019	55,975	72,185	3691	151,971	11,076	75,452	11,821	607	149	709	**383,635**

Table 23
Associated CO_2 emissions of the total electricity generated by fuel type based on the *Fossil Fuel Scenario*, thousand tons.

	Lignite	**Coal**	**Asphaltite**	**NG**	**Fuel oil**	**MWG**	**Total**
2008	45,078	14,472	309	36,427	6862	174	**103,322**
2009	43,411	14,062	297	35,149	7034	167	**100,120**
2010	44,990	15,653	308	36,613	7274	173	**105,012**
2011	48,324	16,724	331	39,307	7782	186	**112,654**
2012	52,179	17,961	357	42,768	8368	201	**121,834**
2013	55,277	21,924	379	45,965	8840	254	**132,639**
2014	58,288	22,891	399	50,752	9298	266	**141,895**
2015	60,938	23,742	417	56,229	9702	298	**151,327**
2016	62,210	36,708	426	57,257	9895	303	**166,799**
2017	64,067	41,702	439	61,356	10,178	310	**178,052**
2018	61,841	63,501	371	54,085	8661	272	**188,731**
2019	60,453	73,484	1701	56,837	8362	264	**201,103**

Table 24
Additionally required electricity between 2011 and 2019 based on fuel type for the *Natural Gas Scenario* (GWh).

	Lignite	Coal	Asphaltite	NG	Fuel oil	Hydro	Wind	Geo	Biomass	MWG	Total
2011	0	0	0	11,749	0	0	0	0	0	0	11,749
2012	0	0	0	25,736	0	0	0	0	0	0	25,736
2013	0	0	0	36,979	0	0	0	0	0	0	36,979
2014	0	0	0	47,907	0	0	0	0	0	0	47,907
2015	0	0	0	57,523	0	0	0	0	0	0	57,523
2016	0	0	0	62,136	0	0	0	0	0	0	62,136
2017	0	0	0	68,875	0	0	0	0	0	0	68,875
2018	0	0	0	32,707	0	0	0	0	0	0	32,708
2019	0	0	0	25,592	0	0	0	0	0	0	25,592

accelerated in 2018 and 2019 due to the high contribution of hydro energy.

For the *Renewable Scenario*, there is a rapid increase in renewable energy usage in 2013. The contribution of renewable energies increases continuously between 2009 and 2019. The ratio of the renewable contribution/total electricity demand will be the highest in 2013. As expected, the renewable energy usage is much higher than in the other scenarios.

There are fluctuations in the shares of the fossil fuels and renewable energies among the scenarios for three main reasons.

Table 25
Amount of total electricity generated by fuel type based on the *Natural Gas Scenario* (GWh), 2008–2019.

	Lignite	Coal	Asphaltite	NG	Fuel oil	Hydro	Wind	Geo	Biomass	MWG	Total
2008	41,738	14,216	670	97,399	9089	33,256	843	162	0	466	**197,839**
2009	41,747	14,342	670	91,521	9654	34,181	924	474	20	466	**194,000**
2010	41,747	15,407	670	97,754	9654	35,022	1516	474	20	466	**202,730**
2011	41,747	15,407	670	109,852	9654	35,598	1956	537	20	466	**215,907**
2012	41,747	15,407	670	124,764	9654	36,702	2135	537	20	466	**232,101**
2013	41,747	18,323	670	137,861	9654	37,821	2300	537	20	576	**249,508**
2014	41,747	18,323	670	155,082	9654	39,078	2534	537	20	576	**268,221**
2015	41,747	18,323	670	173,618	9654	40,145	2988	537	20	636	**288,338**
2016	41,747	30,658	670	178,231	9654	44,267	3255	537	20	636	**309,675**
2017	41,747	34,978	670	191,919	9654	48,820	3610	537	20	636	**332,591**
2018	48,915	59,536	670	157,845	9654	68,748	10,609	537	52	636	**357,202**
2019	49,445	69,961	3586	162,325	9654	75,452	11,821	607	149	636	**383,635**

Table 26
Associated CO_2 emissions of the total electricity generated by fuel type based on the *Natural Gas Scenario*, thousand tons.

	Lignite	Coal	Asphaltite	NG	Fuel oil	MWG	Total
2008	45,078	14,472	309	36,427	6862	174	**103,322**
2009	45,087	14,601	309	34,229	7289	174	**101,687**
2010	45,087	15,684	309	36,560	7289	174	**105,102**
2011	45,087	15,684	309	41,085	7289	174	**109,627**
2012	45,087	15,684	309	46,662	7289	174	**115,204**
2013	45,087	18,653	309	51,560	7289	215	**123,112**
2014	45,087	18,653	309	58,001	7289	215	**129,552**
2015	45,087	18,653	309	64,933	7289	237	**136,507**
2016	45,087	31,210	309	66,658	7289	237	**150,790**
2017	45,087	35,608	309	71,778	7289	237	**160,307**
2018	52,828	60,607	309	59,034	7289	237	**180,304**
2019	53,401	71,220	1653	60,709	7289	237	**194,509**

Table 27
Shares of electricity generated from fossil fuel and renewable energies based on the four scenarios.

	Business as usual		Renewable		Fossil fuel		Natural gas	
	Fossil (%)	Renewable (%)	Fossil (%)	Renewable (%)	Fossil (%)	Renewable (%)	Fossil (%)	Renewable (%)
2008	82.7	17.3	82.7	17.3	82.7	17.3	82.7	17.3
2009	82.2	17.8	82.2	17.8	81.6	18.4	81.6	18.4
2010	81.8	18.2	81.8	18.2	81.7	18.3	81.7	18.3
2011	81.4	18.6	76.9	23.1	82.3	17.7	82.3	17.7
2012	81.1	18.9	71.9	28.1	83.0	17.0	83.0	17.0
2013	81.1	18.9	61.5	38.5	83.7	16.3	83.7	16.3
2014	81.2	18.8	66.4	33.6	84.3	15.7	84.3	15.7
2015	81.4	18.6	64.9	35.1	84.8	15.2	84.8	15.2
2016	81.0	19.0	64.4	35.6	84.5	15.5	84.5	15.5
2017	80.5	19.5	63.4	36.6	84.1	15.9	84.1	15.9
2018	76.0	24.0	68.5	31.5	77.6	22.4	77.6	22.4
2019	75.9	24.1	70.4	29.6	77.1	22.9	77.1	22.9

The first reason has to do with using different types of primary energy sources for each scenario. The second reason is related to the ratio of renewable energy contribution/total electricity demand. The increase in the share of renewable energy sources is different than the increase in the total electricity demand. The third reason is the piling problem of the planned power plants. The planned plants are not distributed equally in terms of fuel type and time range. For 2018 and 2019 in particular, the characteristics of the related scenarios could not be observed easily due to the piling of supply problem. In spite of these factors, there is an apparent difference between the four scenarios.

Fig. 6 presents the fluctuations of the renewable energy shares based on the scenarios between 2009 and 2019. There is a convergence among all scenarios for 2018 and 2019 because the completion times of the planned projects are piled up in these two years. Natural gas, coal, lignite, and hydro are the primary energies of the power plants that cause this piling. There is a convergence in the *Renewable Scenario* due to the lesser amount of additional renewable sources required for 2018 and 2019, and the renewable energy contribution is also less than the other years. Although the *Fossil Fuel* and *Natural Gas* scenarios have the same fossil fuel and renewable energy ratios, as expected, the *Natural Gas Scenario* results in lower CO_2 emissions than the *Fossil Fuel Scenario* due to the emission factor associated with each fuel, as given in Table 8.

A comparison of the CO_2 emissions of all scenarios gives the best mitigation option for the electricity sector. The associated CO_2 emissions of the four scenarios are presented in Table 28. The *Fossil Fuel Scenario* results in the maximum emissions, whereas the *Renewable Energy Scenario* results in the minimum emissions.

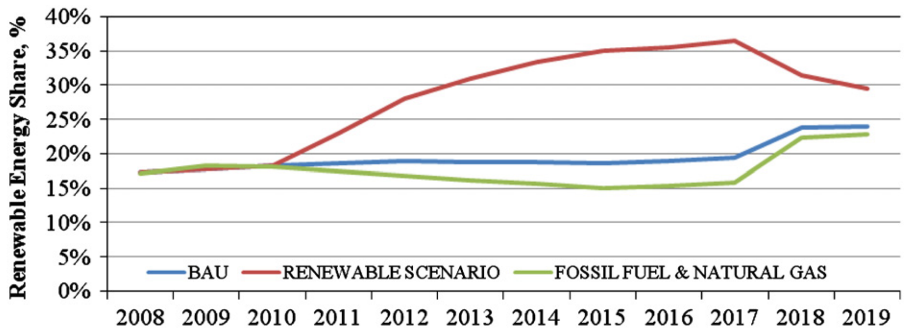


Fig. 6. Changes in the share of renewable energy sources for all scenarios between 2008 and 2019.

Table 28
Comparison of CO_2 emissions based on the four scenarios, million tons.

	BAU		Renewable		Fossil		Natural gas	
2008	106.6		106.6		106.6		106.6	
2009	100.8	−6%	100.8	−6%	100.1	−6%	101.7	−5%
2010	105.1	4%	105.1	4%	105.0	5%	105.1	3%
2011	111.4	6%	105.2	0%	112.7	7%	109.6	4%
2012	119.0	6%	105.6	0%	121.8	8%	115.2	5%
2013	128.6	7%	109.3	3%	132.6	8%	123.1	6%
2014	136.7	6%	111.6	2%	141.9	7%	129.6	5%
2015	145.0	6%	115.0	3%	151.3	6%	136.5	5%
2016	160.0	9%	127.6	10%	166.8	9%	150.8	9%
2017	170.5	6%	134.6	5%	178.1	6%	160.3	6%
2018	185.2	8%	168.1	20%	188.7	6%	180.3	11%
2019	198.3	7%	184.9	9%	201.1	6%	194.5	7%
% 09–19		**86%**		**73%**		**89%**		**82%**

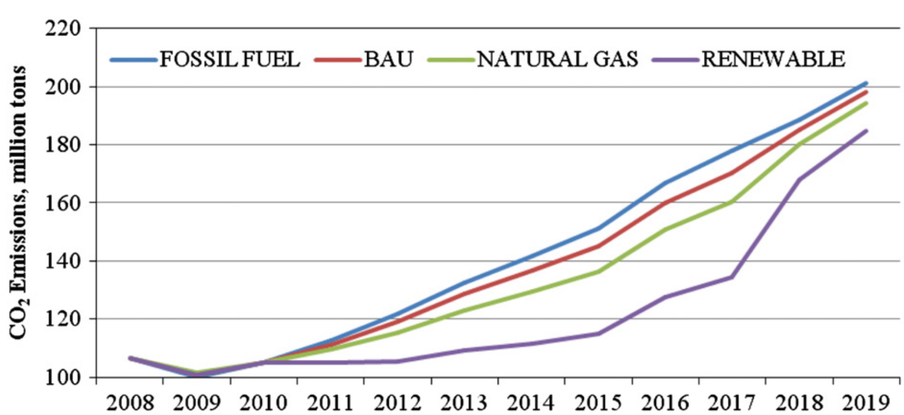


Fig. 7. Traces of each scenario's emissions.

In total, the associated CO_2 emissions of the *Fossil Fuel Scenario* will have the highest increase at 89% between 2008 and 2019, followed by the *Business As Usual Scenario* (86%), *Natural Gas Scenario* (82%), and *Renewable Scenario* (73%).

Fig. 7 presents the emission pathways of each scenario. Starting with 2011, the emissions based on the *Renewable Scenario* follow a different path from the emissions based on the other scenarios. However, in 2018 and 2019, there is a convergence of the emissions of *Renewable Scenario* with those of the other scenarios. This pattern is also due to the ratio of renewable energy usage and total electricity demand as well as the piling up of the planned power plants for these years.

As mentioned earlier, there are a few studies on the projection of electricity generation-associated CO_2 emissions in Turkey, one of which is the report of the Ministry of Energy and Natural Resources (MENR, 2006), which included the results of the associated GHG emission projections to 2020 based on four scenarios: a reference case, low growth, demand side management, and cogeneration. The other study is the report published in 2009 by Greenpeace Turkey (2009), which included the results of two different scenarios on the projection of Turkey's electricity generation-associated CO_2 emissions.

The projection outlook range of all three studies is to 2019 or 2020, and the CO_2 emission projections of all studies show similar increasing trends, as seen in Table 29. However, the emission projections of all studies are in a wide range, between 100 and 248 million tons for 2019 or 2020. The emission projections of the Greenpeace report are lower than those of other studies. There are several explanations for these results. First, the projections of electricity generation or supply used in the MENR (2005) and Greenpeace studies are different from those of this study (Greenpeace, 2009). Second, in the Greenpeace (2009) study, the technical potential of renewable energy sources was also included in the generation of electricity. Third and finally, the consumption projection of the electricity demand in Turkey is different in all studies.

7. Discussion and conclusion

This study investigates the mitigation potential of CO_2 emissions from electricity using renewable energy sources for the shortfall amount between the estimated demand and supply (planned + existing).

To the authors' knowledge, this is the first comprehensive study that analyzes the associated CO_2 emissions from electricity generation using the data available from each of the major power plants in Turkey between 2001 and 2008, calculates the specific emission factors by fuel type using this power plant data, determines the amount of electricity that will be generated by fuel type annually between 2009 and 2019, and analyzes the amount of associated CO_2 emission reduction with available and economically feasible renewable sources.

In the first part of the study, the generated electricity based on fuel type, associated CO_2 emissions, and fuel-specific emission factors are calculated. Based on these calculations, the amount of total electricity generated increased from 122,311 to 197,839 GWh between 2001 and 2008 in Turkey, which corresponds to a total increase if 62% for this period. For the same period, the associated CO_2 emissions increased by approximately 55%, from 68 to 106 million tons.

Table 29
Forecast of CO_2 emissions from different studies, million tons.

		2010	2015	2019	2020
This study	Business as usual	105	145	198	
	Renewable energy	105	115	185	
	Fossil fuel	105	151	201	
	Natural gas	105	136	195	
MENR (2005)	Reference	117	152		222
	Demand side management	110	140		185
	Low growth	107	137		163
	Cogeneration	122	167		248
Greenpeace (2009)	Reference	87			161
	Energy [R]evolution	82			100

The fuel-specific emission factors for Turkey are also generated. The results show that lignite and hard coal have the highest fuel-specific emission factors among the other fossil fuels, at 1080 and 1018 kg CO_2/MWh, respectively. The specific emission factor for natural gas is calculated as 374 kg CO_2/MWh, which is lower than that of lignite and hard coal.

In the next part of the study, the power plants that are planned to be built in Turkey between 2009 and 2019 are analyzed. The results show that it is mainly plants using natural gas, hydro, and coal that are expected to be built in this period. The amount of electricity that is estimated to be generated from the existing and planned power plants is found to be lower than the estimated demand for this period, which means new power plants need to be built.

In the last part of the study, four scenarios are developed to supply the shortfall amount of the total supply, namely, the *Business As Usual*, *Renewable*, *Fossil Fuel*, and *Natural Gas* scenarios. The amounts of electricity generated by fuel type and the associated CO_2 emissions based on each scenario are also determined.

The total electricity generation-associated CO_2 emissions based on the *Business As Usual, Renewable, Fossil Fuel*, and *Natural Gas* scenarios between 2009 and 2019 are given in Fig. 8. As seen here, the *Renewable Scenario* has the least CO_2 emissions at 1,368 million tons; the *Natural Gas Scenario* follows *the Renewable Scenario*, with 1507 million tons of CO_2 emissions; and the *Fossil Fuel Scenario* has the highest CO_2 emissions, with 1600 million tons between 2009 and 2019.

In terms of the mitigation of CO_2 emissions, the scenario with the lowest emissions is the *Renewable Energy Scenario*. This scenario provides a reduction of 192 million tons of CO_2 emissions with respect to the *BAU Scenario* between 2009 and 2019. In climate change negotiations under the UNFCCC, this amount could be declared as the deviation of CO_2 emissions from the business as usual conditions. In addition, Turkey could use this mitigation potential to benefit from flexible mechanisms in the climate change issue, such as emissions trading. The renewable energy scenario also provides an increased share of national energy sources in electricity generation with the hydro, geothermal, wind, and biomass potentials of Turkey, which would also reduce the energy dependency on foreign sources.

In a possible future study, the IPCC Tier-3 approach, which includes combustion technology, operating conditions, and age of equipment, among others, can be used to calculate the associated CO_2 emissions if the required data become available in the future. In addition, with these analyses, the CO_2 mitigation potential by carbon capture, storage, and sequestration technologies in the electricity

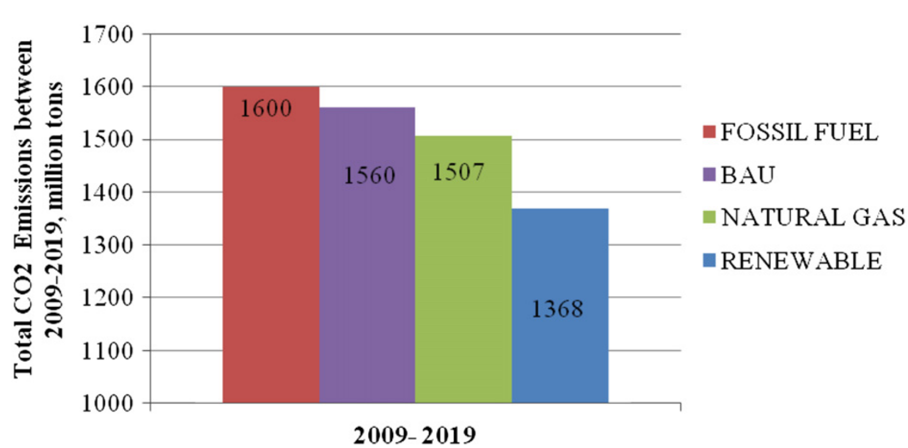


Fig. 8. Comparison of the total CO_2 emissions of the four scenarios between 2009 and 2019.

sector can be examined especially for hard coal and lignite fossil-fueled power plants in Turkey. The economic costs and cost/benefit analyses of these scenarios can also be assessed if the required data become available in the future.

References

Ari, I., 2010. Investigating the CO_2 Emission of Turkish Electricity Sector and Its Mitigation Potential. M.Sc. Thesis, Middle East Technical University, Ankara, Turkey.

Can, A., 2006. Investigation of Turkey's Carbon Dioxide Problem by Numerical Modeling. Ph.D. Thesis, Middle East Technical University, Ankara, Turkey.

EGIC (Energy Generation Cooperation Inc.), 2009a. CDRom The Official Letter about the Elemental Analysis of Thermal Power Plants, obtained on 30.03.09.

EGIC (Energy Generation Incorporated Company), 2009b. Power Plants Item ⟨http://www.euas.gov.tr/⟩ (accessed 22.02.09).

EMRA (Energy Market Regulatory Agency), 2009. Electricity Item ⟨http://www.epdk.gov.tr/lisans/elektrik/ilerleme_proje.htm⟩ (accessed 11.03.09).

EMRA (Energy Market Regulatory Agency), 2011. Electricity Item ⟨http://www2.epdk.org.tr/lisans/elektrik/ilerleme_proje.htm⟩ (accessed 27.05.11).

EPSA (Electrical Power Resources Survey and Development Administration), 2009. ⟨http://www.eie.gov.tr/duyurular/YEK/LawonRenewableEnergyReources.pdf⟩ (accessed 03.10.09).

GNAT (The Grand National Assembly of Turkey), 2008. Research Commission Report on Climate Change and Water Resources ⟨http://www.tbmm.gov.tr/komisyon/denetim/kuresel_isinma/index.htm⟩ (accessed 05.02.09).

Greenpeace, 2009. Energy [R]evolution—Turkey ⟨http://www.greenpeace.org/turkey/Global/turkey/report/2010/5/enerji-d-evrimi.pdf⟩ (accessed 22.02.11).

IEA (International Energy Agency), 2009. CO_2 Emissions from Fuel Combustion 2009. OECD, Paris, Cedex, France.

IEA (International Energy Agency), 2010. CO_2 Emissions from Fuel Combustion 2010. OECD, Paris, Cedex, France.

IPCC (Intergovernmental Panel on Climate Change), 2006. IPCC Guidelines for National Greenhouse Gas Inventories 2006 ⟨http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html⟩ (accessed 02.01.08).

IPCC (Intergovernmental Panel on Climate Change), 2007. IPCC-4: Report Working Group III Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report Climate Change: Mitigation of Climate Change, New York, USA.

Keskinel, F., 2006. Electricity generation and combined natural gas power plants in Turkey. İstanbul Bülteni 87, 17–26.

Kıncay, O., Ozturk, R., 2003. Thermal power plants in Turkey. Energy Sources 25, 135–151.

MENR (Ministry of Energy and Natural Resources), 2005. Working Group Report on Mitigation of GHG Emission in Energy Sector, Ankara, Turkey.

MENR (Ministry of Energy and Natural Resources), 2006. Mitigation of GHG Emission in Energy Sector, Ankara, Turkey.

MoEF (Ministry of Environment and Forestry), 2006. First National Communication Report on Climate Change of Republic of Turkey, Ankara, Turkey.

NLDC (National Load Distribution Center), 2009. Daily Electricity Generation Data, Ankara, Turkey.

Oktay, Z., 2009. Investigation of coal-fired power plants in Turkey and a case study: can plant. Applied Thermal Engineering 29, 550–557.

Say, N.P., Yucel, M., 2006. Energy consumption and CO_2 emissions in Turkey: empirical analysis and future projection based on an economic growth. Energy Policy 34, 3870–3876.

SHW (State Hydraulic Works), 2008. Energy Item ⟨http://www.dsi.gov.tr/english/service/enerjie.htm⟩ (accessed 27.12.08).

SPO (State Planning Organization), 1988. Annual Programme-1988, Ankara, Turkey.

SPO (State Planning Organization), 1989. Annual Programme-1989, Ankara, Turkey.

SPO (State Planning Organization), 2000. Eighth Five Year Development Plan, Special Expert Commission report on Climate Change, Ankara, Turkey.

SPO (State Planning Organization), 2009. Annual Programme-2009, Ankara, Turkey.

SPSS (Statistical Package for the Social Sciences), 2007. SPPS-13 Model ⟨http://www.spss.com.tr/cozumler.html⟩ (accessed 29.05.08).

TETC (Turkish Electricity Transmission Corporation), 2009. Turkish Electrical Energy 10-Year Generation Capacity Projection ⟨http://www.teias.gov.tr/projeksiyon/KAPASITEPROJEKSIYONU2009.pdf⟩ (accessed 28.08.09).

TETC (Turkish Electricity Transmission Corporation), 2010. Electricity Generation—Transmission Statistics of Turkey ⟨http://www.teias.gov.tr/istatistik2008/index.htm⟩ (accessed 04.12.10).

Turker, L., 2008. Forecasting Turkey's Regional Long-Term Electricity Demand and Associated CO_2 Emission by Econometric and Artificial Neural Network Approaches. M.Sc. Thesis, Hacettepe University, Ankara, Turkey.

TURKSTAT (Turkish Statistical Institution), 2009. Turkey Greenhouse Gas Inventory, 1990–2007. National Inventory Report, Ankara, Turkey.

UNFCCC (United Nations Framework Convention on Climate Change), 2006. 2006 Handbook, Bonn, Germany.

UNFCCC (United Nations Framework Convention on Climate Change), 2010. National Inventory Report of Turkey ⟨http://unfccc.int/files/national_reports/annex_i_ghg_inventories/national_inventories_submissions/application/zip/tur_2010_n(ir_15apl.zip)⟩ (accessed 15.01.11).