AN ASSESSMENT OF TURKISH ENERGY SECTOR DEVELOPMENT UNDER THE PARIS AGREEMENT GOALS USING A CGE MODEL WITH DETAILED REPRESENTATION OF POWER SECTOR

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Heavy reliance on imported energy and fossil-intensive energy generation are substantial challenges that contribute to the economic problems that Turkey currently faces. Most of the researchers who assess the economic impacts of energy and environmental policies in Turkey use a general equilibrium approach. All of the models developed for this purpose thus far including assessing the targets that Turkey has submitted for the Paris Agreement employ an aggregated power sector representation, which does not capture the technological details. Given the importance of power sector to a successful climate policy, we develop an integrated computable general equilibrium (CGE) model of Turkish economy (TR-EDGE: Electricity Detailed General Equilibrium Model for Turkish Economy) that combines macroeconomic representation of the non-electric sectors and detailed representation of the electric sector where disaggregation of Turkish power sector in a CGE framework is the first attempt in the literature. Based on this model we assess the compliance cost of Turkish commitments under several scenarios. First, a reference scenario (BAU) that reflects current government plans including two nuclear power plants to be commissioned until 2030 is defined and calibrated in accordance with medium-term expectations. This scenario also includes the subsidy scheme for renewables which was revised after 2010. Then, we define another scenario in which no nuclear power technology is allowed (NoN) during the panning horizon 2011-2030. Finally, a market-based abatement scenario that comprises the analysis of a national emission trading scheme (TrEm) is proposed. Economic and energy related indicators are investigated for the settings where BAU and NoN are coupled with TrEm. Model results indicate that the price per ton of CO_2 equivalent GHG emission in order to attain a 21% reduction in total GHG emissions (by year 2030 as pledged in the Turkish submission to the Paris Agreement) compared to BAU level is $51.46 under BAU+TrEm in 2030, while the corresponding price under NoN+TrEm is $67.90 in 2030. Besides this, coal-fired power generation vanishes by 2030 when the TrEm policy is applied regardless of nuclear assumptions. Another important result of TR-EDGE is that the penetration of wind and solar would not be as much as targeted even if high subsidy rates are modelled as they are specified in the current regulations.

1. INTRODUCTION

For several decades, Turkey acknowledged the importance of preventing dangerous anthropogenic interference with climate system and in 1992 the country joined the United Nations Framework Convention on Climate Change (UNFCCC). As a member of the Organization for Economic Co-operation and Development (OECD), Turkey was listed under Annex I (that includes the developed countries and economies in transition) and Annex II (that includes the OECD countries from Annex I) to the Convention. The Annex II Parties were required to provide financial and technical support to the economies in transition and developing countries to assist them in reducing their greenhouse gas (GHG) emissions and manage the impacts of climate change (UNFCCC 2017). Turkey made several attempts to be removed from these two annexes with the main argument of having special circumstances such as lower per capita emissions compared to the EU-27 and OECD averages (Turhan, Mazlum, and Şahin 2016). During this period, Turkey participated in the Kyoto Protocol negotiations held in 1997 with an "observer" status. It was 2001 (UNFCCC's 7th Conference of the Parties, COP7 in Marrakesh) when Turkey was removed from Annex II and parties to the convention were invited to recognize the special circumstances of Turkey. Although this invitation and "special circumstances" were not clarified until COP16 which was held in Cancún in 2010; Turkey took several steps to be integrated to global climate efforts between 2004 and 2010 which was partly triggered by the efforts for harmonization with the EU norms and standards: Turkey ratified UNFCCC in 2004, Greenhouse Gas Emissions Inventory of Turkey was first published in 2006, first National Communication on Climate Change was prepared in 2007 and Kyoto Protocol was ratified in 2009 (without any emission reduction obligations because of its observer status in preparation of the protocol). Finally, decision 1/CP.16 in 2010 recognized the special circumstances of Turkey and placed Turkey in a different situation than the other Parties included in Annex I. However, Turkey did not join the Kyoto Protocol's second commitment period either.

After 2012, a significant change has been observed in Turkey's attitude towards global efforts for climate change. Declaration of intend to become a party to the new agreement with a flexible target at COP19 in 2013 and at United Nations Climate Change Leaders' Summit in New York in 2014 were remarkable signs of this change. Finally, Turkey prepared and submitted its INDC (UNFCCC 2016) in September 2016 after COP21 which was organized in Paris in 2015. Major measurable highlights in Turkey's INDC, which sets targets for year 2030, are summarized below:

- Up to 21% reduction in GHG emissions compared to the BAU scenario of the government. This decrease corresponds to have a CO_2 equivalent (CO_2e) emission[1] level of 929 Mtons in 2030.
- Installed capacity of 10 GW solar power and 16 GW wind power.
- Full utilization of hydro plants which sums up to 36 GW.

[1] Expressing the emissions in terms of CO_2 equivalent emissions (CO_2e) has been a consensus standard in reporting GHG emissions. In order to convert the GHGs into CO_2e, a measure called Global Warming Potential (GWP) is introduced to the literature. For example, GWP values, which are determined based on radiating force and atmosphere life of the gases, are 1, 21 and 298 for CO_2, CH_4 and N_2O, respectively (IPCC 2017).

Specifically, a 21% reduction in GHG emissions relative to the Turkish Ministry's BAU results in an emission level twice as the 2013 level. Besides, this target indicates a 40% increase in average emission growth rate in 2010-2030 compared to average of 1990-2010 period (TUSIAD 2016).

Among many computable general equilibrium (CGE) models developed for assessing the impacts of various policy applications on Turkish economy, only a few of them focused on environmental policies (Kumbaroğlu 2003; Telli, Voyvoda, and Yeldan 2008; Yeldan and Voyvoda 2015; Akın Olçum and Yeldan 2013). All these studies employ an aggregated power sector representation, thus do not fully capture the technological details and accurately represent the abatement potential from the sector. Kat (2011), on the other hand, constructed a hybrid optimization model that combines a detailed representation of the power sector with five non-electricity sectors of the Turkish economy. Although this model is flexible and successful in representing detailed characteristics of energy sector; it needs improvement in representing microeconomic foundations compared to the established CGE models. For Turkey to achieve its INDC, it will need to rely heavily on abatement from the power sector, thus having a model that better characterizes the power sector in a CGE framework will provide internally-consistent insights. The goal of this study is to fill this gap in the literature by developing a CGE model of Turkish economy with a detailed representation of power generation technologies where the model is built on the electricity-detailed extension of the GTAP 9 Data Base, i.e., GTAP-Power Data Base (Peters 2016).

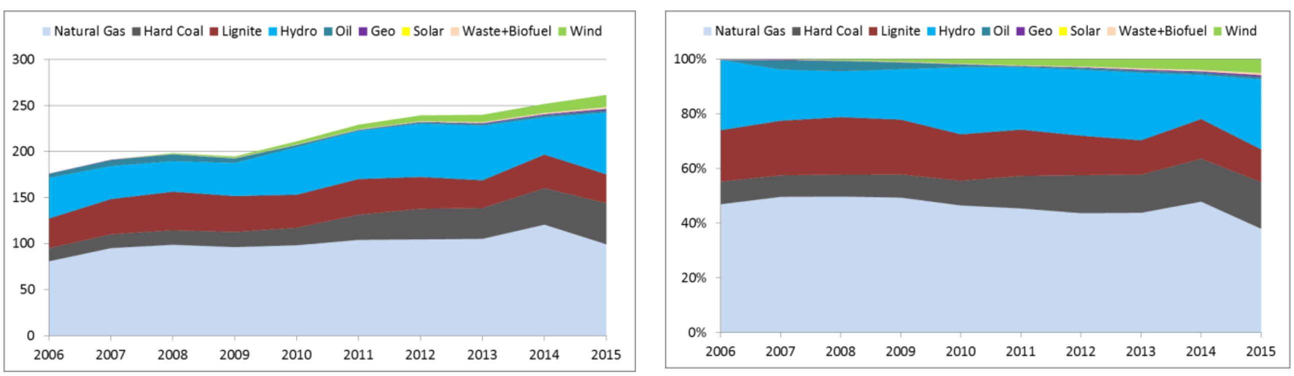
Our detailed representation of the power sector will reveal more insight compared to the previous study (Akın Olçum and Yeldan 2013) in which a national emission trading scheme was analyzed in an aggregated electricity sector representation. We provide the results for power sector development, detailed technology mix, investments requirements and the resulting prices of electricity and other goods. The results are useful for industry representatives and policy makers as they will provide information about sectoral impacts and overall policy costs associated with different options. We also assess the potential benefits of the nuclear program in Turkey and associated costs for large-scale deployment of nuclear energy. We investigate the policies that support wind and solar power development in Turkey. Our analysis provides a discussion of options for achieving low-carbon energy system that maximizes welfare of Turkish citizens. Because Turkey has a rapidly growing population and economy, it is extremely important to provide a discussion for the best way to decarbonize Turkish economy while keeping fast economic growth.

2. AN OVERVIEW of TURKISH ECONOMY and ENERGY SECTOR

Over the period between 1990 and 2015, Turkey has shown a high rate of economic growth even facing with several serious economic and political crises. As illustrated in Table 1, cumulative growth in this era was 158.83% (average annual growth of 3.88%) in real terms. Parallel to economic growth, primary energy demand and electricity generation have increased by 143.96% (average annual growth of 3.63%) and 354.94% (average annual growth of 6.25%), respectively, in the same period. What is more remarkable about Turkish energy sector is the decrease of domestic share of total energy supply from about 50% in 1990 to a quarter in 2015. Total CO_2 equivalent emissions, on the other hand, has shown an average annual growth of 3.41%. Furthermore, Turkey has the highest growth rate of GHG emissions among Annex I countries every year in the last decade. Note that we report the growth rates for periods 1990-2011 and 2012-2015 separately in Table 1, since our base year for the model is 2011.

Table 1. Key indicators of Turkey

	1990	2000	2010	2011	2012	2013	2014	2015	Average Growth (1990-2011)	Average Growth (2012-2015)	Total Growth (1990-2015)
Population (million)	56.473	67.804	73.723	74.724	75.627	76.668	77.696	78.741	1.34%	1.32%	39.43%
GDP (constant 2010 Billion US$)	350.206	500.176	731.145	795.286	812.205	846.257	871.815	906.443	3.98%	3.32%	158.83%
Primary Energy Demand (Million TOE)	52.987	80.500	109.260	114.480	120.093	120.290	123.937	129.267	3.74%	3.08%	143.96%
Electricity Generation (TWh)	57.543	124.922	211.208	229.395	239.497	240.154	251.963	261.783	6.81%	3.36%	354.94%
Electricity Installed Capacity (GW)	16.318	27.264	49.524	52.911	57.059	64.008	69.520	73.147	5.76%	8.43%	348.27%
CO2 emissions (Mt CO2)	207.081	295.796	391.393	411.530	442.269	434.349	462.634	-	3.32%	5.73%	123.41%



(a) TWh (b) Percentage

Figure 1. Electricity generation by technology, Turkey, 2006-2015.

The power generation profile of Turkey between 2006 and 2015 can be seen in Figure 1 (a) and (b). Figure 2, on the other hand, displays the decomposition of total generation by technology in 2015. As seen from these figures, two thirds of the total electricity demand is satisfied by fossil fuels while hydroelectric power plants generate nearly a quarter of total generation and there is a slow diffusion of wind power in recent years.

Recent studies indicate that the wind and solar energy potential in Turkey is significant, i.e., 48GW for wind and 1.527 kWh/m²year for solar energy (MENR 2015). However, as seen in Figure **1** (a), there is only 4.5 GW of installed wind turbines while the corresponding figure for solar energy is in negligible amounts by the end of year 2015. Currently, there is no nuclear power plants in Turkey; however, two plants (with installed capacities that correspond to more than 10% of the current total capacity) are on the government agenda. These plants, each having 4 units, are proposed to be commissioned gradually between years 2019 and 2028.

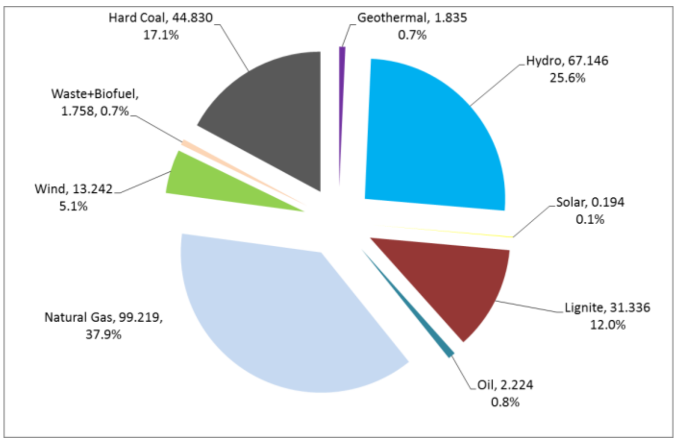


Figure 2. Electricity generation by technology, Turkey, 2015: TWh and percentage.

3. TR-EDGE MODEL

3.1 Theoretical Framework

The model that we created for this study has two regions, i.e., Turkey and the rest of the world (ROW). It also represents several economic sectors (discussed later). The model is a recursive dynamic model where the base year is 2011. From 2015 to 2030 it is solved at 5-year intervals. The model mainly relies on the GTAP Power Data Base; however national accounts data published by Turkish Statistical Institute (TUIK) and energy statistics by Ministry of Energy and Natural Resources of Turkey are also used to calibrate the model to represent recent economic and energy trends in Turkey especially for power sector.

The model is formulated as a mixed complementary problem (MCP), which includes both equations and inequalities (Mathiesen 1985; Rutherford 1995). The model is coded in GAMS using

Mathematical Programming System for General Equilibrium (MPSGE) (Rutherford 1999) and PATH is employed as the solver (Dirkse and Ferris 1995).

The activities of different agents in the economy are described by three types of conditions in a CGE model:

- **zero-profit conditions**: these condition require that value of inputs must be equal or greater than value of outputs, i.e., any activity operated at a positive level must earn zero profit. For the households, economic activity is the utility while it is the output for each producer. Then the condition can be described as follows

$$-profit \ \geq 0; output \geq 0; output^T \cdot (-profit) = 0$$

- **market-clearing conditions**: these conditions imply that supply must be equal to demand for each commodity with a positive price. This condition can be described with the following expressions:

$$supply - demand \ \geq 0; p \geq 0; p^T \cdot (supply - demand) = 0$$

- **income-balance conditions**: for each agent, including government, expenditures must be less than or equal to total income (value of factor endowments and tax revenue)

$$income = endowment + tax\ revenue$$

3.2 Dynamic Process

The recursive structure implies that production, consumption, savings and investment are determined by current period prices. Investment is triggered by savings, and capital in a period is formed by investment in the previous year together with the surviving capital from the previous periods. The dynamics of capital formation is described as follows:

$$K_{r,t} = Inv_{r,t-1} + (1 - \delta_r)^5 \cdot K_{r,t-1}$$

where $K_{r,t}$ is the capital in region r in period t and $Inv_{r,t-1}$ is the investment in region r in period t-1 and δ_r is the depreciation rate of capital in region r. Note that the term $(1 - \delta_r)^5$ is used since the period length is five years.

In TR-EDGE labor endowment grows at a rate parallel to population growth rate. The historical data and projections published by TUIK as well as OECD are used in the model. Similarly, government expenditures and current account balance are exogenous variables in TR-EDGE. Growth paths for these variables are defined based on historical data.

Besides the dynamic progress summarized above, a 2% productivity growth is assumed for both capital and labor through the planning horizon of the model. Similarly, a 1% annual increase has been used for land use under the assumption that there will be improvements in productivity of land use.

Finally, natural resources for the rest of the world are assumed to be depleted with an annual rate of 0.1% while corresponding figure for Turkey is assumed to be 2% based on the recent consumption and reserve amounts.

3.3 Data

GTAP-Power (Peters 2016) is used as the main data base for TR-EDGE. It is an electricity-detailed extension of the GTAP 9 Data Base (Augiar, Narayanan, and McDougall 2016). Electricity sector in GTAP 9 Data Base is disaggregated into: transmission & distribution, nuclear, coal, gas (base and peak load), oil (base and peak load), hydroelectric (base and peak load), wind, solar, and other power technologies. This extended version consists of 68 sectors and 140 regions with reference years 2004, 2007, and 2011. TR-EDGE has the base year of 2011 and consists of two regions, i.e., Turkey and ROW. The sectoral data is aggregated to obtain a compact dataset while maintaining the requirements of the policy issues addressed by TR-EDGE. As seen in Table 2, final aggregation consists of 17 sectors, eight of which are electricity technologies including transmission and distribution. Note that, as a first attempt, the power data is employed in a way that the base vs. peak load disaggregation is not used. It was also realized that the aggregated data is more consistent with the actual values reported by Turkish Electricity Transmission Company (TEIAS 2015). Besides electricity related sectors, there are five non-energy sectors (agriculture, services, energy-intensive industries, other industries, and transport), and four energy sectors (crude oil, refined oil products, coal, gas). The electricity sector is represented by transmission and distribution services, conventional fossil fuel-fired power plants, nuclear, hydro, wind, solar and other electricity which contains waste, biofuels, biomass, geothermal, tidal and oil.

The data base distinguishes four main endowments: capital, land, natural resources and labor where labor is further disaggregated into five sub-categories (officials and managers, technicians, clerks, service/shop workers, agricultural and unskilled workers). In TR-EDGE the disaggregation of labor is not taken into account and a single labor endowment is used.

Table 2. List of sectors

Non-Energy Sectors	
agri	Agriculture
eint	Energy-intensive Industry
serv	Services
tran	Transportation
othr	Other Industries
Energy Sectors	
coal	Coal
gas	Natural gas
oil	Crude oil
roil	Refined oil products
Electricity Technologies	
ColE	Coal-fired power
GasE	Gas-fired power
HydE	Hydroelectric power
OthE	Other power: waste, biofuels, biomass, geothermal, tidal, oil
WndE	Wind power
NucE	Nuclear power
SolE	Solar power
TnD	Transmission and distribution

Besides GTAP 9 Data Base, additional data used to calibrate TR-EDGE model is obtained from several national sources. National accounts data published by Turkish Statistical Institute (TUIK 2017) is employed to approximate government expenditure growth rate. Energy consumption and production data published by Republic of Turkey Ministry of Energy and Natural Resources and Turkish Electricity Transmission Company (MENR 2015; TEIAS 2015) is used to calibrate the model in a way that TR-EDGE replicates 2015 actualizations. Finally, emission coefficients by sector and technology are calculated based on data published by U.S. Energy Information Administration (EIA) where calculated emissions are seen to be consistent with those reported in GHG emissions inventory published by TUIK.

3.4 Production and Consumption Structures

Nesting structure of production and consumption activities are taken from several versions of MIT EPPA model (Paltsev et al. 2005; Chen et al. 2015) and MIT USREP model (Rausch et al. 2009; Lanz and Rausch 2011) with minor revisions to adapt them for Turkish economy. Table 3 summarizes the types of substitution elasticities and their notation; elasticity values, on the other hand, are specified on the nesting diagrams in the rest of this section.

The preference structure of households can be seen in Figure 3. Savings enters directly into the utility function of households which endogenizes the consumption-investment decision within the model. Note that emissions which are proportional to final use of fossil fuels are integrated into this nesting structure using Leontief functions while all other substitution possibilities are represented via CES functions.

Table 3. Types of substitution elasticities and their notation in TR-EDGE

Type of substitution elasticity	Notation
between domestic and imported goods	sdm
among non-electricity energy	noe
between non-electric energy and electricity	noe_el
between capital/labor bundle and energy bundle	kl_e
between material and energy bundles	e_m
between land and energy/material bundle	ln_em
between land/energy/material bundle and capital/labor aggregate	lnem_kl
between capital and labor	kl
between capital/labor bundle and material	kl_m
between fixed resource and capital/labor/material bundle	klm_f
between fixed resource and capital/labor bundle	kl_f
among capital, labor and material	klm
between land and capital/labor/material/fixed resource bundle	klmf_ln
between fixed resource and capital/labor/energy bundle	kle_f
between technology specific factor and capital/labor/energy bundle	kl_tsf
between technology specific factor and capital/labor/energy/material bundle	klm_tsf
between land and capital/labor/material/technology specific factor bundle	klmtsf_ln
domestic-export transformation	sde
among energy inputs	e
among material inputs	m
Intra-import elasticity of substitution	imp

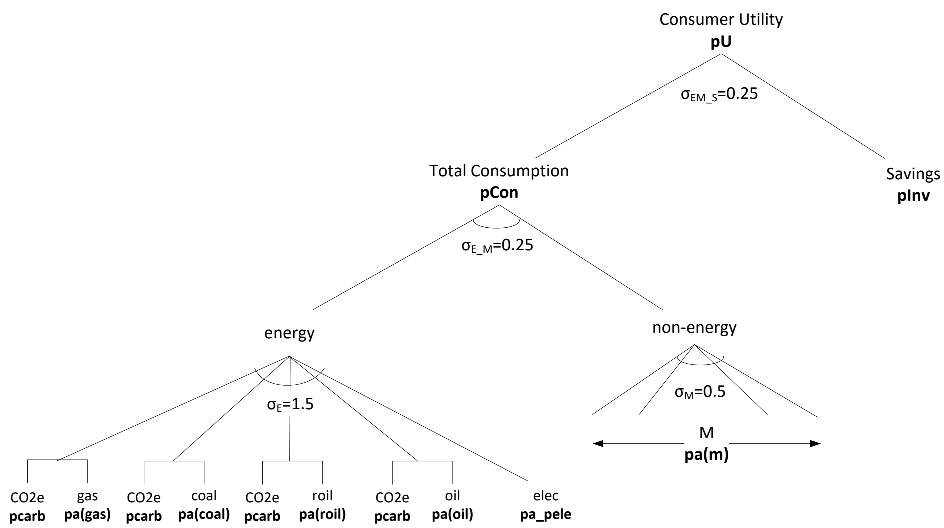


Figure 3. Nesting structure of the household sector.

Since TR-EDGE mainly focuses on power sector, we pay more attention to define the nesting structure of this sector; that is why it is the most detailed among the sectors. Figure 4 shows the nesting structure of alternative power technologies. As seen from this figure, electricity generated by fossil-fired, nuclear, hydro and "other" power plants are perfect substitutes while electricity generated by solar and wind power plants are treated as imperfect substitutes for these technologies in accordance with the treatment in EPPA models (Paltsev et al. 2005; Chen et al. 2015). The idea lying behind this treatment is the intermittent nature of these technologies which increase system cost in case they provide a large share of electricity production.

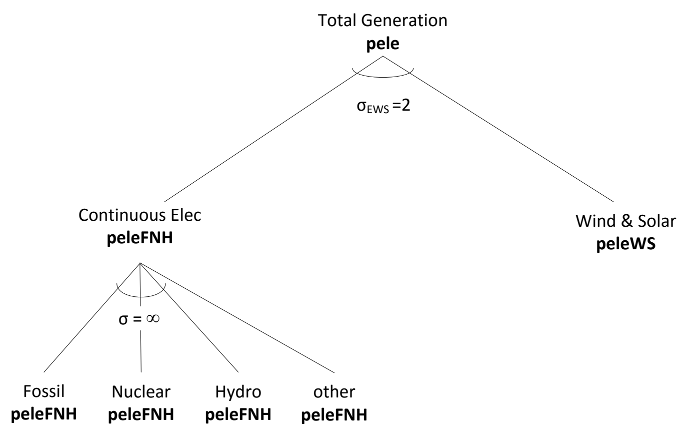


Figure 4. Nesting structure of electricity generation.

Figure 5 (a) and (b) show the nesting structures of nuclear and hydroelectric power technologies, respectively. Note that a fixed factor is built into the these technologies to allow for gradual penetration of these technologies (Paltsev et al. 2005). Both technologies have similar structures in which KL composite is combined with relevant resource of fixed factor endowments. At the top nest, on the other hand, other material inputs and transmission and distribution services are aggregated via Leontief function.

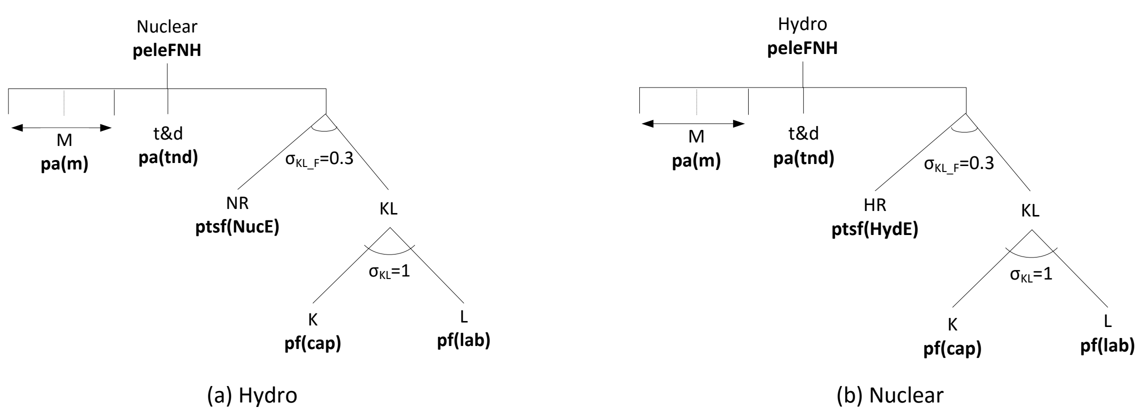


Figure 5. Nesting structure of electricity generation: Hydro and Nuclear

Wind and solar technologies are represented by the nesting structure illustrated in Figure 6. Capital, labor and other material inputs enter at the lower nest and the composite of these inputs have the substitution possibility with technology specific factor in the upper nest. Next, these inputs are combined with land. Finally, transmission and distribution services are aggregated with the composite of remaining inputs with a Leontief function.

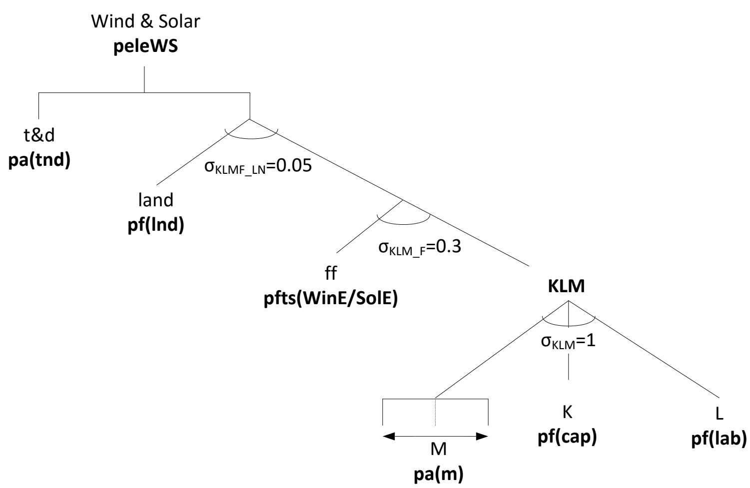


Figure 6. Nesting structure of electricity generation: Wind and Solar

Fossil-fired power technologies and "other" power technologies have similar nesting structures as seen in Figure 7 and Figure 8, respectively. Capital-labor composite and energy inputs are combined with a CES function in the lower nests while other material inputs and transmission and distribution services enter at the top nest in fixed proportions. Note that, non-electric energy inputs and electricity enter the nesting structure in constant proportions unlike the treatment followed in EPPA or USREP. This difference arises from the data structure used in TR-EDGE. GTAP Power Data Base provides disaggregated data for power sector; therefore, there is no need for representing the substitution among these technologies at fuel level. Different from fossil-fired power technologies, "other" power technologies also includes technology specific factor in its nesting structure to represent the nature of technologies aggregated under this option, i.e., geothermal, waste, biofuels, biomass and tidal.

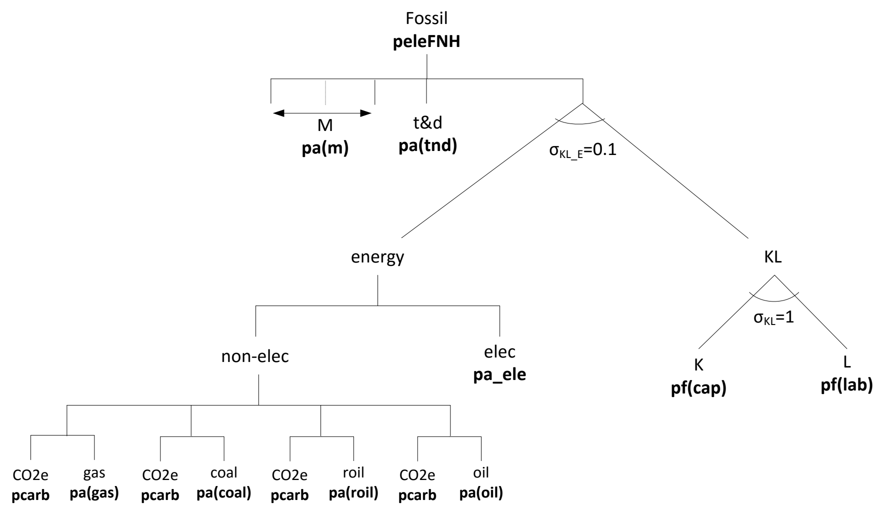


Figure 7. Nesting structure of electricity generation: fossil fuels

Figure 9 (a) and (b) illustrates the refined oil sector and primary energy sectors, respectively. The refined oil sector uses oil as a "feedstock" to produce refined oil products that is why oil enters not as part of the energy nest but as a Leontief intermediate input at the top nest. Primary energy sectors (coal, gas and oil), on the other hand, combine fuel specific resource and non-resource input bundle at the top nest while capital-labor composite is combined with other inputs at the lower nest via Leontief function.

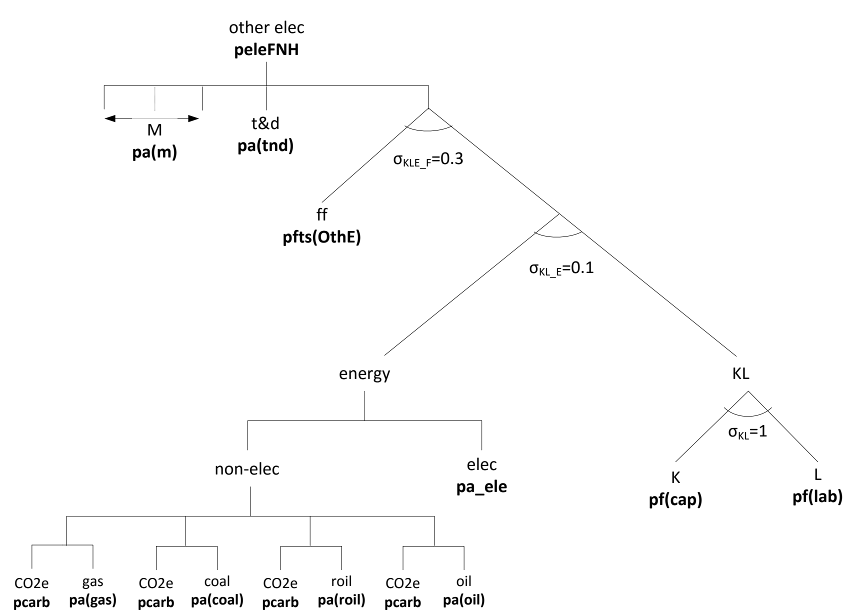
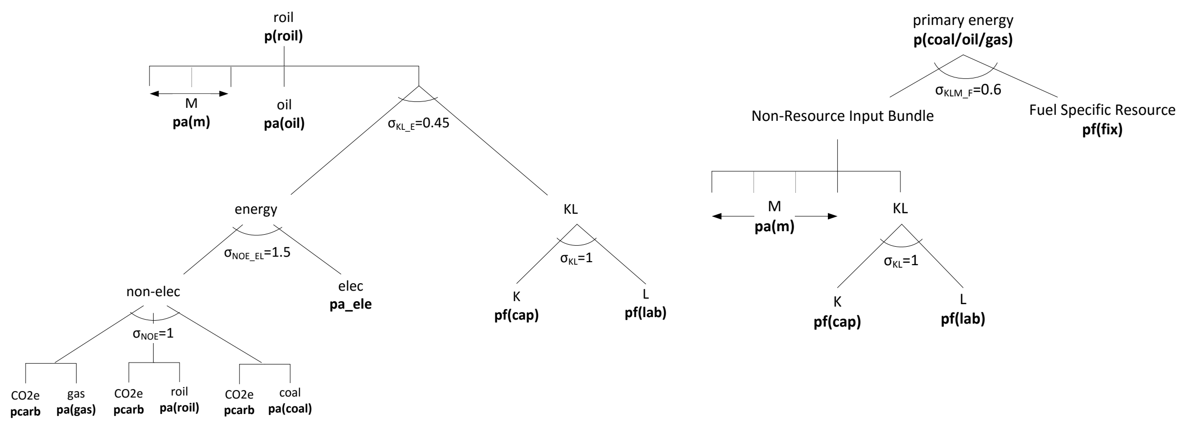


Figure 8. Nesting structure of electricity generation: "other" electricity



(a) refined oil sector (b) Nesting structure of primary energy sectors

Figure 9. Nesting structure of energy sectors

Non-energy sectors are represented in two categories, i.e., agriculture and the rest of the production sectors. Since the land input is critically unique in agriculture, nesting structure for agriculture includes substitution between land and other inputs as seen in Figure 10. Note that, the nesting structure also includes natural resources and GHG emissions as fixed proportions at the top nest.

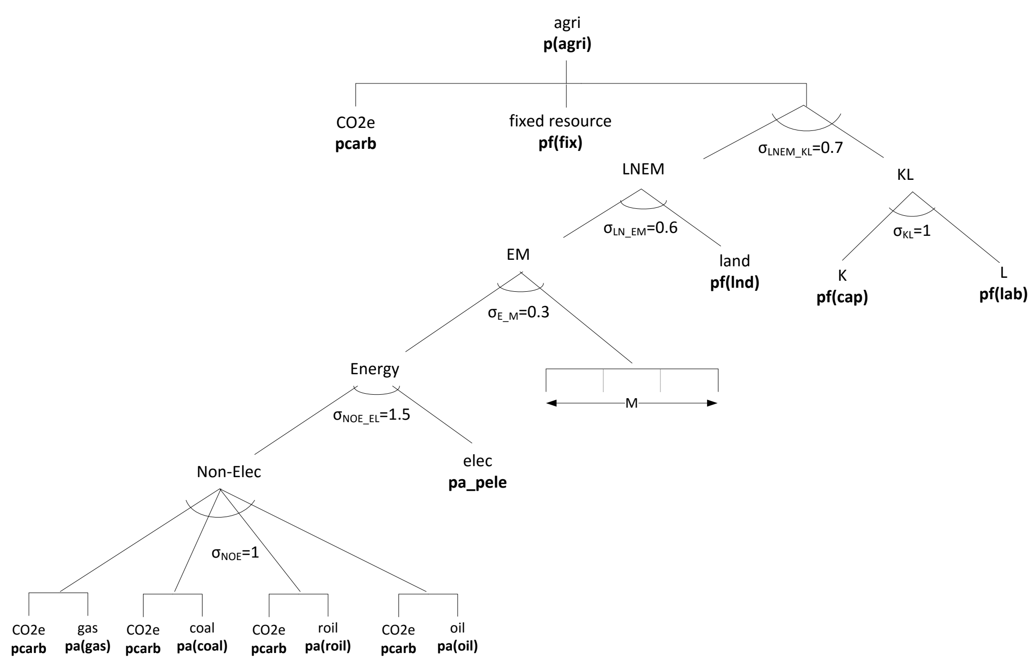


Figure 10. Nesting structure of agriculture sector

Figure 11 illustrates the nesting structure for non-energy sectors other than agriculture. As seen in this figure, non-electric energy inputs are combined with a CES function and then the composite non-electric energy good enters the upper nest with electricity again via CES function. Next, capital-labor composite and energy inputs are aggregated. This final bundle is then further aggregated with other material inputs via Leontief function.

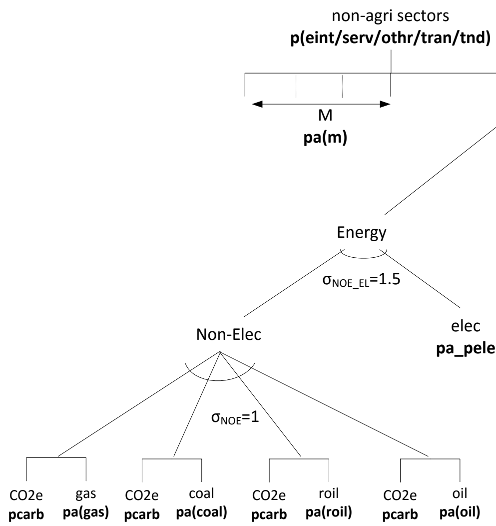
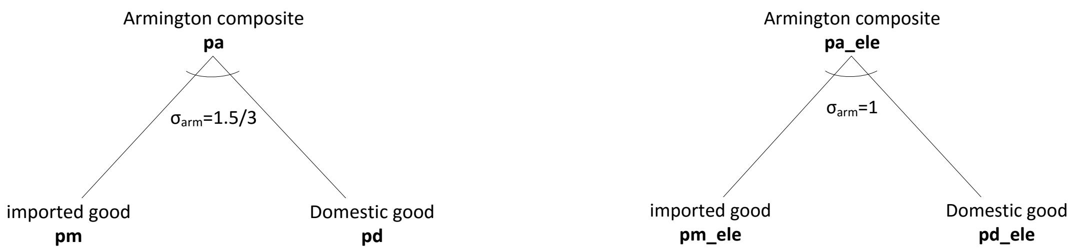


Figure 11. Nesting structure of Services, Transportation, Energy Intensive Industry, Other Industries, Transmission and Distribution

TR-EDGE aggregates imported and domestic goods to create an Armington composite (Armington 1969) as illustrated in Figure 12 (a) and (b) for non-electric goods and electricity, respectively. Elasticity of substitution between imported and domestic electricity is assumed to be 1 while this value is 1.5 for non-electric energy goods and 3 for non-energy goods. Aggregate domestic output, on the other hand, are allocated between domestic sales and exports subject to a constant elasticity of transformation (CET) with an elasticity value of 2.



(a) non-electric sectors

(b) Electricity sector

Figure 12. Armington structure of non-electric sector and electricity sector.

3.5 Backstop Technologies

Two backstop technologies are defined for Turkey, i.e., nuclear power plants and solar power. As mentioned in the previous sections, currently there is no nuclear power plant in Turkey. The input structures for these power plants are approximated using the corresponding values for ROW. Besides this, a mark-up factor is used based on the joint report by World Wide Fund for Nature-Turkey (WWF-Turkey) and Bloomberg New Energy Finance (BNEF), (WWF-Turkey and BNEF 2014). In accordance with this document, mark-up factors for nuclear and solar are estimated to be 1.5 and 1.4 relative to coal-fired power plants, respectively. Mark-up for nuclear is slightly higher than the corresponding value in EPPA 6; however, the value for solar is significantly lower owing to high insolation levels in Turkey.

4. SCENARIOS

In this study, we aim to analyze two main scenarios and the impact of emission trading scheme for each of the scenario. That is, the results will be reported for four different settings, i.e., main scenarios as well as these scenarios coupled with national emission trading scheme.

4.1 Business as Usual (BAU) Scenario

This scenario represents the current plans of the Government including two nuclear plants scheduled to be commissioned until 2030. One of the plants will be in south coast of Turkey (Akkuyu Nuclear Power Plant) and the other one is at the north end of Turkey (Sinop Nuclear Power Plant). According to official plans, Akkuyu Nuclear Power Plant consists of four identical units each having 1.2 GW capacities where first unit will be commissioned by 2019 and each additional unit will be operative every year until 2023. This plant will be built under the agreement signed between Turkey and Russia. Sinop Nuclear Power Plant, on the other hand, is planned to be built under the agreement signed between Turkey and Japan. This plant consists of four identical units with a total capacity of 4.48 GW and the first two units will be commissioned by 2023 and 2024 while the third and the fourth units will be commissioned in years 2027 and 2028, respectively. However, considering the delays and numerous updates realized in the near past due to several political and financial reasons, a more realistic schedule plan would be assumed as commissioning of Akkuyu by year 2025 and Sinop by year 2030.

Turkey's renewable energy industry has shown a significant progress after 2010 when the feed in tariff scheme was revised. Especially, the increasing share of wind power is promising, i.e., the share of wind has been increased from 0 to 5% in the last decade. The revised feed-in tariff structure is embedded into BAU scenario in order to represent the recent trends in renewable technologies.

Official projections of energy use and electricity generation as well as GHG emissions rely on high growth rates in real GDP. However, recent political turbulences in the country as well as uncertainty in the neighborhood area negatively impacted main economic indicators. Moreover, there is no significant sign of stability in the near future for the region. Obviously, it is hard to make predictions and projections in such an instable economic environment. Besides this, recent growth figures indicate that more realistic growth paths would be needed to represent medium-term progress in Turkey. For example, electricity demand in 2015 and 2016 is lower than the projections even for low growth scenarios of the government. Moreover, the high diffusion of wind and solar electricity would bring inevitable complications due to their intermittent nature. On top of these, actual generation values for wind and solar are far behind the targets addressed in "National Renewable Energy Action Plan for Turkey" (MENR 2014). Then, we propose a more realistic growth path in our business as usual scenario in which there is an average annual real GDP growth rate of 3-3.5% until 2030.

4.2 No Nuclear (NoN) Scenario

Although recent actions imply that the Government is very decisive on building nuclear plants, many people, especially non-governmental environmental organizations, are against nuclear power due to the accompanying risks. Furthermore, proposed nuclear program needs to be carefully analyzed together with the economic and environmental targets. For example, change in average electricity price or change in carbon price with or without a nuclear program would be valuable indicators for the impact of such a program. Then, NoN scenario is proposed in which the only change from the BAU scenario is that the no nuclear power plant is allowed until 2030.

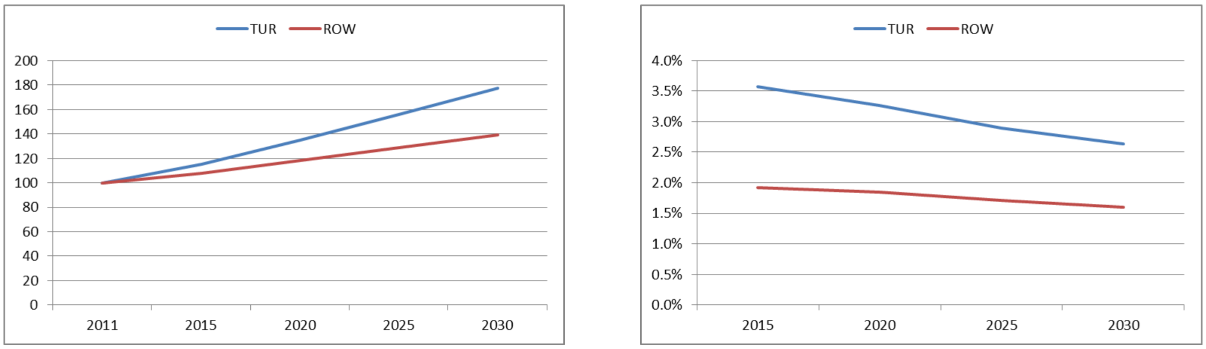
4.3 National Emission Trading Scheme (TrEm) Scenario

This scenario proposes that a national emission trading market is designed in Turkey. That is, each production and consumption activity needs to have permits for each unit of CO_2 equivalent GHG emissions they produce. This scenario will be used to evaluate the carbon price needed to meet the target GHG emission level by year 2030 which is 21% percent decrease compared to BAU emissions. A gradual emission decrease pathway is defined to reach this target, i.e., 5% decrease in 2020 and 10% decrease in 2025 are set as constraints in the model.

This scenario is coupled with both BAU and NoN scenarios in order to assess the impact of nuclear power on economic and environmental indicators.

5. RESULTS

TR-EDGE is solved for four different policy settings which are BAU, NoN, BAU+TrEm and NoN+TrEM. In this section, analysis for each of these settings as well as comparative results will be summarized. Figure 13 illustrates the development of real GDP both for Turkey and ROW between the years 2011 and 2030. As seen in (a), real GDP of Turkey has shown a cumulative growth of nearly 180% while the corresponding growth for ROW is around 140%. Figure 13 (b), on the other hand, displays the annual growth rates. During period 2011-2030, Turkey grows at an average rate of 3.07% while the growth rate in the initial period is around 3.50% which is consistent with the realized values between 2011 and 2015.



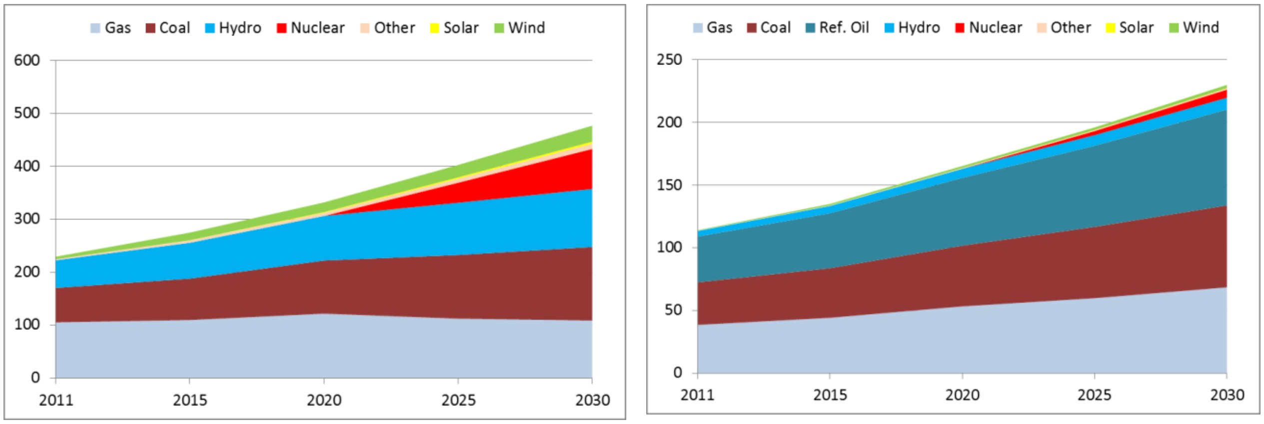
(a) GDP index (100 for base year)

(b) Annual growth rates

Figure 13. Development of real GDP: BAU

Development of power generation and primary energy supply profiles under BAU can be seen in Figure 14 (a) and (b), respectively. Total generation reaches up to 477 TWh and total primary energy becomes 230 Mtoe by year 2030. There are several important observations to be noted from (a):

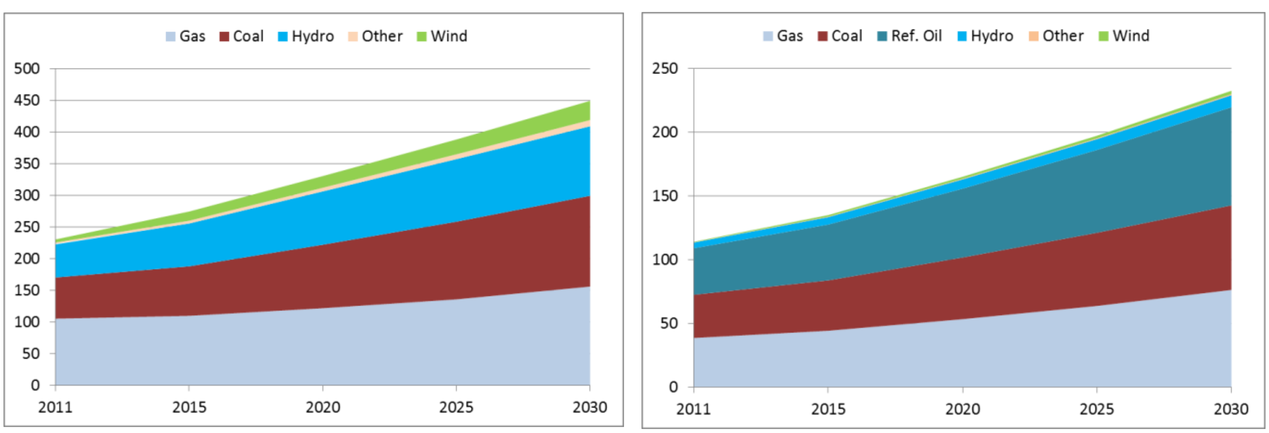
- the share of nuclear power in total generation becomes 15.9% by year 2030.
- the share of natural gas-fired power plants decrease from 45.8% to 22.8% which is aligned with official targets.
- share of wind and solar reaches 7.2% which is far behind the official targets. However, it must be noted that actual generation values for wind and solar are currently nearly 30% behind the targets addressed in “National Renewable Energy Action Plan for Turkey” (MENR 2014).



(a) Electricity generation by technology, TWh (b) Primary energy supply by source, Mtoe

Figure 14. Electricity generation and primary energy supply: BAU, Turkey

Figure 15 (a) and (b) display the similar figures for NoN scenario. These figures indicate that there is a significant decrease for both power generation and primary energy supply in case no nuclear power plants are allowed. Figure 16 clarifies the comparison between BAU and NoN by displaying the difference between these two scenarios in terms of power generation. As seen from this figure, nuclear power mainly substitutes natural gas fired power plants while a net decrease under NoN (4.9%) is observed in overall generation, i.e., amount of electricity generated by nuclear power plants is higher than the generation it replaces.



(a) Electricity generation by technology, TWh (b) Primary energy supply by source, Mtoe

Figure 15. Electricity generation and primary energy supply: NoN, Turkey

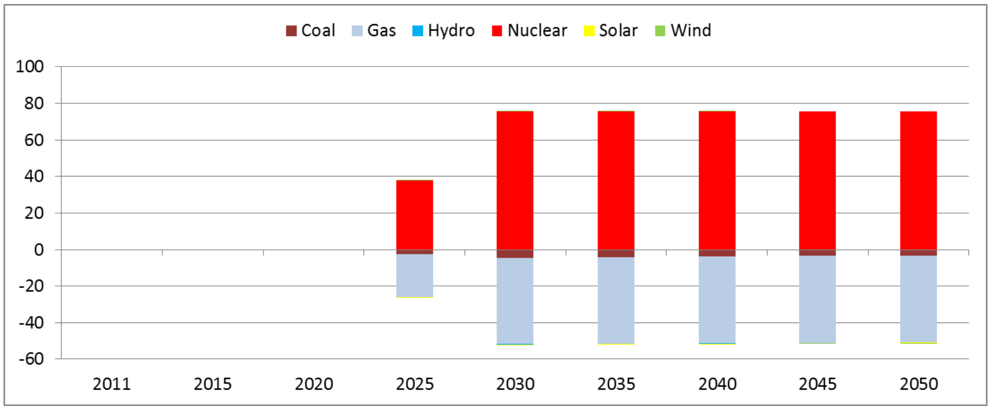
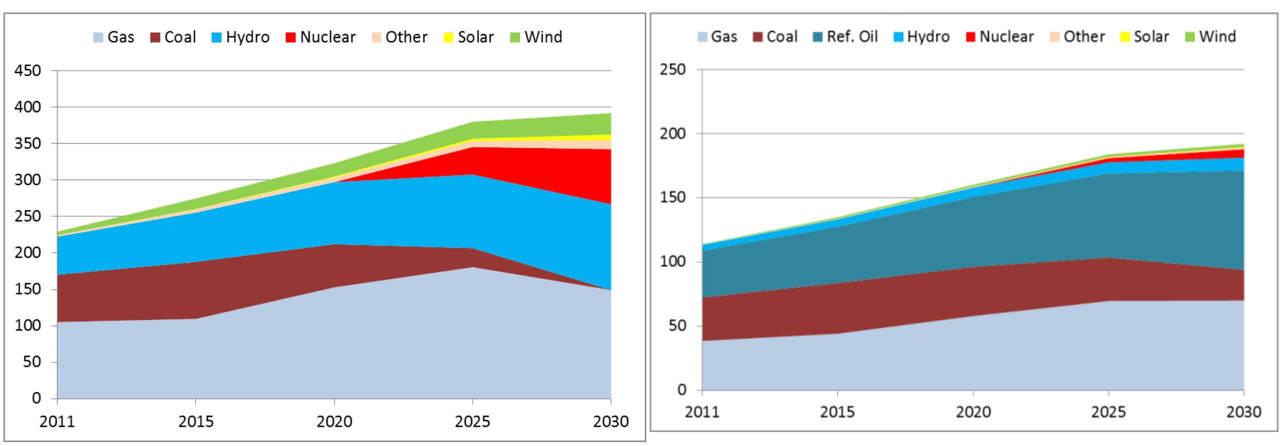


Figure 16. Difference between BAU and NoN: Electricity generation, TWh

Power generation and primary energy profiles under BAU+TrEm scenario is illustrated in Figure 17. Main observations from these figures are as follows:

- There are significant decreases both in power generation and primary energy supply. The decrease in power generation is 17.8% where the same figure for primary energy supply is 16.4%.
- The share of coal-fired power plants vanishes by year 2030 due to the high emission content per dollar of coal, i.e., emission per dollar of coal is nearly 9 times greater than oil and nearly 5 times greater than natural gas.
- The share of wind and solar power reaches up to 9.5% by year 2030.
- As seen in Figure 18, the decrease in coal-fired power generation is compensated by natural gas and renewable resources to some extent.



(a) Electricity generation by technology, TWh

(b) Primary energy supply by source, Mtoe

Figure 17. Electricity generation and primary energy supply: BAU+TrEm, Turkey

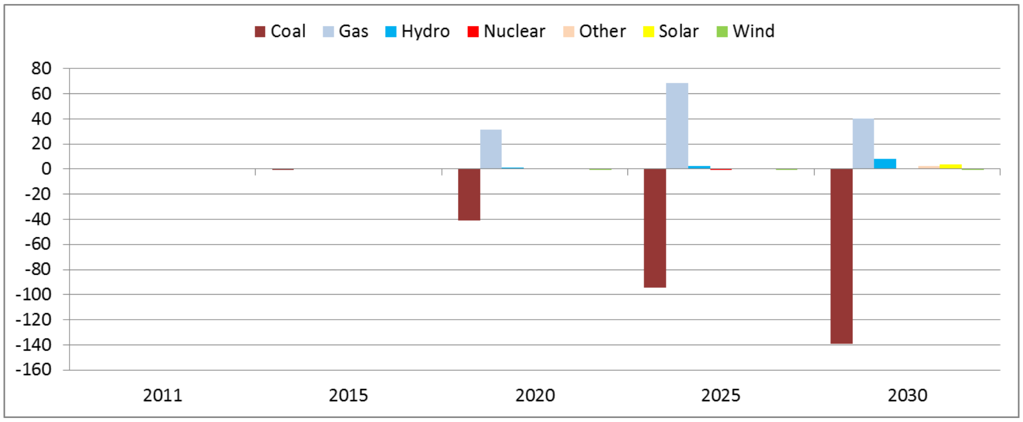
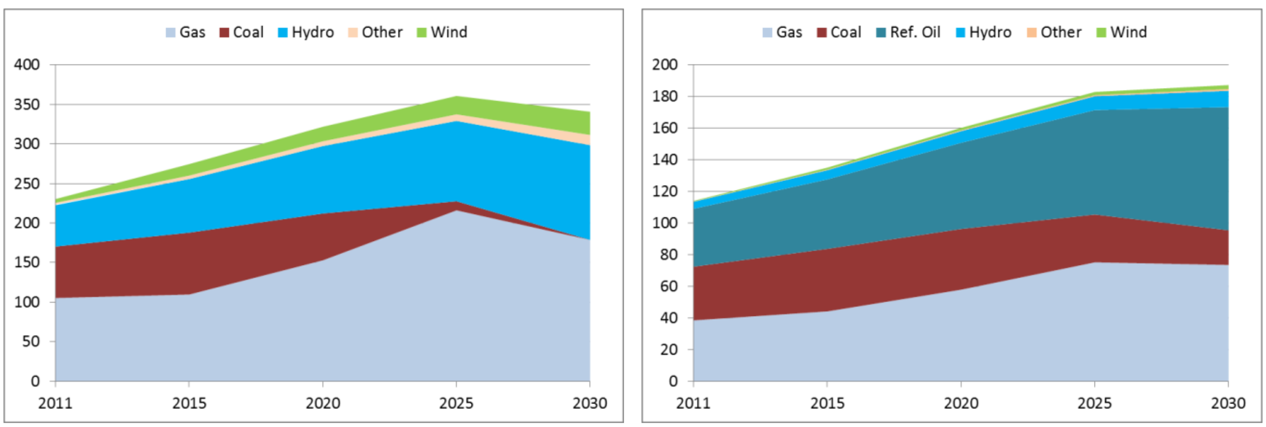


Figure 18. Difference between BAU and BAU+TrEm: Electricity generation by technology, TWh



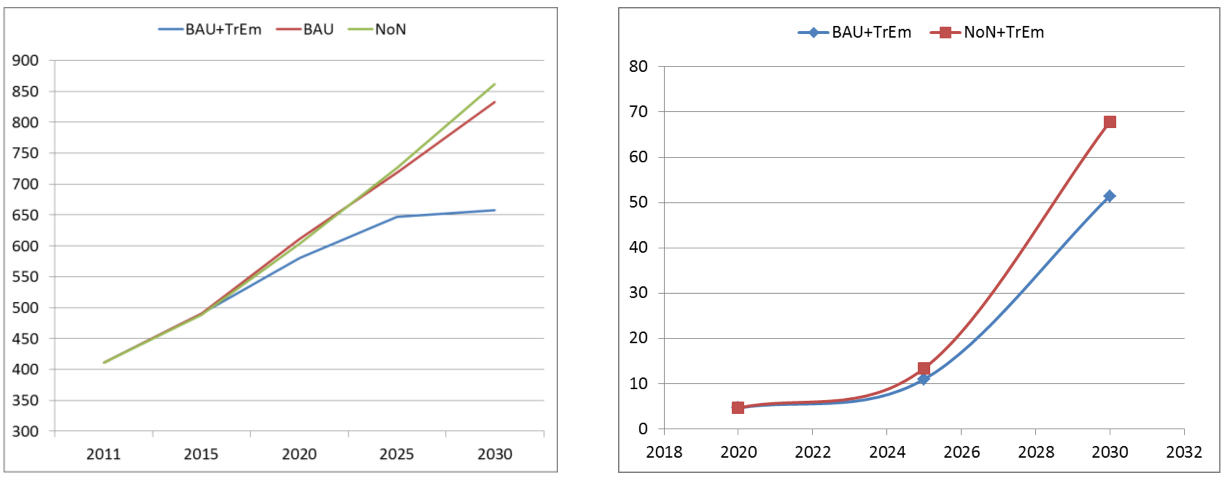
(a) Electricity generation by technology, TWh (b) Primary energy supply by source, Mtoe

Figure 19. Electricity generation and primary energy supply: NoN+TrEm, Turkey

Figure **1**Figure 19 illustrates the power generation and primary energy profiles under NoN+TrEm scenario. Note that the difference between NoN+TrEm and BAU+TrEm in terms of power generation and primary energy (10.8% for power generation and 2.18% for primary energy) is more significant compared to difference between BAU and NoN. This result implies that the potential benefit expected from nuclear power would be higher under emission restrictions. Another important point to emphasize here is that the coal-fired power generation vanishes regardless of nuclear assumptions.

Figure 20 (a) compares BAU, BAU+TrEm and NoN scenarios in terms of total GHG emissions. As noted in the previous section, an emission decrease pathway is defined to satisfy the official targets of 21% decrease compared to BAU levels by year 2030. Then, the comparison between BAU and

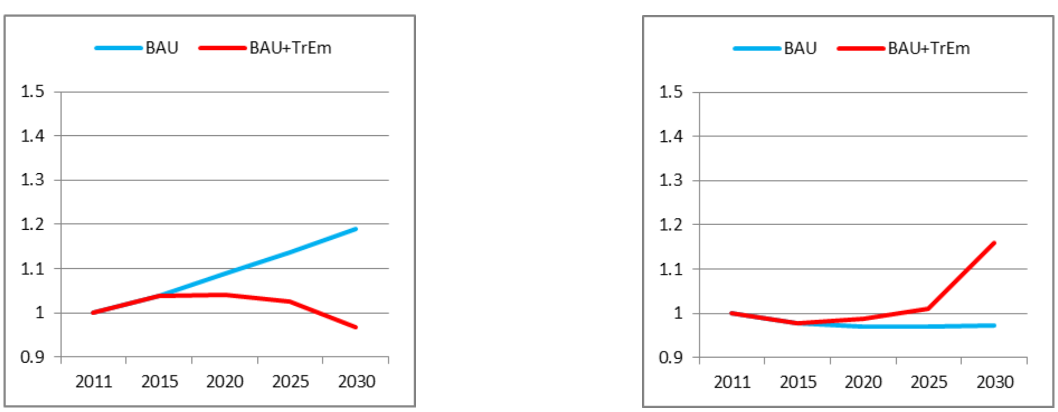
BAU+TrEm is obvious. However, this figure also indicates that the decrease in GHG emissions due to the nuclear program is only 3.1% without any further abatement action. Figure 20 (b) provides another insight about the nuclear program by comparing the emission price with or without a nuclear program. It is seen from this figure that the price per ton of CO2 equivalent emission is around $50/tonne with the nuclear program and $67/tonne in case no nuclear power plant is allowed.



(a) CO2 equivalent GHG emissions, Mtonne (b) CO2 equivalent GHG price: BAU+TrEm vs NoN+TrEm, $/tonne

Figure 20. Total emissions and emission price

No significant change has been observed in prices of oil and gas when TrEm scenario is applied. However, TrEm scenario induces significant changes in coal and electricity prices as shown in Figure 21. The decrease in coal prices is due to the decrease in demand since the impact of emission price affects the coal most. The increase in electricity, on the other hand, is triggered mainly by the increase in input prices due to emission price introduced in the market.



(a) coal (b) electricity

Figure 21. Consumer price index of coal and electricity: BAU vs TrEm

Comparison of BAU and BAU+TrEm in terms of percentage change in real GDP change can be seen in Figure 22. As indicated in this figure, a 1.3% decrease in real GDP has been observed by year 2030 in case an emission reduction target is set on the economy.

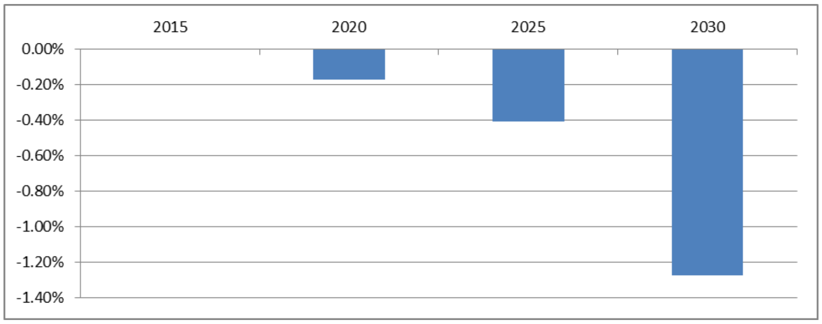


Figure 22. BAU vs BAU+TrEm: percentage change in real GDP

6. CONCLUSION

Economic development in Turkey has shown a significant improvement since 2000, especially until 2012. Structural financial reforms, harmonization of laws and regulations with EU standards as well as improvements in health and transportation sectors brought a significant increase in wealth level of the country. However, progress after 2012 raises concerns about future of the country. Political turbulence in the country as well as uncertainty in the neighborhood area negatively impacted main economic indicators. Moreover, there is no significant sign of stability in the near future for the region. Obviously, it is hard to make predictions and projections in such an instable economic environment. However, very assertive targets and actions to decarbonize power sector and change energy profile of Turkey makes it crucial to develop models and assess the impacts of various policy scenarios. TR-EDGE model is motivated by these facts. Given the importance of power sector to a successful climate policy, TR-EDGE differs from other models with its representation of disaggregated electricity generating technologies in general equilibrium framework, i.e., the model combines macroeconomic representation of the non-electric sectors and detailed representation of the electric sector.

TR-EDGE is run under four different scenario settings: a business as usual scenario (BAU) which represents the current plans of the government including a nuclear program and revised feed-in tariff scheme for renewables, a no-nuclear scenario (NoN) in which nuclear power is omitted and a national emission trading scheme (TrEm) which is coupled with each of previous scenarios. TrEM scenario is designed in a way that total CO_2 equivalent GHG emissions decrease by 21% compared to BAU scenario by year 2030. An important point to be noted here is that INDC proposed by Turkey claims a 21%

decrease compared to its own business as usual scenario which projects total emissions to be nearly 1,200 Mton CO_2e and total power generation be 580 TWh by year 2030. However, recent trends in the economy and energy consumption show that these projections are already beyond the current realizations, especially for renewable projections. Then, the pledge of the country to decrease the total emissions to 929 Mton CO_2e by year 2030 becomes null since it would be satisfied without any abatement effort. However, in order to assess the impacts of policies which results in significant contribution to global climate change efforts and stabilize GHG emissions, the 21% decrease is set as a target to our BAU scenario.

The results of TR-EDGE indicates that a national emission trading market would help in decreasing GHG emissions without sacrificing much from the real growth rates. Another important insight obtained from TR-EDGE is the forecast of the emission price to satisfy the targets of the country. This value is found to be around $50 per ton of CO_2e emission which is in accordance with the one calculated by Akın Olçum and Yeldan (2013) which was $43.25 under a 20% decrease in emissions by 2020. Finally, TR-EDGE results imply that a high penetration of renewables would not be as easy as targeted in official projections. One of the main reasons of this result is the intermittent nature of these technologies; that is why we modeled these technologies as imperfect substitutes to other power generation options. Recent progress in this sector supports this result, i.e., the penetration of wind and solar is significantly behind the official targets. Moreover, the cost burden of increasing share of renewables has been becoming more apparent in the power market. Then, it will not be surprising that renewables with back-up technologies or power storage technologies would be on the agenda of system operator as well as producers in the near future.

One of the future research areas to improve TR-EDGE is the introduction of so-called "vintaging" procedure. This procedure implies that capital stock consists of two forms of components, i.e., malleable capital and non-malleable (or "rigid") capital. Malleable capital is the portion for which the mix of inputs can be altered in response to changing relative prices. On the other hand, the proportions of the inputs is fixed for the non-malleable portion (Babiker et al. 2001).

Another important improvement direction for TR-EDGE would be the revision of disaggregated electricity data for Turkey in GTAP-Power Data Base. In this study, we employed the data in an aggregated fashion disregarding the base vs. peak load disaggregation in the data base since the aggregated data was more consistent with the actual values in Turkey. Furthermore, GTAP data does not cover recent regulations and subsidy reforms introduced for renewable resources as well as for domestic coal resources. An important caveat to our study is that it provides a cost-effectiveness analysis, i.e., what are the costs of achieving certain emission targets. We have not quantified the benefits of emission reductions or damages related to continuing GHG emissions. Quantification of these benefits might offset costs, at least partially. However, the current literature on the benefit calculations still provides very wide ranges of values. Future research is needed to reduce uncertainty in the estimates of the benefits of GHG reduction.

BIBLIOGRAPHY

Akın Olçum, Gökçe, and Erinç Yeldan. 2013. "Economic Impact Assessment of Turkey's Post-Kyoto Vision on Emission Trading." *Energy Policy* 60: 764–74.

Armington, Paul S. 1969. "A Theory of Demand for Products Distinguished by Place of Production." *Staff Papers - International Monetary Fund* 16 (1): 159.

Augiar, Angel, Badri Narayanan, and Robert McDougall. 2016. "Journal of Global Economic Analysis." *An Overview of the GTAP 9 Data Base* 1 (1): 181–208.

Babiker, Mustafa H, John M Reilly, Monika Mayer, Richard S Eckaus, Ian Sue Wing, and Robert C Hyman. 2001. "The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparisons of Results." MIT Joint Program on the Science and Policy of Global Change Report Series.

Chen, Y.-H Henry, Sergey Paltsev, John M. Reilly, Jennifer F. Morris, Mustafa H. Babiker, and Ronald G. Prinn. 2015. "The MIT EPPA6 Model: Economic Growth, Energy Use, and Food Consumption." *MIT Joint Program on the Science and Policy of Global Change Report Series*. Cambridge.

Dirkse, Steven P., and Michael C. Ferris. 1995. "The Path Solver: A Nommonotone Stabilization Scheme for Mixed Complementarity Problems." *Optimization Methods and Software* 5 (2): 123–56.

IPCC. 2017. "IPCC Fourth Assessment Report: Climate Change 2007." Accessed April 14, 2017. https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html.

Kat, Bora. 2011. "Mathematical Modeling for Energy Policy Analysis." Ankara, Turkey: Middle East Technical University.

Kumbaroğlu, Gürkan Selçuk. 2003. "Environmental Taxation and Economic Effects: A Computable General Equilibrium Analysis for Turkey." *Journal of Policy Modeling* 25 (8): 795–810.

Lanz, Bruno, and Sebastian Rausch. 2011. "General Equilibrium, Electricity Generation Technologies and the Cost of Carbon Abatement." *Energy Economics* 33 (5): 1035–47.

Mathiesen, L. 1985. "Computational Experience in Solving Equilibrium Models by a Sequence of Linear Complementarity Problems." *Operations Research* 33 (6): 1225–50.

MENR. 2014. "National Renewable Energy Action Plan for Turkey."

MENR. 2015. "Enerji ve Tabi Kaynaklar Bakanlığı Ile Bağlı, İlgili ve İlişkili Kuruluşların Amaç ve Faaliyetleri." Ankara.

Paltsev, Sergey, John M. Reilly, Henry D. Jacoby, Richard S. Eckaus, James R. Mcfarland, Marcus Sarofim, Malcolm Asadoorian, and Mustafa H. Babiker. 2005. "The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4." *MIT Joint Program on the Science and Policy of Global Change Report Series*. Cambridge.

Peters, Jeffrey C. 2016. "The GTAP-Power Data Base: Disaggregating the Electricity Sector in the GTAP Data Base." *Journal of Global Economic Analysis* 1 (1): 209–50.

Rausch, Sebastian, Gilbert E. Metcalf, John M. Reilly, and Sergey Paltsev. 2009. "Distributional Impacts of a U.S. Greenhouse Gas Policy: A General Equilibrium Analysis of Carbon Pricing." *MIT Joint Program on the Science and Policy of Global Change Report Series*. Cambridge.

Rutherford, Thomas F. 1995. "Extension of GAMS for Complementarity Problems Arising in Applied Economic Analysis." *Journal of Economic Dynamics and Control* 19 (8): 1299–1324..

Rutherford, Thomas F. 1999. "Applied General Equilibrium Modeling with MPSGE as a GAMS Subsystem: An Overview of the Modeling Framework and Syntax." *Computational Economics* 14 (1): 1–46.

TEIAS. 2015. "Turkish Electricity Generation-Transmission Statistics." http://www.teias.gov.tr/istatistikler.aspx.

Telli, Çağatay, Ebru Voyvoda, and Erinç Yeldan. 2008. "Economics of Environmental Policy in Turkey: A General Equilibrium Investigation of the Economic Evaluation of Sectoral Emission Reduction Policies for Climate Change." *Journal of Policy Modeling* 30 (2): 321–40.

TUIK. 2017. "Main Statistics." http://www.turkstat.gov.tr/UstMenu.do?metod=temelist.

Turhan, E, S Cerit Mazlum, and Ü Şahin. 2016. "Beyond Special Circumstances: Climate Change Policy in Turkey 1992–2015." *Wiley Interdisciplinary Reviews: Climate Change*.

TUSIAD. 2016. "Addressing Climate Change from an Economic Policy Perspective." Istanbul. http://tusiad.org/tr/yayinlar/raporlar/item/9388-ekonomi-politikalari-perspektifinden-iklim-degisikligi-ile-mucadele.

UNFCCC. 2017. "United Nations Framework Convention on Climate Change." Accessed April 14, 2017. http://unfccc.int/2860.php.

UNFCCC. 2016. "Republic of Turkey Intended Nationally Determined Contribution." http://www4.unfccc.int/Submissions/INDC/Published Documents/Turkey/1/The_INDC_of_TURKEY_v.15.19.30.pdf.

WWF-Turkey, and BNEF. 2014. "TURKEY'S RENEWABLE POWER: Alternative Power Supply Scenarios for Turkey."

Yeldan, Erinç, and Ebru Voyvoda. 2015. "Low Carbon deveLopment Pathways and Priorities for Turkey." İstanbul.