# *ANALYSIS OF THE TURKISH ENERGY SECTOR WITH THE BUEMS ENERGY MODELING FRAMEWORK*[1]

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## Overview

In today's dynamically changing and energy-sensitive environment, it is essential to build comprehensive energy models and analyze system dynamics under alternative scenarios. Reducing $CO_2$ emissions, developing alternative energy sources, increasing energy efficiency, decreasing import dependence while striving to maintain stable energy prices at reasonable levels are among the primary energy policy goals. From this perspective, in this study, a national energy planning model for Turkey is developed through the Boğaziçi University Energy Modeling System (BUEMS) framework.

Turkey's total primary energy supply (TPES) was 129.3 Mtoe in 2015. Since 2010, TPES has grown on average by 3.4% per year. Fossil fuels accounted for 79.2% of TPES in 2015, with a breakdown of 26.8% coal, 30.7% natural gas, and 21.7% oil. The country depends heavily on imports for its TPES including practically all her oil and natural gas needs, and most of her coal needs. In addition, just from 2010 to 2015, electricity consumption increased by 26.3%, growing at an average of 4.8% per year. Natural gas-fired power generation has the largest share of total electricity production, accounting for 37.9% in 2015. Coal is the second largest energy resource with 29.1% share, while hydropower and other sources provide 25.7% and 7.3% respectively of electricity generation. These consumption patterns and growth behaviors lead to environmental and supply security concerns and bringabout the need for alternative technology and supply options. Therefore, it is very important to analyze the alternative ways of satisfying energy demand in Turkey (especially regarding possible environmental limitations). From this point of view, this paper describes a study aimed at doing that, while attempting to shed some light on realizable levels and associated costs of greenhouse gas emission reductions, based on the newly developed BUEMS modeling framework of Turkey's energy system.

## Methods

The BUEMS framework is designed as a new bottom-up, large-scale energy-modeling framework focusing on the mechanisms and relationships that mimic the energy sector as a whole. It is a straightforward, flexible, general purpose, linear optimization modeling system. All the complex relationships of producing, transforming, transmitting and/or supplying energy sources according to the demand requirements are represented with a deep technological detail. The objective is the minimization of the total energy system cost (which includes supply costs of energy sources, capital, operational and maintenance costs of technologies, various environmental costs, and any additional possible system costs) of an economy. The framework is run on a multi-period horizon, while requiring partial equilibrium of the energy market. The levels and prices of the various energy sources are in equilibrium in each period. The equilibrium also guarantees that the net total cost of supplying all levels of energy services are minimized, while satisfying a number of constraints, such as, system constraints (which are standard for any model application) regarding energy sources, demands, capacities, activities, electricity generations, emissions and other optional constraints such as user imposed policy constraints, including emissions restrictions, bounds on activities, capacities, and energy source supply levels.

In this study, a BUEMS framework of the Turkish Energy Sector has been developed and calibrated by compiling detailed technical, sectoral, resource based parameters, and demand data. Model validation is accomplished in three steps using the well-known TIMES (The Integrated Markal Efom System) modeling framework. At the first step, results obtained from a similar TIMES model of the Turkish Energy System are compared with the related actual data announced by the official organizations for the base year. The

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second phase is the consistency check of the TIMES model results for the other years with goals, forecasts, and resource potentials announced by official organizations. The third step is the consistency check of the BUEMS model results for the base year with the data announced by the official organizations. Additionally, the BUEMS model results are also compared with TIMES model results for years up to the end of the planning horizon for consistency.

The planning horizon is set in 5-year time intervals extending from 2017 to 2052. Besides the Business-As-Usual BAU scenario, the model has been run under various emission bound and emission tax scenarios, yielding sectoral marginal abatement cost curves for $CO_2$ emissions in Turkey. A supply shock analysis is performed as well.

## Results

Figure 1 includes the BAU primary energy consumption values for both models, TIMES and BUEMS. Deviations vary from 1.02% to 9.25% with the average variation for the whole planning horizon being 4.53%. In general, deviations of model variables are below 10%, indicating that the results obtained by the BUEMS model are quite reliable.

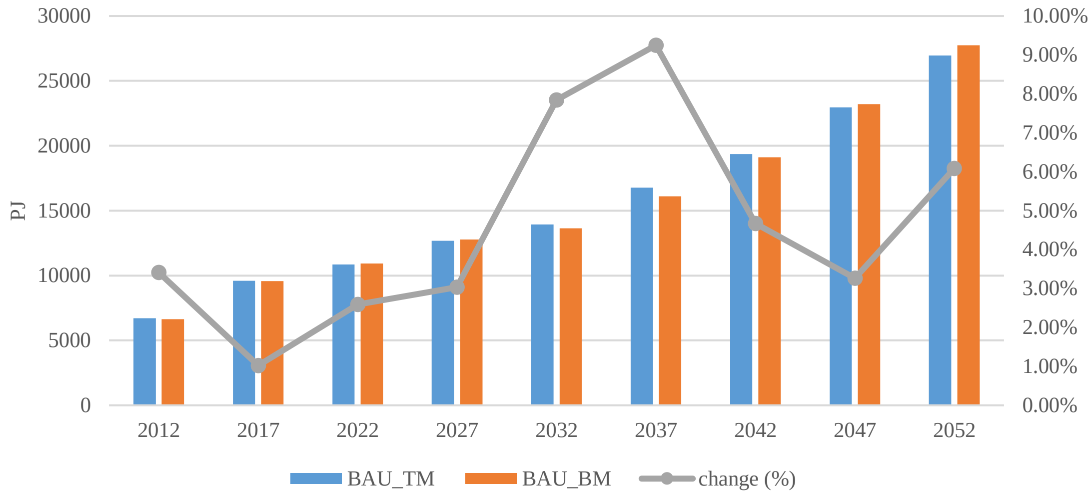


Figure1. Comparison of BAU scenario fuel consumption values.

Model results reveal that a carbon tax is quite effective in reducing CO2 emissions that belong to the electricity sector, thereby facilitating very large reductions in the use of coal. According to the BAU scenario results, the amount of hard coal and lignite used to generate electricity are 347,4 PJ and 409,3 PJ respectively in 2032,. Whereas, under the implementation of a $50 tax per ton of CO2, these values decrease to 253,6 PJ and 280,9 PJ. As a result, the percentages of coal and lignite in power sector diminish and to about 16,8% and 28% respectively. Sectoral implications are various. In the transport sector, the energy consumptions for LPG and diesel fuel decrease, while vehicle technologies based on electricity and hydrogen are used when the $50 emission tax is imposed. Scenario results reveal that the sector with the highest contribution to emission mitigation in the case of a carbon tax is the electricity sector. Industry sector is one of the prominent sectors that contribute the most to the emission reduction in these scenarios. By the time all other sectors start to react with the help of increased carbon taxes, a gradual decrease in the contribution of the industry sector to greenhous gas emissions is observed.

## Conclusions

This study presents BUEMS as a new, reliable modeling framework with a full-scale application on the Turkish energy sector and illustrates how energy demand is supplied and consumed, and how emissions and system costs change under alternative emission scenarios. The findings suggest various useful policy implications for an environmentally and economically sustainable development of the country and provide long-term prospects for effective and applicable energy policy solutions to foster investment into new technologies.