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The scenario analysis on CO_2 emission mitigation potential in the Turkish electricity sector: 2006–2030

Betül Özer [a,*], Erdem Görgün [a], Selahattin İncecik [b]

[a] Istanbul Technical University, Department of Environmental Engineering, Civil Engineering Faculty, Maslak, Istanbul, Turkey
[b] Istanbul Technical University, Department of Meteorology, Faculty of Aeronautics and Astronautics, Maslak, Istanbul, Turkey

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ABSTRACT

A scenario analysis method based on the Long-range Energy Alternatives Planning system (LEAP) model was used for an analysis of reduction of emissions in the electricity sector of Turkey. Business As Usual (BAU) and Mitigation Scenarios address the simulations from different approaches. Each scenario represents a different development path which is possible in Turkey's electricity sector due to various policies. The simulations are applied until the year 2030, while 2006 is set as the base year. Carbon dioxide (CO_2) emissions will rise significantly under the Baseline Scenario. In the Mitigation Scenario, electricity-related CO_2 emissions grew by 5.8% annually between 2006 and 2030, while electricity output grew at an average of 6.6% per annum in this period. Comparison between the CO_2 emissions suggested by the scenarios presents the mitigation potential of the electricity sector. The Mitigation Scenario is characterized by its aggressive greenhouse gas (GHG) control policies and can achieve mitigation ratio of 17.5% over the simulation period. The cumulative CO_2 emission reduction between the BAU and Mitigation Scenarios from 2006 to 2030 is 903 million tons. Additionally, CO_2 emission intensity has decreased by 18.4% in 2030 compared to 2006.

1. Introduction

Turkey (36° − 42°N; 26° − 45°E) has a total area of approximately 778,000 km^2 and is located in the south-eastern part of Europe between Europe and Asia in the Mediterranean macroclimate zone. Temperature differences between the south and the north of the country are significant. In winter, air temperature varies greatly between western and eastern regions of Turkey. The average minimum temperature in Erzurum, an eastern city, is −15.2 °C, while in Izmir, on the western coast, average winter temperatures are around 6 °C. Future predictions indicate a mean annual temperature increase of 2–3 °C for Turkey by 2100 [1,2].

It is expected that climate change will alter energy demand patterns in the country. Turkey had a total population of 74.7 million in 2011, and as a fast-developing economy, it is among the industrialised countries of the world. Turkey has maintained rapid economic growth since last decade in particular. Its gross domestic product (GDP) increased from 240 billion US$ in 2001 to 734.3 billion US$ in 2010 [3]. The average annual increase was about 7% in the last decade except in 2001 and 2009-years when there was an economic crisis.

The relationship between economic growth and energy consumption has been studied by several researchers. Lai et al. [4] overviewed some of the studies investigating the causal relationship between electricity consumption and economic growth. He concluded that–especially basing on Ferguson et al.'s [5] study results about electricity use and economic development over 100 countries – there is strong correlation between economic growth and electricity consumption especially for Latin American, Asian and OECD countries those were defined as wealthy countries.

This link presupposes the adequacy of electricity supply to sustain future high rates of economic growth [6]. Global electricity output grew by 56% between 1990 and 2008 [7]. As one of the best

Abbreviations: BAU, Business As Usual; C, carbon; DPT, State Planning Organization; EU, European Union; EUAS, Electricity generation company of Turkey; GDP, gross domestic product; GHG, greenhouse gas; GNP, gross national product; GW, gigawatt; GWh, gigawatt-hour; IPCC, Intergovernmental Panel on Climate Change; LEAP, Long-range Energy Alternatives Planning system; MoEF, Ministry of Environment and Forestry; MoEU, Ministry of Environment and Urbanization; MW, megawatt; MWh, megawatt-hour; SEI–B, Stockholm Environment Institute, Boston; TEDAS, Electricity Distribution Company of Turkey; TEIAS, Electricity Transmission Company of Turkey; TJ, terajoule; TURKSTAT, Turkish Statistical Institute, TUİK in Turkish.

* Corresponding author. Tel.: +90 542 722 48 39, +90 533 490 22 90; fax: +90 212 276 33 67.
E-mail address: betlozer@hotmail.com (B. Özer).

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representative countries to reflect these characteristics, Turkey ranks among the fastest growing energy markets in the world. The country is the 17th largest economy in the world, and total electricity demand in 2010 was 211 TWh. Turkey is among the world's leading producers of textiles, motor vehicles, ships and construction materials, consumer electronics and home appliances. The country has large lignite reserves and renewable resources and relatively little oil and natural gas production. Hence it is an importer of both oil and natural gas. The electricity sector in Turkey is heavily dependent on fossil fuels. As a result of this, the rate of fossil fuel use in power sector is likely to continue increasing depending on growth in energy demand. Due to the energy intensive industries that support its manufacturing and economic development, CO_2 emissions are on the rise in Turkey, – this is a key consideration in Turkish energy policies.

As a potential candidate country for EU accession, Turkey is under a pressure to reduce its CO_2 emissions. Thus Turkey should focus on building up its capacity for mitigation of greenhouse gas (GHG) emissions and adaptation to climate change. This raises a series of crucial questions: e.g. how large is Turkey's CO_2 emission reduction potential? What will be the possible mitigation options? This study would try to give answers to these questions. One of the common approaches in the world for mitigation of GHGs is the sector-based emission mitigation policy. Accordingly, Turkey has a national policy on increasing share of renewable energy sources in the electricity generation.

The goal of this paper is to evaluate the future CO_2 emission reduction potential of Turkey's electricity sector, which is the priority sector for taking action for CO_2 mitigation. For this purpose, initially the total electricity demand was estimated depending on the six sectors: residential, industrial, transport, commercial, agricultural, and services. Estimation was based on the population, GDP and the proportion of each demand sector in total consumption with the annual growth rates. Correspondingly electricity generation scenarios were built. In this paper, two scenarios based on Long-range Energy Alternatives Planning system (LEAP) model which is a bottom-up approach were employed to simulate the current energy situation and to develop forecasts under certain assumptions. The scenarios include Business As Usual (BAU) and Mitigation Scenario options. Time horizon of the study is 2006–2030, with 2006 as base year.

2. The structure of the electricity sector in Turkey

The rise in electricity demand exceeded economic growth in the last two decades. Electricity generation and consumption increased more than threefold since 1990, as shown in Fig. 1. The gross electricity demand of Turkey increased by 6.8% annually from 57,543 GWh (Gigawatt-hours) in 1990 to 211,208 GWh in 2010 [8]. The total installed capacity of the power industry is approximately 49.5 GW (Gigawatt) at the end of 2010, while it was 16.3 GW in 1990. The annual growth rate is about 5.8% [8]. Consumption of natural gas increased significantly from 1990 to 2010 while the share of natural gas in electricity generation increased from about 18% in 1990 to 46.5% in 2010. As seen in Fig. 1, there are downward trends for the gross electricity demand in the years 2001 and 2009 due to economic crisis in Turkey.

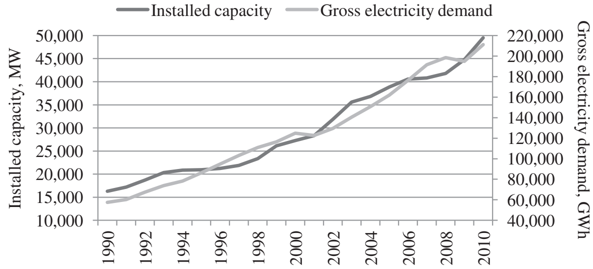

Fig. 1. The growth of the electricity sector in Turkey [8].

The distribution of electricity supply by market in Turkey is presented in Table 1. The electricity generation company of Turkey (EUAS, state-owned) accounts for about 40% of power generation as of 2011. However, EUAS has been the subject of privatization since 2009. As seen in Table 1, about 60% of the electricity supply is sourced from private companies. The major players in the private sector are Independent Power Producers (IPP) with 27.2% and Build-Operate (BO) with 19.7%. Build-Operate-Transfer (BOT) plants and autoproducers – owned and operated by big industries for their own consumption – together account for about 10.7%. Two percent of the total is the Transfer for Operating Rights (TOR) [9]. However, market fluctuations and some technical barriers have obstructed the widespread adoption of some promising resources.

2.1. Electricity generation by fuel

Although there are varieties of generation technologies installed in Turkey, such as thermal, hydroelectric, wind and geothermal, the power sector is heavily dependent on fossil fuels. Coal (lignite), being the most common type of fuel in Turkey, has remained the dominant primary energy source for decades. Using coal in unclean and inefficient ways has created most of the Turkey's energy related air pollution problems, specifically in the Southwestern and Central Eastern Anatolia regions. According to the latest EUAS Report [10], as of 2009 Turkey has recoverable reserves of 11.4 billion tons of lignite and 1.3 billion tons of hard coal. However, Turkey has relatively little oil and natural gas production: 42 million tons of crude oil and 7 billion cubic metres of natural gas [10]. Furthermore, there is a technically recoverable shale gas volume of 420 billion cubic metres [11]. Turkey has great potential for hydroelectric power and its estimated potential is about 37 GW. At the end of 2010, the total installed capacity of hydropower is 15.8 GW, or 32% of the total national power generation capacity, and generated electricity is 51.8 GWh. Currently, there are three large hydropower stations with capacities of 1 GW or above.

Turkey also has abundant renewable energy resources, most notably wind energy. Its economically viable potential is estimated at 48 GW [10]. Although the wind generation network is developing rapidly, the installed wind power capacity is only about 1500 MW (Megawatt), with a further 2500 MW commissioned. With 48 GW of economically viable potential it is the second largest energy source in the country next to thermal power. Electricity generation by fuel (%) is shown in Fig. 2. Main fossil fuels for electricity generation include lignite, imported coal and natural gas. Much of this production (about 73.8%) is based on thermal and combined cycle generation where natural gas alone accounts for 46.5% of the total electricity generation, followed by lignite and coal at about 26% and fuel oil at 1%, respectively in 2010. Whereas the

Table 1
Distribution of electricity supply by market as of 2011 [9].

Institution	Ratio (%)
EUAS (Government Company)	40.42
Independent Power Producers (IPP)	27.18
Build-Operate (BO)	19.67
Build-Operate-Transfer (BOT)	5.61
Autoproducers	5.13
Other (TOR)	2.00

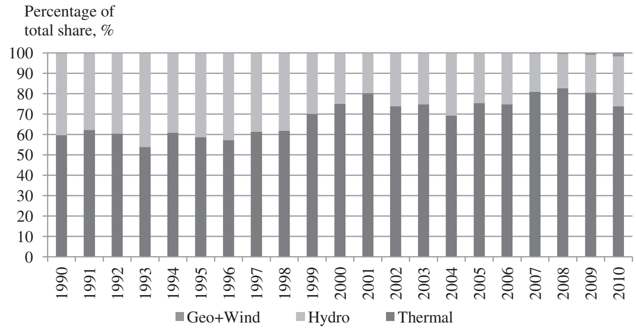

Fig. 2. Electricity generation by fuel type [8].

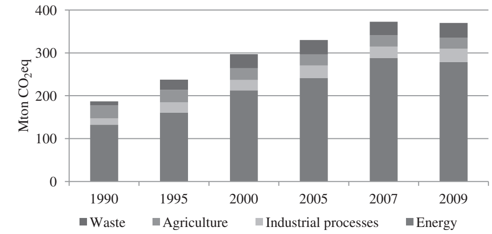

Fig. 4. GHG trend in Turkey for 1990–2009 [17].

contributions of hydro and geothermal (geo) + wind power for electricity generation are about 24.5% and 1.7%, respectively. The share of thermal power plants in electricity generation increased from 60% in 1990 to 74% in 2010, while hydro decreased from 40% in 1990 to 24.5% in 2010, and geo + wind increased from 0.14% in 1990 to 1.7% in 2010 [8].

The distribution (%) of energy sources in installed capacity of Turkey for 1990–2010 is shown in Fig. 3. As seen in Fig. 3, the share of thermal power plants in the total installed capacity has increased from 58.4% in 1990 to 65.2% in 2010, while hydro has decreased from 41.5% in 1990 to 32% in 2010 and geo + wind has increased from 0.1% to 2.9% in 1990–2010, respectively.

2.2. CO_2 emissions

There is a strong initiative across the world, particularly in the EU, to reduce the CO_2 emissions by changing the policies since the 1990s [12–15]. These policies are based on reducing the carbon intensity associated with electricity by increasing the energy efficiency and replacing fossil fuels with renewable energy sources [15]. As an example, in EU-27, total electricity output has increased at an annual rate of 1.7% over the last decade, while CO_2 emissions have remained relatively stable. The emission intensity has decreased from 0.39 to 0.35 tCO_2/MWh [7]. Turkey's CO_2 emissions are on the rise, and have approximately doubled since 1990 especially due to economic growth. GHG emissions in Turkey are approximately 370 million tons (Mt) in 2009. Turkey is ranked as the 24th largest emitter of GHGs in the world, with an average per capita CO_2 emission of 3.57 tons [16] – lower than the OECD average of 9.83 tons. Fig. 4 shows the GHG emissions trend in Turkey between 1990 and 2009 [17]. The energy sector has the largest share in total emissions with about 75%, followed by waste and industrial processes at 9% and agriculture at 7% in 2009. The electricity generation sector, in particular, has share in total CO_2 emissions of more than 30%. Therefore, it is considered the primary sector which must identify its mitigation potential and take action for mitigating GHG emissions while continuing to supply the increasing electricity demand. The share of fossil fuels in electricity generation is likely to continue to increase due to the growth in energy demand as explained above. This indicates that energy policies, energy supply and consumption all have major effects on GHG emissions.

Turkey's current obligations include submitting regular reports, national communication and making GHG inventories, implementing policies for climate change mitigation and adaptation, systematic research, education, training and public awareness.

3. Review of electricity demand projections in the literature

According to the results of the large number of studies in the literature about electricity consumption forecasting and modelling, variables affecting demand and energy consumption may vary from one region to another. A model developed for one region may not be appropriate for another region. Electrical demand and energy models are required for a variety of utility activities. Therefore, models should be developed for different regions of efficient planning and organization [18]. Some of the studies about the conduction of the factors those may affect electricity consumption are reviewed below.

Egelioglu et al. [18] investigated the influence of economic variables on the annual electricity consumption in Northern Cyprus and they found that a model using number of customers, number of tourists and electricity prices has a strong predictive ability. Bianco et al. [19] has a study on Italian electricity consumption forecasting using linear regression models that has the results of Italian GDP is closely linked to the electricity consumption. Furthermore, Acaravcı and Ozturk [20] examined the causal relationship between carbon dioxide emissions, energy consumption, and economic growth by using autoregressive distributed lag bounds testing approach of cointegration for nineteen European countries. The results varied from country to country. They found different unidirectional and bidirectional causal relationship between energy consumption per capita, real GDP per capita, square of per capita real GDP and energy consumption. Besides some of the studies for Turkish electricity demand projections can be summarised as below.

Ozturk et al. [21] used the genetic algorithm approach to investigate the relationship between total electricity consumption, gross national product (GNP), population, imports and exports for the period 1980–2001 in Turkey with annual data. Total electricity demand of Turkey was estimated as 220 TWh and 300 TWh in 2020 with exponential and quadratic forms of the genetic algorithm electricity demand models respectively. However, Ozturk and Ceylan [22] concluded that aggregate electricity demand for Turkey would be between about 462 TWh and 500 TWh in 2020 for the low and high growth scenario respectively as the results of genetic algorithm electricity demand (GAED) quadratic model. Besides Hamzaçebi [23] used the artificial neural network model with

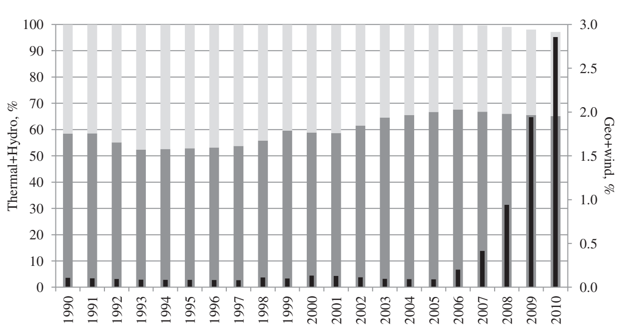

Fig. 3. Distribution of energy sources in Turkish installed capacity [8].

annual data for the period 1970 and 2004 to analyse sectoral electricity consumption in order to forecast sectoral and aggregate electricity demand. The result indicated that aggregate electricity demand would be just below 500 TWh in 2020. Nevertheless, Toksarı [24] used ant colony optimisation approach for estimating Turkey's net electricity generation and demand basing on economic indicators by using linear and quadratic forms of equations. GDP, population, import and export data were used. Electricity generation and demand estimations were thought to be separate and varied according to the forms of the equations. Consequently the electricity demand estimates varied from 125 TWh to 2500 TWh in 2025 for three scenarios. Moreover, Kavaklioglu et al. [25] used artificial neural networks for predicting electricity consumption of Turkey. Electricity consumption was modelled as a function of economic indicators such as population, GNP, imports and exports. Turkey's electricity consumption was predicted to reach 279 TWh by the year 2027. Dilaver and Hunt [26] have predicted Turkish aggregate electricity demand to be somewhere between 259 TWh and 368 TWh in 2020. This forecast study depends on GDP, electricity price and Underlying Energy Demand Trend (UEDT).

All the results from different studies in the literature mentioned above indicate that electricity demand projections differ from each other with varying methodologies based on the different assumptions of the variables. In this study electricity demand forecast is mainly based on the historical consumption, GDP, value added per activity sector, the energy intensity of the different sectors with sectoral growth rates and the ratio of each sector in total electricity demand. Turkish electricity demand increased by an average of 7.3% per year from 47 TWh to 143 TWh during the period 1990–2006. GDP increased on average by about 4% per annum over the same period. Electricity demand per capita is calculated as 5.3 MWh in 2024 which is about the average value of EU-27 as 5.7 MWh for 2008 [27]. Annual average total electricity demand growth rate is 6.8% (from 2006 to 2030) which is also convenient with 20 years (1990–2006) average growth rate of 7.3%.

The results indicate that Turkish net electricity demand will be 341 TWh in 2020 which is in the range of the results of Dilaver and Hunt's [26] study as they also took into consideration of GDP and UEDT as similiar criteria with this study. On the other hand, one of the main reasons that the results of this study are also different than the other previous studies is, in this study sectoral demand growth rates and the ratios' of each sector in total demand is taken into consideration addition to GDP, value added per sector and population. According to the authors' knowledge this is the first study on Turkish total electricity demand projections untill 2030 which takes into consideration of the sectoral demand trends.

4. Methodology

4.1. LEAP model

The study uses an accounting and scenario-based modelling platform called Long-range Energy Alternatives Planning system (LEAP) to assess the CO_2 emission mitigation potential of Turkey's electricity sector. Two scenarios based on the composition and structure of electricity and fuel use have been generated in the model. LEAP is an energy-environment modelling tool developed at Stockholm Environment Institute, Boston (SEI–B) to assess the effects – physical, economic, and environmental – of alternative energy programmes, technologies and other energy initiatives [28]. LEAP includes the technology and environmental databases. The modelling tool provides extensive information describing the technical characteristics, costs and environmental impacts of a wide range of energy technologies including existing technologies, current best practices and next generation devices [15].

The central concept of LEAP is user-driven scenario analysis. LEAP contains a full energy system accounting framework, which enables consideration of both demand and supply-side technologies and accounts for total system impacts. LEAP can describe how energy is consumed, converted, and produced under a range of alternative assumptions on population, economic development, technology, and price [29]. The methodology of the model is based on bottom-up electricity generation simulation approach, including production ability with capacity factors of different fuelled power plants, energy intensity of the plants and emission intensity of the fuels. According to different scenario results from the model, CO_2 mitigation potential in any target year or period can be acquired. The structure of LEAP used in this study is presented in Fig. 5.

LEAP procedure in this study consists of four major steps: Electricity production according to the demand projection, energy demand, CO_2 emissions and emission mitigation potential.

4.2. LEAP dataset

4.2.1. Electricity demand projections

In this study, the major socioeconomic indicators of the scenarios are GDP, population growth and electricity demand [30]. The inputs require for the demand analysis include the level of

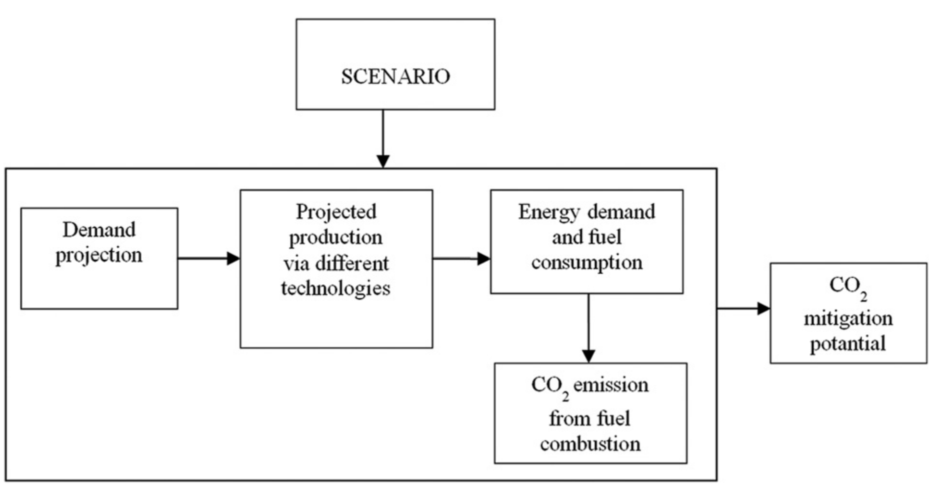

Fig. 5. The structure of LEAP used in this study.

activities and final energy intensity for each demand sector. Turkey's electricity demand projections are obtained from GDP and population growth projections by State Planning Organization (DPT in Turkish, by Private Communication) and Turkish Statistical Institution (TURKSTAT), respectively. The GDP values used in the model are based on 1998 prices. The populations are projected up to 2025 by TURKSTAT [31]. Additional five-year data are obtained by trend analysis, and growth rates for 2024 and 2025 years are assumed constant until 2030.

The breakdown of electricity demand by sector from 1990 to 2009 is used [32] as a point of reference to determine the shares of sectors based on socioeconomic structure and path of development in predicting net electricity in Turkey for the study. The projected electricity demand distributions by sectors are given in Table 2 [30]. In this table, electricity demand distribution from 2011 to 2030 consists of residential, industry, transport, commercial, agriculture and services sectors.

Fig. 6 shows the final electricity demand by sector of Turkey for 2009 [32]. As shown with Fig. 6 Turkey's energy end-use is dominated by the industrial sector, which takes up about 45% of total end-use electricity consumption while it was 62.4% in 1990 and has an average annual growth rate of about 5%. The residential sector accounts for about 25%, the commercial and services sectors follow by a cumulative 27% in 2009.

In the period between 2010 and 2030, an average 41.8% of the electricity is consumed for industrial production followed by households and commercial firms with 27.1% and 14.6%, respectively (Table 2). These figures are supported by IEA [7] and EU-27 [27]. According to IEA [7], industry is the largest consumer of electricity, with about 42% of the total final consumption in the world in 2008, against 45% in 1990. However, some EU countries have different profiles for industry: the average values between 2005 and 2008 are 45% for Germany, 39.8% for Spain and 32% for France [27].

In the residential sector, the share of electricity consumption in Turkey is 25% in 2009, while 19.4% in 1990, with an average annual growth rate of 8% [32]. In the period between 2023 and 2030, the residential sector is estimated to account for approximately 28% of the electricity consumption. This is slightly lower than in EU-27 (average of 2005–2008 is 28.6%) [27]. The projected shares of the services and commercial sectors are also growing while transport and agriculture sectors are assumed as remaining stable.

Table 2
Turkey's electricity demand distribution projections by sector, % (2010–2030) [30].

Years	Residential	Industry	Transport	Commercial	Agriculture	Services
2010	24.3	47.0	0.5	14.0	3.3	10.9
2011	24.6	46.5	0.5	14.1	3.3	11.0
2012	24.9	46.1	0.5	14.2	3.2	11.1
2013	25.2	45.6	0.5	14.3	3.2	11.2
2014	25.5	45.1	0.5	14.3	3.2	11.4
2015	25.9	44.4	0.5	14.5	3.1	11.6
2016	26.2	43.8	0.5	14.6	3.1	11.8
2017	26.6	43.1	0.5	14.7	3.1	12.0
2018	26.9	42.5	0.5	14.9	3.1	12.1
2019	27.3	41.8	0.5	15.0	3.0	12.4
2020	27.6	41.2	0.5	15.1	3.0	12.6
2021	27.9	40.6	0.5	15.1	3.0	12.9
2022	28.1	40.1	0.5	15.1	3.0	13.1
2023	28.4	39.6	0.5	15.1	3.0	13.4
2024	28.5	39.1	0.5	15.2	3.0	13.7
2025	28.6	38.5	0.5	15.3	3.1	14.0
2026	28.6	38.4	0.5	15.2	3.1	14.3
2027	28.5	38.2	0.5	15.2	3.1	14.6
2028	28.2	38.4	0.5	15.2	3.0	14.7
2029	28.2	38.3	0.5	15.2	3.0	14.9
2030	28.2	38.1	0.5	15.2	3.0	15.0
Average	27.1	41.8	0.5	14.6	3.1	12.8

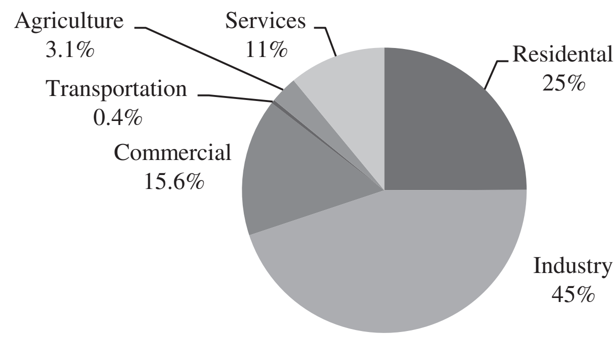

Fig. 6. Final electricity demand by sector for 2009 [32].

Based on these calculations, Turkey's net electricity demand projections for the time horizon of the study are presented in Fig. 7 with GDP and population projections [30]. According to the demand forecast calculation of the study, each demand sector's and total demand growth rate are different due to the different development paths of the sectors. Gross electricity demand was obtained by adding the internal consumption of the power plants, transmission and distribution losses of the system to the total net electricity demand. The annual gross demands have been calculated in this study and provided by Electricity Transmission Company of Turkey (TEIAS in Turkish) [33] were compared. TEIAS has estimates for low and high demand scenarios until 2019. As the time horizon of this study is 2011–2030, the demand values from 2019 to 2030 were calculated with the assumption that the growth rates in both TEIAS scenarios stay the same. The gross demand projections in each scenario are shown in Fig. 8. Calculated projections after 2019 for TEIAS scenarios are shown with broken lines in Fig. 8.

4.2.2. *Energy demand from electricity production*

Fig. 9 shows the distribution of electricity production by energy resources of Turkey in 2009 [8]. According to Fig. 9, thermal energy has the largest share with approximately 81% in electricity production. Natural gas and coal are the major resources. Other includes: fuel oil, diesel, LPG, naphtha, renewables + waste.

Annual gross electricity production is calculated by the model with Eq. (1).

$$P_{\text{year}} = \sum_{i}^{n} p_i \tag{1}$$

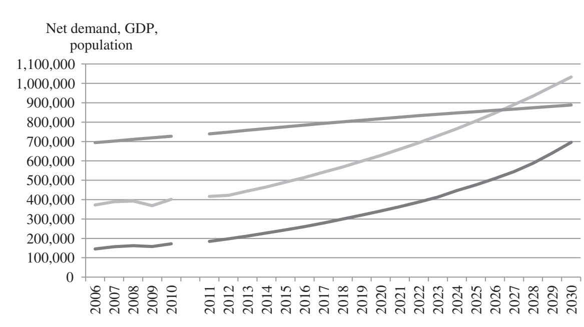

Fig. 7. The estimated values of the net electricity demand, GDP and population.

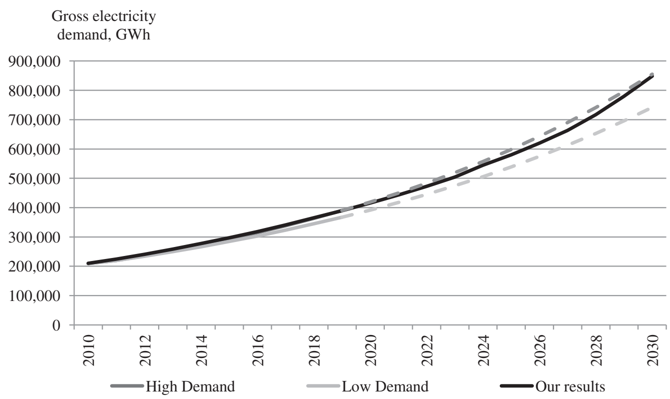

Fig. 8. Gross electricity demand projections of Turkey.

where, i is fuel type, n is number of fuels used for electricity production, p_i is gross electricity production from fuel i (MWh).

Primary energy demand for the gross electricity production is calculated by the model with the electricity production per unit energy consumption, which is thermal efficiency of each fuel type with Eq. (2).

$$(\mathrm{FC})_i = \sum_i (pi*0.0036)/\eta_i \tag{2}$$

where, FC is fuel consumption (Terajoule, TJ) of fuel i, η_i is the thermal efficiency (%) of i fuelled power plant, 0.0036 is for unit conversion as 1 MWh = 0.0036 TJ.

Different production compositions related with fuel types in scenarios result different energy demand.

4.2.3. CO_2 emissions from electricity production

Annual CO_2 emissions are calculated according to the carbon emission factors and oxidation ratios of each fuel type in the electricity generation with Eq. (3):

$$E = \sum_i^n (\mathrm{CEF})_i*(44/12)*(\mathrm{OR})_i*(\mathrm{FC})_i \tag{3}$$

where, CEF is carbon emission factor, ton C/TJ, OR, oxidation ratio of carbon in the fuel, 44 is molar weight of CO_2 (grams) and 12 is molar weight of C (grams).

CEF and oxidation ratios of each fuel type are input data to the model, those are supplied according to country-specific values [30]. For lignite, hard coal and import coal CEFs are 29.5, 30.6 and 24.3 tC/TJ respectively. The oxidation ratio of power plants fuelled by lignite and hard coal are 89% and 95% respectively [30]. For international fuels such as natural gas, fuel oil, diesel and naphtha IPCC [34] CO_2 emission factors were used.

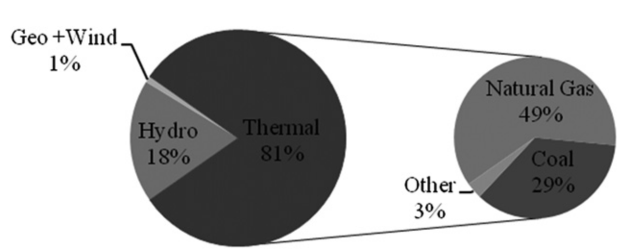

Fig. 9. Resource distribution of electricity production for 2009 [8].

The CO_2 emissions calculated by country-specific data are found to be 14% less (about 5 million tons of CO_2) than that of oxidation ratio of 98% as given with IPCC Guidelines [30,34].

The calibration of the model is done for year-2006 according to net and gross electricity demand values, thermal efficiencies of power plants where verification is done for years 2007–2009. The differences between the calculated CO_2 emissions and the model results for the years 2007–2009 are below 1%.

5. Scenario design

Scenario planning is a useful approach to design and plan long-term electricity infrastructures to cope with the uncertain future demand for power [35]. Due to the increasing economic growth and energy demand, the GHGs-mitigation potential of Turkey's electricity sector needs to be assessed by scenario assumptions. In this study, the two energy scenarios are based on BAU and Mitigation options. Each scenario represents a different development path that is possible in Turkey's electricity sector due to various policies. The LEAP model was applied to quantitatively analyse, evaluate and compare the two scenarios. A common net demand projection for future power generation is assumed to be the same among the scenarios, and gross electricity production is established for each scenario. The time span for this scenario analysis is from 2006 to 2030, with 2006 as the baseline year. BAU will not help Turkey in reducing its GHG emissions. Significant modifications are called for. As an example, thermal power generation accounts for over 70% of the total electricity generated. Environmental concerns associated with reliance on fossil fuels are also leading to a need to question the existing energy systems with respect to the environment. Hence, energy security, climate change policies and CO_2 mitigation and environmental concerns should be considered by energy planners and policymakers under the technical pathways. Scenarios in this study are based on previous policies and projected policy directions, and differ in their technical compositions of generating electricity. This could result in changes in energy demand and CO_2 emissions. By comparing these scenarios, the energy-saving and CO_2 abatement potential in Turkey's electricity sector can be acquired.

5.1. Business As Usual (BAU) scenario

The Business As Usual or The Reference Scenario represents the energy pathway that is implied if current energy policies, supply and demand trends in Turkey persist. This includes basically economic growth and energy conversion. Current trends in the Turkish economy and the power sector continue in the BAU Scenario. In this scenario, installed capacities are based on the High Demand Scenario data given in the TEIAS Report [33]. As the scenarios in this study extend beyond 2019 and the predicted installed capacities with maximum capacity factors are not sufficient to fulfil the projected electricity demand from 2018 onwards, capacity additions are made in order to maintain the current installed capacity composition through all scenario years. The average values of the internal consumption, transmission and distribution losses of the years 2006–2009, which are 4.2%, 2.4% and 12.2%, respectively are used for obtaining the gross electricity demand for the scenario years. According to these assumptions, CO_2 emissions by fuel type caused by electricity generation are given in Table 3. Electricity generation has an average growth rate of 6.8% from 2006 to 2030 [30], and the growth rate is 7% for CO_2 emissions.

The BAU Scenario represents the most conservative CO_2 emissions projection according to the current national and sectoral policies. The scenario reveals that if no controls were imposed in

Table 3
BAU Scenario CO_2 emissions by fuel type, thousand tons CO_2.

Years	Natural gas	Lignite	Import coal	Fuel oil	Hard coal	Diesel	Naphtha	Total	Growth rate, %
2006	35,193	34,024	8732	5378	2487	193	43	86,049	
2007	41,981	41,227	9476	6874	2851	159	36	102,604	19.2
2008	44,184	44,475	10,036	6640	2552	408	35	108,330	5.6
2009	43,532	39,949	10,671	4987	2517	562	26	102,243	−5.6
2010	42,890	39,309	10,429	5429	2339	214	11	100,621	−1.6
2011	43,049	47,759	15,860	6568	2339	139	11	115,725	15
2012	48,385	48,123	21,200	6568	2317	139	11	126,743	9.5
2013	51,161	51,946	24,144	4171	2339	139	11	133,910	5.7
2014	56,623	53,178	25,441	4171	3839	139	11	143,401	7.1
2015	59,049	55,103	26,442	4547	3924	139	11	149,215	4.1
2016	63,903	56,268	27,027	4716	4009	139	11	156,073	4.6
2017	67,099	60,547	27,027	5726	4299	139	12	164,850	5.6
2018	70,021	62,989	27,826	13,139	6568	158	114	180,815	9.7
2019	73,808	67,954	29,648	14,455	7007	189	127	193,189	6.8
2020	80,815	72,274	30,903	15,152	7240	210	133	206,728	7.0
2021	86,500	77,689	32,496	16,293	7625	242	140	220,985	6.9
2022	92,429	83,573	34,214	17,525	8037	279	152	236,210	6.9
2023	98,430	90,122	36,139	18,898	8503	321	165	252,578	6.9
2024	106,709	97,117	39,133	20,363	9166	347	177	273,012	8.1
2025	113,605	103,413	41,481	21,694	9757	368	191	290,509	6.4
2026	121,452	110,707	44,349	23,236	10,438	394	203	310,779	7
2027	129,973	118,297	47,438	24,806	11,200	394	216	332,323	7
2028	140,099	128,046	51,354	26,862	12,096	473	254	359,185	8.1
2029	152,426	139,283	55,865	29,206	13,171	495	254	390,700	8.8
2030	165,874	151,530	60,778	31,791	14,336	552	286	425,147	8.8
Annual mean growth rate, %									6.98

Turkey, CO_2 emissions in the electricity sector would likely be 206.5 million tons more for each year between 2006 and 2030, where the cumulative emissions would be 5.16 billion tons of CO_2.

5.2. Mitigation Scenario

The Mitigation Scenario includes the addition of renewable energy technologies (except solar) in the overall energy mix. It is established as an alternative to the predominantly thermal electricity production in the current composition and is based on the evaluation of the existing potential of renewable energy sources of Turkey. This scenario provides the CO_2 emissions under conditions that the installed power provides maximum benefit, there are no power plants operating under capacity and all potential renewable energy sources except solar are used. Nuclear energy is not included. Another assumption in the scenario is that internal consumption and distribution losses are reduced; i.e. overall internal consumption decreases from 4.2% in 2011 to 3.9% from 2016 to 2030. Furthermore, as transmission losses at 2.4% are within the global percentage range [33], it is assumed to remain constant throughout the time horizon. Distribution losses are based on Turkish National Climate Change Action Plan projections and decrease from 12.2% in 2011 to 8% from 2023 to 2030 [36]. In this scenario, it is taken into account that the installed power will not change from 2011 to 2014 and hence CO_2 emissions from natural gas and lignite fuelled power plants in particular are expected to rise due to the increasing capacity factors. Table 4 presents CO_2 emissions by fuel type for the Mitigation Scenario.

An important finding in Table 4 is that electricity-related CO_2 emissions grow by 5.8% annually between 2006 and 2030 while electricity output grows at an average 6.6% per annum in this period [30].

Fig. 10 shows the change in annual carbon dioxide emissions through the time horizon of the study for both scenarios. If a higher proportion of renewable energy becomes available from 2015 onwards, the increase of CO_2 emissions until 2023 is expected to be more gradual. With the assumptions of the Mitigation Scenario, the CO_2 emissions from the electricity sector are likely to increase by 170.4 million tons every year, where the cumulative emissions would be 4.26 billion tons of CO_2.

6. Results and assessment of the CO_2 emission reduction potential

The LEAP model is applied to BAU and Mitigation Scenarios in this study to assess the projections of the energy consumption and CO_2 emissions from the electricity sector of Turkey. The simulations are applied from the base year 2006 up to 2030. Turkey's electricity sector will develop rapidly until 2030, along with its booming economy and the high electricity demand from the industry and society. The basic parameters of analysis for the model, including future assumptions, are derived from DPT and TURKSTAT. Most of the data and several official and technical reports for Turkey are derived from EUAS and TEIAS.

This study results including the policy implications of the LEAP modelling for Turkey are as follows:

- In the first part of the study, electricity demand projections of Turkey are made for six sectors, namely residential, industrial, transport, commercial, agricultural and services, up to 2030. The electricity demand projections are based on the growth rates of the population and GDP. The growth rates and the shares of the six sectors in total demand are also considered.
- Based on the calculations, total net electricity demand increases from 184 TWh in 2011 to 696 TWh in 2030 with an annual mean growth rate of 7.3%.
- Country-specific carbon emission factors and oxidation ratios are used as input data of the model. For lignite, hard and import coal the carbon emission factors are found 29.5, 30.6 and 24.3 ton C/TJ respectively. The oxidation ratio of carbon in lignite fuelled power plants is 89% where it is 95% for hard coal power plants. IPCC [34] gives 27.6 and 25.8 ton C/TJ as emission factor of carbon for lignite and hard coal respectively and oxidation ratio of 98% for coal, which causes 14% more CO_2 emissions than the emissions are obtained from country-specific values [30].

Table 4
Mitigation Scenario CO_2 emissions by fuel type, thousand tons CO_2.

Years	Natural gas	Lignite	Import coal	Fuel oil	Hard coal	Diesel	Naphtha	Total	Growth rate, %
2006	35,193	34,024	8732	5378	2487	193	43	86,049	
2007	41,981	41,227	9476	6874	2851	159	36	102,604	19.2
2008	44,184	44,475	10,036	6640	2552	408	34	108,330	5.6
2009	43,532	39,949	10,671	4987	2517	562	26	102,242	−5.6
2010	42,890	39,309	10,429	5429	2339	214	11	100,621	−1.6
2011	44,908	47,759	10,381	5477	2317	158	11	111,011	10.3
2012	49,551	52,666	10,332	5477	2317	158	11	120,512	8.6
2013	54,962	57,033	10,332	5477	2317	158	11	130,290	8.1
2014	58,397	58,106	16,557	5651	2317	158	11	141,197	8.4
2015	57,710	57,710	16,557	10,505	3862	158	107	146,609	3.8
2016	58,397	58,533	16,557	9809	3862	158	107	147,423	0.6
2017	60,521	59,535	16,557	9889	3862	158	107	150,628	2.2
2018	62,398	60,869	16,557	12,632	3862	214	107	156,638	4
2019	62,400	62,000	16,557	12,632	6339	214	107	160,248	2.3
2020	62,576	62,490	18,554	12,632	6339	214	107	162,912	1.7
2021	65,164	65,075	19,972	12,632	9002	214	107	172,166	5.7
2022	64,552	66,445	21,969	12,463	10,511	214	107	176,261	2.4
2023	68,740	71,834	21,969	12,463	13,139	214	126	188,484	7
2024	72,828	78,413	21,969	12,632	14,515	214	126	200,696	6.5
2025	72,828	95,068	22,968	14,082	14,515	214	126	219,800	9.5
2026	72,828	116,250	24,871	14,082	14,322	214	126	242,692	10.4
2027	72,828	116,327	29,846	17,603	14,322	214	126	251,264	3.5
2028	77,737	126,726	29,927	17,603	14,322	214	126	266,654	6.1
2029	103,945	126,249	29,958	17,603	14,515	214	126	292,609	9.7
2030	132,414	126,317	29,958	17,603	14,515	214	126	321,146	9.8
Annual mean Growth rate, %									5.8

- BAU and Mitigation Scenarios are established and related CO_2 emissions for the scenarios are obtained according to the electricity demand and sectoral production data. Scenarios are different from each other with respect to their energy demand and technical compositions of generating electricity. The BAU Scenario is established first as a point of reference, and the Mitigation Scenario is developed due to the increasing share of renewable energy sources in electricity production. In both scenarios, electricity production and corresponding CO_2 emissions are increasing through the time horizon of the study as a result of the increasing electricity demand.
- In the BAU Scenario Electricity generation has an average growth rate of 6.8% from 2006 to 2030 and the growth rate is 7% for CO_2 emissions, where in the Mitigation Scenario, electricity-related CO_2 emissions have grown by 5.8% annually while electricity output has grown at an average 6.6% per annum in the same period [30]. This shows a significant contribution to GHG mitigation and climate change through policies.
- The Mitigation Scenario is characterized by its GHG control policies with an increased share of renewable energy sources in electricity generation and can achieve emission reductions of 44 Mt in 2020 and 104 Mt in 2030.
- The cumulative CO_2 emission reduction between BAU and Mitigation Scenarios from 2006 to 2030 is 903 million tons, which corresponds to approximately 36 million tons of abatement per year.

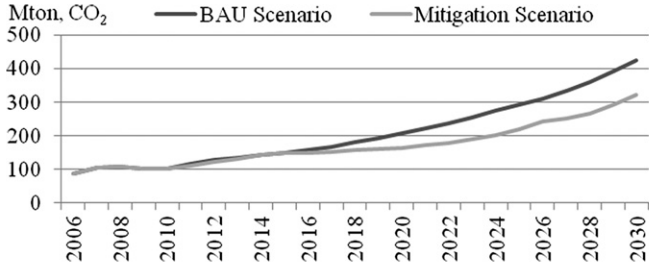

Fig. 10. CO_2 emissions trend for BAU and Mitigation Scenarios 2006–2030.

- In the Mitigation Scenario throughout the time horizon of the study 17.5% mitigation ratio is achieved, compared to the Reference Scenario, and the specific mitigation ratios are 21% in 2020 and 24.5% in 2030.
- CO_2 emission intensity decreases to 0.398 tCO_2/MWh for the Mitigation Scenario in 2030. This indicates an abatement of 18.4% compared to the 2006 baseline value of 0.488 tCO_2/MWh, and 20.6% compared to the Reference Scenario value in 2030. This figure is slightly above the CO_2 emission intensity in Europe, which is 0.35 tCO_2/MWh [7].
- Reducing the internal consumption in power plants and distribution losses will help to decrease gross electricity demand and corresponding CO_2 emissions.
- Throughout the study period, the mean shares of renewable energy sources are approximately 24% and 36% in total electricity production in the BAU and Mitigation Scenarios, respectively. This indicates that the increased share of renewable energy sources in electricity production contributes towards mitigating CO_2 emissions.

7. Conclusion

The results imply that electricity demand and associated CO_2 emissions in Turkey will rise in both scenarios due to the economic growth until 2030. CO_2 emissions under the BAU Scenario will rise significantly, while the increase under the Mitigation Scenario is slower. However, through structural adjustments in Turkey's electricity sector and the implementation of several technical measures, varying degrees of CO_2 abatement can be achieved. The level of abatement will be limited by the technical abatement potential and corresponding costs. As Turkey is a developing country the emissions continue to rise, thus the mitigation target for CO_2 emissions can be defined from BAU. This study presents comparative results for decision makers to develop national strategies for establishing a long-range policy for CO_2 emissions mitigation in the electricity sector of Turkey, which may then be discussed in climate change negotiations.

Costs of unit reduced-CO_2 and other scenarios with further mitigation potentials may be the subject of future work.

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