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Exploring the options for carbon dioxide mitigation in Turkish electric power industry: System dynamics approach

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HIGHLIGHTS

- An original computer model is created to investigate carbon mitigation.
- It is holistic and comprises investment, generation, dispatch, and resources.
- The model's structure, information base and foresights are specific to Turkey.
- Direct and indirect strategies are explored and integrated.
- Dramatic reductions are possible only with supply side strategies.

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ABSTRACT

Electric power industry has a huge carbon mitigation potential, fundamentally because there are large carbon-free, renewable resource options. In Turkey, with growing demand in electricity consumption and incentives offered for natural gas fired electricity generation, CO_2 emissions sourced from electric power industry had tripled over the last two decades. Current governmental strategy focuses on energy security and resource diversity in a growing economy and does not articulate sufficient mitigation targets and appropriate regulations. In this research, an original dynamic simulation model is built, validated and analyzed to explore the options for carbon mitigation in Turkish electric power industry. Model structure represents the investment, dispatch and pricing heuristics as well as the natural resource base of electricity generation in Turkey. It operates on annual basis over 30 years to simulate installed capacities and generations of power plants with alternative resources and their resulting CO_2 emissions. The analysis presented in this paper reveals that there are mitigation options below 50% of business as usual growth, with common policy options such as feed-in-tariffs, investment subsidies and carbon taxes. The model can serve as an experimental platform for further analysis of problems related to carbon mitigation in Turkish electricity sector.

1. Introduction

Carbon dioxide (CO_2) is the prominent greenhouse gas (GHG) that leads to global warming and climatic change with increasing concentrations above preindustrial levels. In the World average and in Turkey, electric power industry (EP industry) has the largest share in anthropogenic CO_2 emissions among other economic sectors. Because electricity can be produced by various means such as fossil fuel burning, nuclear fission and by harnessing of various carbon-free renewable energy resources (RES), there are strong options for carbon mitigation in EP industry, with different socio-environmental costs and benefits. Hence, considering its large resource alternatives, electric sector can respond to incentives aiming to reduce fossil fuel fired generation and can lead the way towards a low carbon economy (Ford, 2008a).

Turkey ratified UNFCCC in 2004 and Kyoto Protocol in 2009. However, arguing for its case for lower GDP, primary energy consumption and CO_2 emissions compared to those of OECD and other European countries on per capita basis (which are about four to five times higher on the average), it evaded being part of Kyoto's Annex B and did not declare quantified emission reduction targets (MEF, 2010). According to TURKSTAT (2011) Turkey's national vision within the scope of climate change is to "become a country which has integrated its climate change policies into the development policies, has let the energy efficiency become widespread, has increased the use of clean and renewable energy resources and, actively participates in the efforts for tackling climate change within the framework of its 'special circumstances'".

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Table 1
Turkey's key energy indicators compared to OECD and the World average (IEA, 2010a; TURKSTAT, 2011; MEUP, 2011).

Indicators	Turkey 1990	Turkey 2008	OECD 2008	World 2008	Turkey % change
Population (million capita)	56.20	71.08	1190	6688	26.48
GDP (2000 USD/capita)	2.47	5.29	25.63	6.05	113.92
Primary energy supply (TOE/capita)	0.94	1.39	4.56	1.83	47.87
Electricity consumption (KWh/capita)	1024	2400	8486	2782	134.38
Energy intensity of the economy (TOE/2000 USD)	0.37	0.26	0.18	0.3	−29.73
Carbon emissions (tCO_2/capita)	2.23	3.71	10.61	4.39	66.36
Carbon intensity of the economy (tCO_2/2000 USD)	0.97	0.70	0.41	0.73	−27.84
Carbon intensity of primary energy supply (tCO_2/2000 TOE)	2.4	2.8	2.33	2.40	16.67

Although not strictly quantified and supplemented with appropriate policy instruments, MEF (2010) presents perspectives for controlling GHG emissions sourced from Turkish EP industry. Incentives for hydro and wind as well as for clean coal and nuclear power generation; efficiency gains in existing coal and hydropower plants are among the short and medium term perspectives on the supply side. A target in the longer term, which will be investigated in this study, is to increase the share of RES in electricity production to 30%, to achieve 20.000 MW of installed capacity in wind, 600 MW in geothermal and to fully utilize the nation's approximately 37.000 MW hydropower potential by 2023.

Together with possible gains on the demand side, compared to business as usual growth by 2020, MEF (2010) targets a 7% reduction in CO_2 emissions. Another target is to reduce the primary energy intensity in overall economy by 10% by 2020 (MEUP, 2011).

Carbon intensity of Turkish economy and the carbon intensity of Turkey's energy supply are higher than those of OECD countries and close to world average. Between 1990 and 2008, Turkey's key indicators on material and energy consumption and CO_2 emissions had doubled, and the carbon intensity of its energy supply increased. This has been due to a shift in electricity sector towards coal and gas based generation. Table 1 summarizes Turkey's key indicators of material consumption, energy supply and CO_2 emissions all in per capita basis, compared to OECD and World data and in historical perspective. The figures in the table are based on IEA (2010a) and TURKSTAT (2011) and the table is adopted from MEUP (2011).

The major source of CO_2 emissions in Turkey is fuel combustion in energy sector in general, and within the energy sector, electricity production in particular. Between 1990 and 2009, national CO_2 emissions from all economic sectors increased by 110% while the CO_2 emissions increase in the energy industries has been 114% (TURKSTAT, 2011). With this relative difference in growth rates, energy industries increased their share in CO_2 emissions from 32% to 35%.[1]

Fig. 1 depicts the annual development in EP installed capacity (TETC, 2011) and generation (TETC, 2010) with respect to primary energy resources used and also the resulting CO_2 emissions calculated by EC (2010). Data show that the three variables have been increasing over the last 20 years. This is due to EP industry's response to growing population and per capita electricity demand in Turkey.[2] Fig. 1 also illustrates that, coal, lignite, natural gas and hydropower (fossil fuel and hydro) constitute the major primary energy resources in electricity generation. Another fact is the increasing share of natural gas fired generation particularly after mid 1990s and corresponding decrease in the share of hydropower. Electric generation based on wind, geothermal and biomass is at negligible level. Photovoltaic and nuclear do not exist, though they are involved in the state plans. In 2010, about 65% of Turkey's installed base is fossil fuel powered and about 75% of its electricity is generated by fossil fuel burning. Ari and Koksal (2011) observe similar developments. Moreover, it can be argued that Turkey's case is similar to Latin American, where privatization in power generation without regulations and incentives for RES had lead to an increase in the share of gas based generation and to underutilisation of the continent's RES potentials (Arango and Larsen, 2010).

1.1. Sector structure in Turkey

Until 1980s, all segments of the electricity sector in Turkey were under state monopoly. In 1984, Law no. 3096 enacted private participation in generation with Build-Operate-Transfer (BOT) and Transfer of Operating Rights (TOOR) contracts. In 1993, by Law no. 4283, Turkish Electricity Institution (TEK), the state company integrating generation, transmission, sales and distribution functions of the electricity sector was divided into two companies, TEAS (Turkish Electricity Generation and Transmission Company) and TEDAS (Turkish Electricity Distribution Company). In 1997, Law no. 4283 enacted private sector participation in generation through Build–Operate–Own (BOO) contracts. The Electricity Market Law (no. 4628) in 2001 has been the critical step towards liberalization which radically changed the structuring of the sector. It aimed "financially strong, stable, transparent and competitive electricity market". With Law no. 4628, the Energy Market Regulatory Authority (EMRA) was established as an independent regulatory public organization. The same law further unbundled TEAS into three state owned companies: TEUAS (Turkish Electricity Generation Company), TEIAS (Turkish Electricity Transmission Company) and TETAS (Turkish Electricity Trading Company) which is responsible for the electricity wholesale from generators to distributers. Private participation is allowed in distribution as well as in generation but not in transmission.

Now, TEUAS owns about 49% of the national generation capacity, produces about 45% of the nation's electricity and this share is in decline with new privatization contracts (MENR, 2011). The distribution activity under TEDAS is fully privatized. Cetin and Oğuz (2007) discusses reasons why in spite of the Law no. 4628, the industry moves towards a more centralized structure and why the

[1] According to TURKSTAT (2011), energy industries comprise electricity generation and the use of fossil fuels for petroleum refining. CO_2 emissions from petroleum refining constitute 2.23% of the energy industries' emissions. In the year 2009, Turkey's CO_2 emissions from electricity generation (namely, from burning of lignite, natural gas, hard coal, residual fuel oil and diesel oil) is 96.27 Gt CO_2, that is 35% of overall national CO_2 emissions.

[2] TETC (2010) reveals that the electricity import and export of the country is less than 1% and 2% of the domestic generation respectively, indicating that the

(*footnote continued*)
observed growth in installed base and generation are responses to the increasing domestic EP demand.