ANALYSIS OF CO2 ABATEMENT COSTS İN TURKEY USING THE TIMES-MACRO ENERGY MODELİNG SYSTEM

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ABSTRACT

Turkey submitted its INDC to the UNFCCC in 2015, through which committed to reach 21% reduction in GHG emissions from the Business-as- Usual scenario by 2030, signed the Paris Agreement in 2016; and ratified in October 2021 after concurring to reach net zero emissions by 2053. It is therefore needed to examine Turkey's energy sector to understand the leading cause of emissions and elaborate the policy options to reduce emissions. The TIMES-MACRO modeling framework, a hybrid energy system and economic growth model, is employed in this study to evaluate Turkey's energy sector and CO2 emissions under various emission reduction scenarios together with associated economic implications. The results show that in the absence of scenario constraints, coal dominates the primary energy supply mix, implying that without mitigation measures, emissions will grow rapidly. The abatement costs of emissions vary according to policy, ranging from 45-265 $/ton CO2 by 2050, while the GDP loss range fluctuates between 0.4% and 1.5%.
Keywords: CO2 emissions, TIMES-MACRO model, Emission bound, Emission tax, Macroeconomic impacts, GDP loss

INTRODUCTİON

Immense increase in worldwide energy demand, the need to reduce greenhouse gases, the anticipated exhaustion of energy resources, and macroeconomic implications of energy policies point to the necessity of scientific analysis derived from energy-economy modeling. Turkey ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 2004, be- came a member to the Kyoto protocol in 2009, signed the Paris Agreement in 2016, and rati- fied in 2021. Furthermore, Turkey submitted its Intended Nationally Determined Contribution (INDC) to the UNFCCC in 2015 committing to achieve 21% reduction in GHG emissions from the Business-as-Usual level by 2030. Total CO2 emissions produced in Turkey increased from 128.76 metric tons (Mt) of CO2 in 1990 to 366.11 Mt in 2020, an increase of 184%. It is im- perative for Turkey to restructure its energy system to become less carbon-intensive and to lower GHG emissions. Sustainable green development is a top priority for policy-makers. Turkey's first Climate Convention was held in February 2022 with over one thousand experts from all over the country including government, industry, academia and NGO representatives. A total of 217 recommendation decisions, of which 76 prioritized, were agreed-upon. If, in the long run, considerable emission abatement is required, two crucial measures getting affected are energy demand and energy prices. Consequently, models ignorant to macroeconomic interactions and intolerant to price changes remain insufficient. Within the TIMES-MACRO model, as a result of the interaction between the energy system and the economy, energy demand and prices are cal- culated endogenously, which enables demands to be adjusted to price changes and determine the economic impacts of emission constraints simultaneously [3]. The development of the TIMES-MACRO model for Turkey rests upon the TIMES-Turkey model developed by Isik (2016), a model in which the Turkish energy system is modeled and integrated. In the current study, the TIMES-

MACRO model has been calibrated to the exogenous demand projections in the TIMES model, so that the results in the energy system part of the TIMES model match with the ones in the TIMES-MACRO model for the reference case, and then the results of the calibrated model have been used as a base scenario to evaluate the influences of different policy scenarios.

The next section provides the concept of the TIMES-MACRO model in a more detailed way. Section 3 describes scenario definitions. The results are presented in section 4, and the last section recaps the study.

THE TIMES-MACRO MODEL

TIMES-MACRO determines the interaction between the energy system and the economy subject to a set of technological and macroeconomic constraints. In this modeling framework demands for energy services are linked between the two submodels [19].

The MACRO submodel is an aggregate macroeconomic model that represents the long-term economic growth within an economy-wide production function. The primary production factors capital, labor, and energy establish the aggregate economic output that is allocated to consump- tion, investments, and energy costs. This model maximizes utility subject to a national budget constraint.

In TIMES-MACRO, the interaction between the energy system and the economy is captured through the production function, the economic output equation, and the capital dynamics equa- tion. The main characteristic of the MACRO model is the production function [6]:

$$Y_t = a.\ Kkpvs\ .p. \qquad kpvs\ )p + X^{\wedge 1P}$$
$$Ş\ dm.\ EDp,\ dm$$

dm

The production function is a nested, constant elasticity of substitution (CES) function that defines the gross output Yt as a function of three primary input factors capital, labor and energy. The primary factors capital Kt and labor lt build an aggregate together and can be substituted by each other through a unitary elasticity of substitution. The second term in the production function indicates that each of the useful energy demand forms EDt,dm can be substituted for the other such that if the price of one of these end use energy forms increases, the other ones become more attractive to use. Furthermore, there is the possibility of substitution between the aggregate of energy forms and the aggregate of capital-labor, in case of relative price variations [4]. The substitution constant p is defined through the elasticity of substitution a via this equa- tion: p = 1 - esUb . Elasticity of substitution ESUB expresses the elasticity of price-induced substitution between the aggregate of the energy services and the aggregate of capital and labor [2]. In TIMES-MACRO, the demand for energy services becomes an endogenous model vari- able ED that enters the production function. The production function constant a and the demand coefficients fidm are determined through the calibration process [6].

The economic output Yt is the sum of consumption Ct, investment INVt , and energy costs ECt:

Yt = Ct + INVt + ECt

The capital dynamics equation implies that the capital stock of a period comes from the capital surviving from the previous period and investments made during the period:

Kt +1 = tsrvt. Kt + 1 (dt. tsrvt. INVt + dt+1. INVt+1)

where dt denotes the period length in years.

The capital survival factor tsrvt represents the capital share in a period that has survived until the next period and is based on the depreciation rate depr as follows:

(dt +1+ dt)

tsrvt = (1 - depr) 2

TIMES-MACRO maximizes the discounted utility which is represented by the logarithm of con-sumption Ct :

T-1

Max dft.ln(Ct)+dfT.ln(CT)

t=1
where dft is the discount factor for period t. The discount factor for the last period dfT has a greater influence that continues until the infinite horizon after the last period. The demand constraints link the energy demand in the MACRO model ED-Mtdm with the TIMES energy demand ED.Tt.dm through the 'autonomous energy efficiency improvement factor' for demand dm in period t, (aeei ft,dm):

EDT, dm = aeeift, dm. ED Mt, dm

The energy demand in the TIMES model can be lower than the energy requirement of the MACRO model due to demand reductions, which are caused by autonomous energy efficiency improvements (aeei ft,dm) and come in addition to those taken into account in the energy sector of the TIMES model. The autonomous energy efficiency improvement factors capture the price- independent improvements in energy efficiency [5]. These factors are capable of lowering energy demands per unit of gross economic output [2] and are calculated during the calibration process [6].

Parameters of the TIMES-MACRO Model

The main input parameters needed to run TIMES-MACRO are listed in Table 1 and Table 2.

The elasticity of substitution, parameter ES UB, between the aggregate of capital and labor and the aggregate of energy is not available from statistics. Loulou et al.[17] argue that for en- ergy models having a detailed technological substitution and conservation in end-use sectors, the elasticity of substitution should be in the lower range (0.2-0.3). In line with similar applications for Turkey (e.g. Kumbaroglu et al. [8]) this range was used and ESUB = 0.25 was selected. The pre-defined default values were used for all other Macro input parameters.

Table 1: Macroeconomic Parameters of the TIMES-MACRO Model

Parameter	Description	Value
KGDP	Initial capital to GDP ratio	2.5
KPVS	Initial capital value share	0.25
DEPR	Depreciation rate	5%
GDP0	GDP in the first period	878 (2012$USb)
ESUB	Elasticity of substitution	0.25
DMTOL	Lower bound factor for the demand variables	0.1
IVETOL	Upper bound for investment and energy cost	0.5
ESC	Cost escalation factor	0.001

Table 2: GDP Growth Rate Assumptions

Parameter	2012	2015	2018	2020	2023	2025	2030	2035	2040	2045	2050
gr	2.1	3.3	4.4	4.2	4.3	4.2	4.1	3.9	3.6	3.4	3.1

The energy data for the reference year 2012 were obtained from the Turkish Statistical In- stitute [11]. Energy price forecasts were based on the Turkish Statistical Institute and expert views.

MACRO Calibration

In TIMES-MACRO, energy demand turns into an endogenous variable. Since the exoge- nous demand projections in the TIMES model are disaggregated, and developing disaggregated demand projections according to aggregate levels of economic output is not reasonable, sec- tors with different levels of demand growth should be distinguished [3]. This is the reason that TIMES-MACRO needed to be calibrated through demand decoupling factors (DDF s).

Demand decoupling factors decouple energy demands from economic growth, for instance when rail transport is growing faster/slower than GDP [7]. These factors are MACRO parameters that express price-independent technological improvement and are defined as follows:

. T dt+dt+1

aeeift,dm = | |(1 — ddft,dm) 2

where dd f t,dm is the demand decoupling factor for demand dm in period t, and T is the number of periods in the model horizon.

The calibration process has two goals: the first goal is to calculate demand decoupling factors (DDF s), and the second goal is to match the GDP growth rates that are calculated during the calibration process with the pre-defined GDP growth rate assumptions grt [12].

Scenario Definitions

The BAU scenario

The ”Business-as-usual” (BAU) scenario is defined as the extension of the existing policies and regulations in the energy system without introducing any emissions constraints. In this scenario itis assumed that the current status in the energy demand sectors; agriculture, industrial, residential and commercial, transportation, and the electricity generation sector is continued as usual without any major changes in Turkish energy and environmental regulations throughout the model horizon.

Emission Bound Scenarios

In emission bound scenarios, emissions are constrained to a desired percentage below the BAU levels. In these scenarios, emission constraints are imposed on the total emission levels obtained from the BAU scenario. In this study, emission bound scenarios are analyzed under two levels: 10% and 21%. The 21% emission bound scenario was defined based on the INDC of Turkey, which intended to lower emissions up to 21% by 2030 compared to the BAU Scenario. The 10% emission bound scenario was selected as an easy-to-understand relaxed bound scenario which had meaningful results when compared to the latter one.

Emission Tax Scenarios

Another tool for reducing energy-related CO2 emissions is imposing taxes on carbon emis- sions, which enables to restrict emissions to a specified level. Some nations and regions are already under carbon taxes, such as, British Columbia, Canada, Norway, and Sweden. In Swe- den, carbon tax is charged on every ton of carbon dioxide released, beginning at a rate of €24 in 1991, progressively rising to €114 in 2021 [14]. In British Columbia, Canada, the carbon price is imposed on each ton of CO2 equivalent emissions (tCO2e), the rate of which was $20 in 2019 and increased to $45 per ton in 2021 [20]. Emission taxation is under discussion as a policy tool to reduce emissions. The

magnitude of the carbon tax is much debated by policy makers. A matter under recent debate is whether the amount of tax should rise to a degree as to demotivate nations and industries from employing carbon-based fuels. For instance, Columbia University center on global energy policy has analyzed 3 carbon tax policies $14, $50, and $73 per ton increasing by about 3%, 2%, and 1.5% per annum, respectively. Results of the 50% tax policy indicate that emissions fall by about 40% below 2005 levels and 25% below where the US is currently on track for in 2030 [21]. Carbon taxation is also considered as an emission abatement policy option for Turkey. In this study, emission tax scenarios are examined under $50 and $80 per ton CO2, being constant throughout the model horizon. The $50/ton rate is selected based on anticipated CO2 price levels. The $80 tax scenario is chosen according to the estimated marginal costs of the emission constraints in the 21% emission reduction scenario obtained from the TIMES-MACRO model run. The reason is that the marginal costs (shadow prices) of emis- sion constraints provide reasonable approximations of the carbon tax that is required to achieve the needed emission reductions. This way, the $80 tax scenario can be adequately compared with the 21% emission reduction scenario.

Model Validation

Model results of 2020 are compared with published statistics obtained from [9] and [10] for primary energy use, electricity generation and CO2 emissions as a model validation.

Primary Energy Consumption

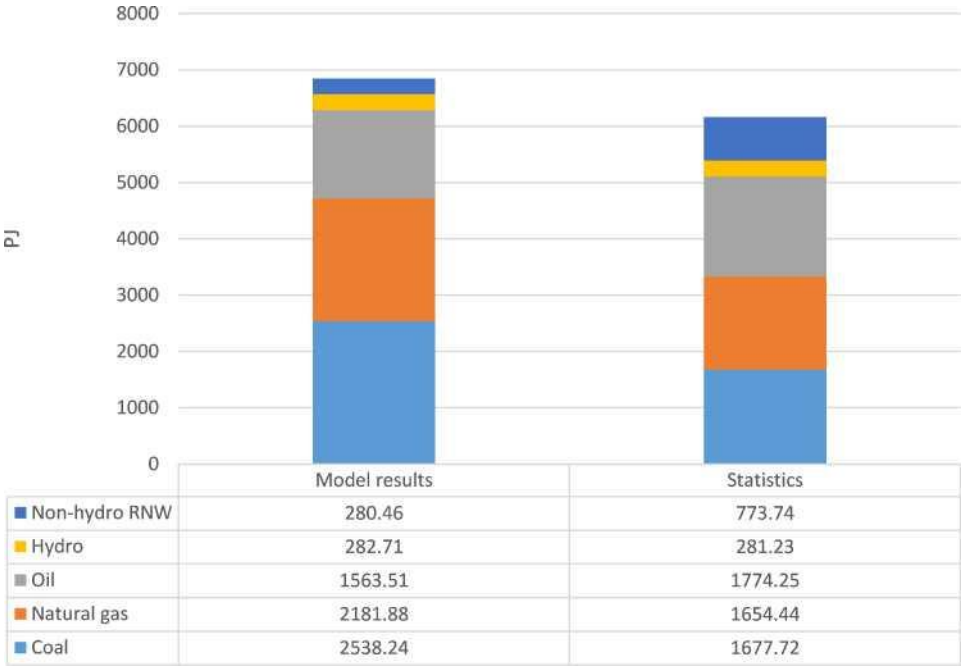


Figure 1: Validation of primary energy use: model results and statistics, 2020.

Primary energy use: model results and realized statistics

Figure 1 illustrates the comparison in primary energy consumption of the model results and the realized statistics for 2020. Overall primary energy consumption levels are higher in model results compared to real data. The reason could be that the economic growth was lower than expected in 2020. In comparison to realized data, the model provides lower levels of high-price renewable energy sources for energy consumption except for hydro. Primary energy results from hydropower aligns closely with the real data. The reason is that hydro is utilizing its exploitable potential.

Electricity Generation: model results and realized statistics

Figure 2 compares model results of electricity generation to the confirmed data in 2020. The

electricity generated from renewable energy sources, except hydropower, is lower in the model results

CO_2 Emissions

than in the real statistics. As a result, the model generates considerably higher levels of electricity from coal and natural gas compared to actual data in 2020. High costs of renewable technologies are likely the reason for this.

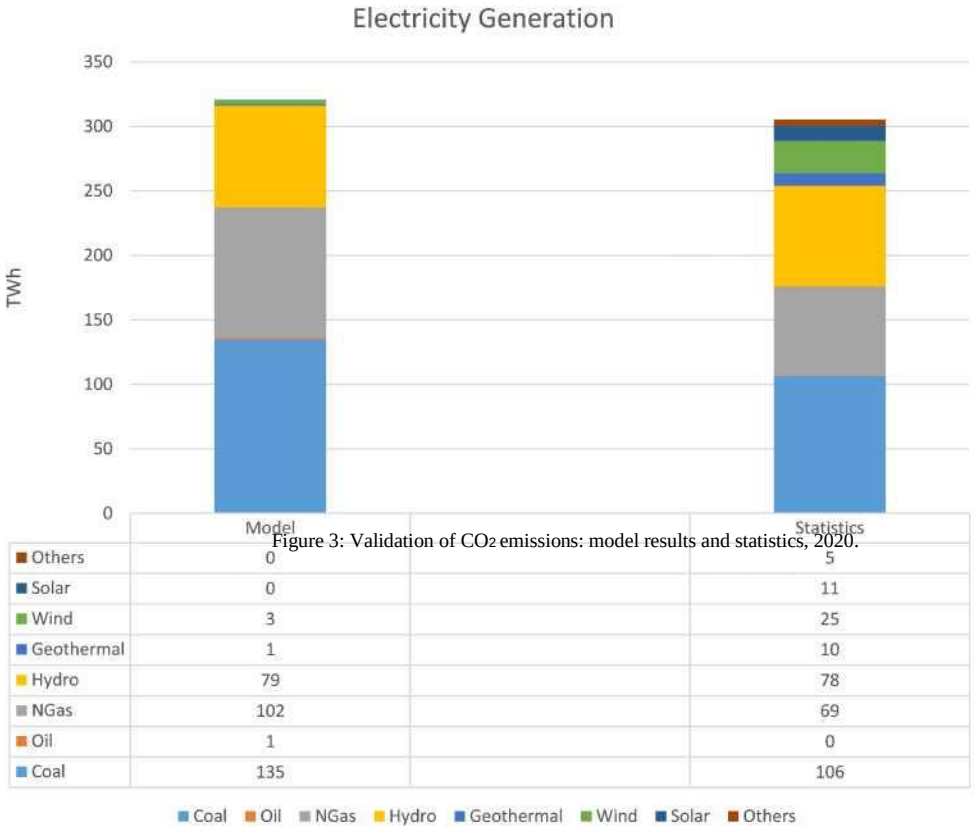


Figure 2: Validation of electricity generation: model results and statistics, 2020.

600
500
400 c
S 300
200
100
0

CO2 Emissions: model results and realized statistics

Since sectoral CO2 emissions were not available from published statistics for the year 2020, total CO2 emission values from model results are compared with real data. CO2 emissions of model results and statistical data are presented in Figure 3. The model generates higher emission levels than the actual 2020 emissions. The reason for this discrepancy is considered to be the lower degree of economic growth in reality than assumed in the model in 2020 and also providing higher levels of fossil fuels by the model compared to the real data in this year.

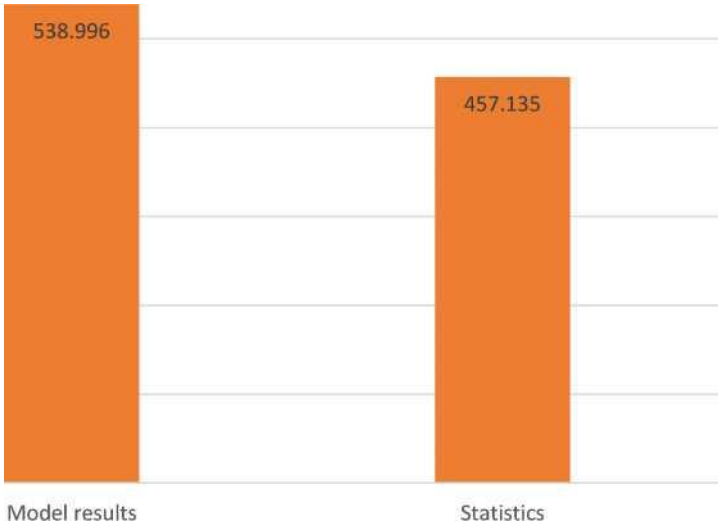
Figure 3: Validation of CO_2 emissions: model results and statistics, 2020.

Model Results

The validation results from previous section prove the consistency of the model for further scenario analysis. In section 5.1, results from the BAU scenario are compared with the emission bound scenarios. Results of the tax scenarios are presented in section 5.2.

Emission Bound Scenario Results

In this section, the results from the reference scenario and the emission bound scenarios are presented and compared. Emission bounds are applied from 2018 onwards.



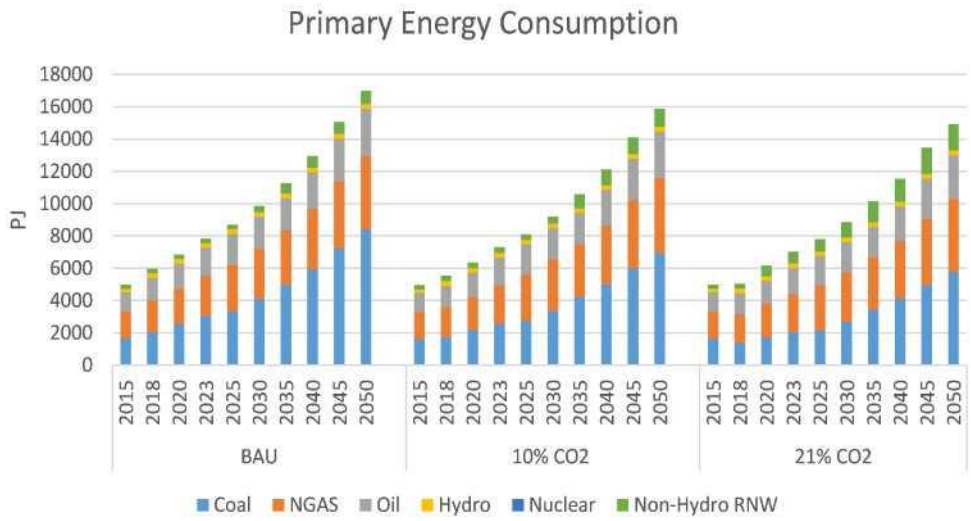


Figure 4: Primary Energy Consumption estimated in BAU and Emission Bound Scenarios

Primary Energy Consumption

As can be seen in Figure 4, primary energy consumption starts to decrease from 2018 in both emission reduction scenarios, for instance, in 10% emission reduction scenario, there is 7.27% reduction in energy consumption compared to the reference scenario in 2018 and under 21% emission reduction scenario, model achieves to reduce energy use to 15.42% lower than the reference scenario. Coal is the dominant energy source in the BAU scenario, since it is the cheapest domestic energy source. Under both emission reduction scenarios, coal consumption increases throughout the model (although at a lower rate), except the severe fall in 2018 in which the emission bound is imposed, and in 2025 that there is a slight decrease in coal share, which is due to the imposed activity bounds on coal power plants in this year. Coal has the highest percentage drop among other fuels and is mainly substituted by renewable sources, while natural gas and oil keep on providing almost the same fractions of energy consumption.

Electricity Generation

The effect of emission constraints on the level of electricity generation is depicted in Figure 5. Under 21% emission bound, the model manages to decrease electricity generation by 15% compared to the reference scenario in 2018. The structural mix of electricity generation is almost the same between the BAU and the emission reduction scenarios. As can be seen in the figure, coal starts decreasing significantly by introducing emission bounds in 2018 in both scenarios. In 2018, the model manages to lower coal by 46% under 21% bound scenario compared to the base scenario, although this percentage is volatile and decreases throughout the model horizon except in 2035 (due to activity bounds that are fixed until 2030 according to the policy assumptions related to lignite use). In the reference scenario, electricity generation from solar power is not preferred. Also, under 10% emission bound, solar power is not favored, although by introducing

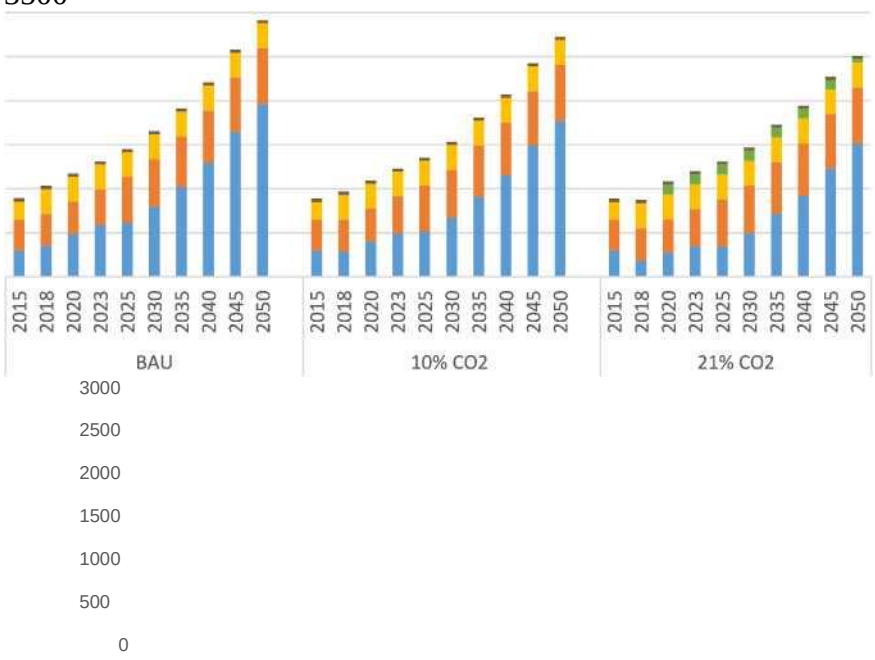


Figure 5: Electricity Generation under Emission Reduction Scenarios

21% emission bound, electricity generation from solar power is promoted and provides nearly 31.18 TWh annually from 2020 until 2045.

Emissions

As can be seen in Figure 6, there are significant reductions in emission levels starting from 2018 compared to the base scenario. The decline in CO2 emission levels under reduction bound scenarios follows the similar pattern that emerges in the base scenario. The electricity sector is the most responsive sector in cutting down emissions and is followed by industry and residential sectors. The transport sector has the least emission reductions relative to the reference scenario even under 21% emission bound. One reason might be the inelastic demand in the transport sector, which can be caused by the high variety of end-use technologies in the transport sector.

Abatement Cost

This section presents the resulting change in GDP of the emission-constrained scenarios with the reference scenario, divided by the relative emission reductions. As illustrated in Figure 7, rel- ative abatement costs do not get progressively higher over time as expected. For instance, under 21%

bound, the abatement cost is calculated to be 266 $/ton CO2 in 2025, which implies tech- nologies used in lowering emissions are costly and there are additional restrictions introduced in 2025. Under the same emission constraint, the relative cost reduces to 138 $/ton CO2 in 2030, which can be an indication that the system has low carbon technologies available at a lower cost in 2030.

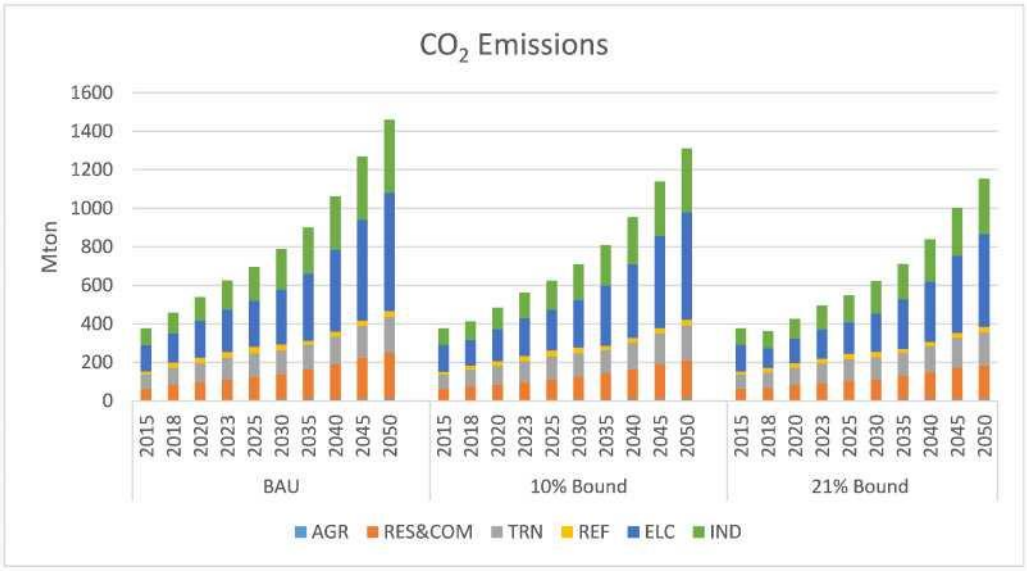


Figure 6: CO2 Emissions estimated in BAU and Emission reduction scenarios. AGR=Agriculture; RESCOM=Residential and Commercial; TRN=Transport; REF=Refinery; ELC=Electricity; IND=Industry.



Figure 7: Abatement costs of emission bound scenarios

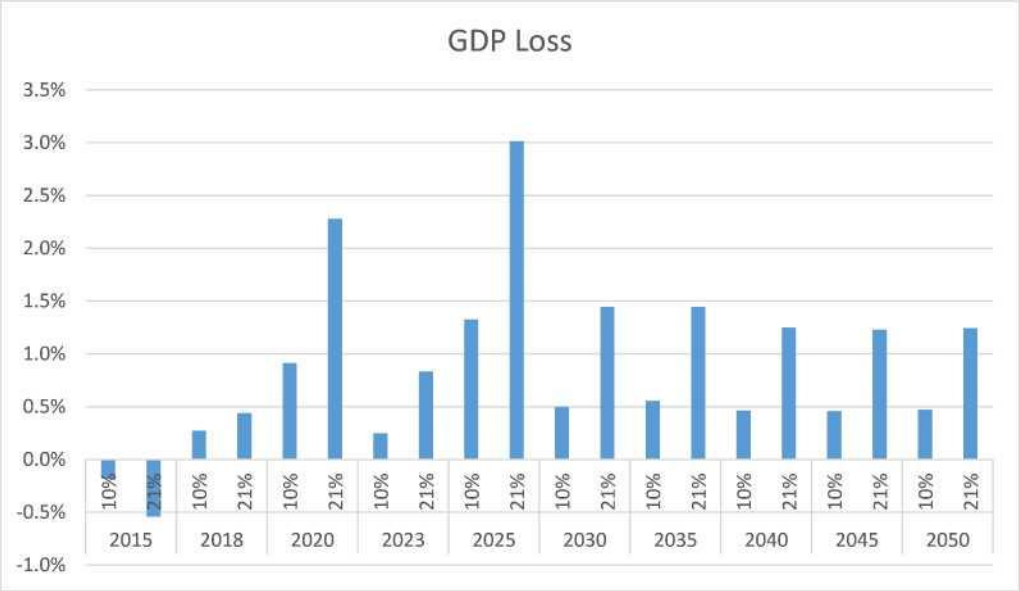


Figure 8: Percentage GDP Loss w.r.t. the Base Scenario in Bound Scenarios

GDP Loss

As emission constraints get stricter, energy costs increase and investment levels decrease that lead to losses in GDP. As can be seen in Figure 8 under 21% emission constraint, GDP decreases by 0.47% in 2050, while under 21% constraint GDP loss is 1.24% compared to the base scenario.

Tax Scenario Results

This section presents the TIMES-MACRO model results under various tax scenarios. In all tax scenarios, the value of tax is applied from 2018 until the end of the model horizon.

Primary Energy Consumption

Figure 9 illustrates primary energy mix by energy source for the base scenario and tax sce- narios throughout the planning horizon. Taxation causes reductions in primary consumption levels equivalent to 5.6% reduction under $50 tax and 8.4% under $80 tax in 2050 compared to the baseline's energy use. As can be seen in the figure, coal and natural gas are dominant fuel sources in all tax scenarios and the shares of renewable sources remain low even under $80 tax. The reason is that TIMES-MACRO has the potential to reduce emissions resulting from a decline in GDP growth and also a reduction in energy demand per unit of GDP. These joint reductions are the reasons that comparatively expensive non-fossil energy supplies are not required.

Electricity Generation

Figure 10 represents electricity generation by source for the base scenario and the tax sce- narios. As can be seen in the figure, the volume of electricity generated decreases as the level

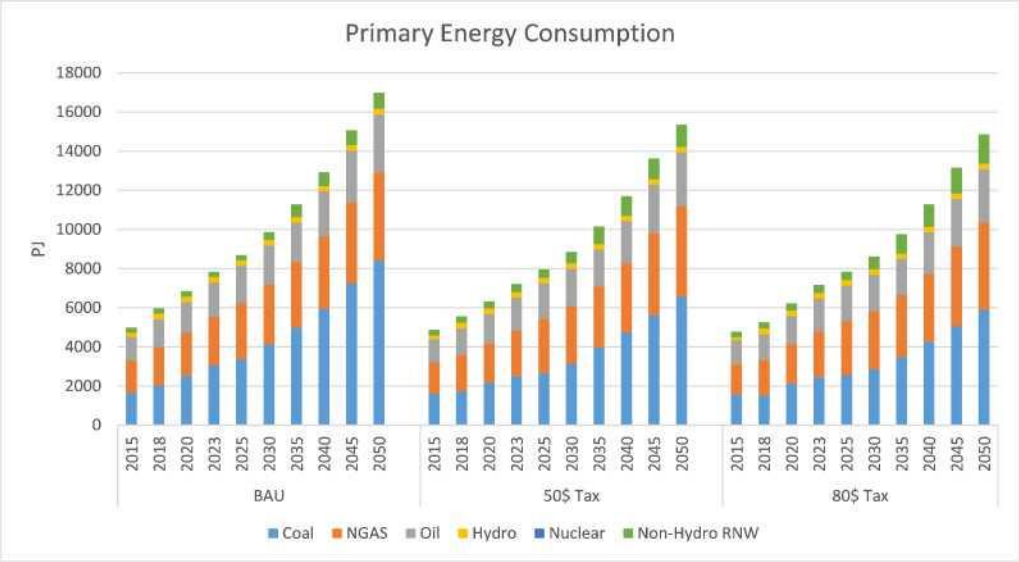


Figure 9: Primary Energy Consumption in BAU and Tax Scenarios

of tax increases, mainly due to demand reductions through behavioral changes in the MACRO model. The mix of electricity generation is dominated by coal and natural gas in all tax scenar- ios throughout the model horizon. In all tax scenarios, the share of renewable sources increases when the tax is imposed in 2018, however decreases towards 2050. For instance, under $50 tax, the share of renewable sources in the generation mix is 31.14% in 2018, while it decreases to 20.3% in 2030 and 11.37% in 2050.

Emissions

As can be seen from Figure 11, as the level of applied tax increases, the overall CO2 emission decreases. The residential sector has the largest decarbonization under tax scenarios, followed by the industry sector and the power sector. The transport sector is the last sector in reducing emissions under taxation. In the transport sector, emission reductions already become available in the reference scenario without any emission restrictions as the system moves to more efficient and electric vehicles. This might be another reason that transport sector is not very responsive to emission constraints.

Abatement Cost

Costs of CO2 abatement in terms of GDP for tax scenarios are presented in Figure 12. In the $80 tax scenario, abatement costs are higher relative to the $50 tax scenario in 2020 and 2025. This difference is due to fewer and more expensive abatement alternatives required to meet the $80 tax in these years. However, as can be seen in Figure 11 after 2025, emission reduction levels are greater in the $80 tax scenario. As a result, even though the GDP values are higher in the $50 tax scenario after 2025 relative to the $80 tax scenario (Figure 13), abatement costs of $80 tax scenario are lower relative to the $50 tax scenario.

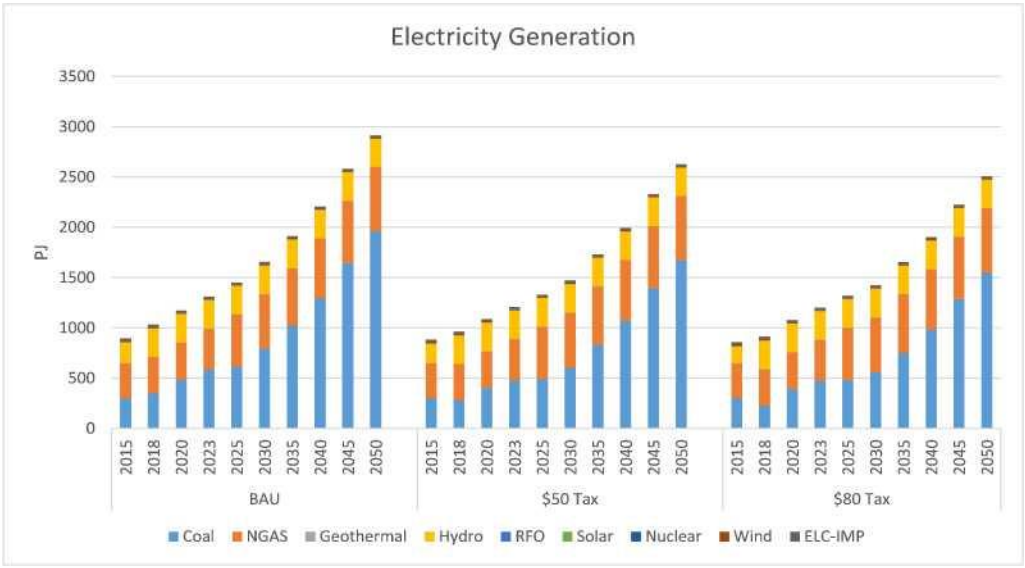


Figure 10: Electricity Generation in BAU and Tax Scenarios. NGAS=Natural Gas; RFO=Residual Fuel Oil; ELC- Imp=Imported Electricity.

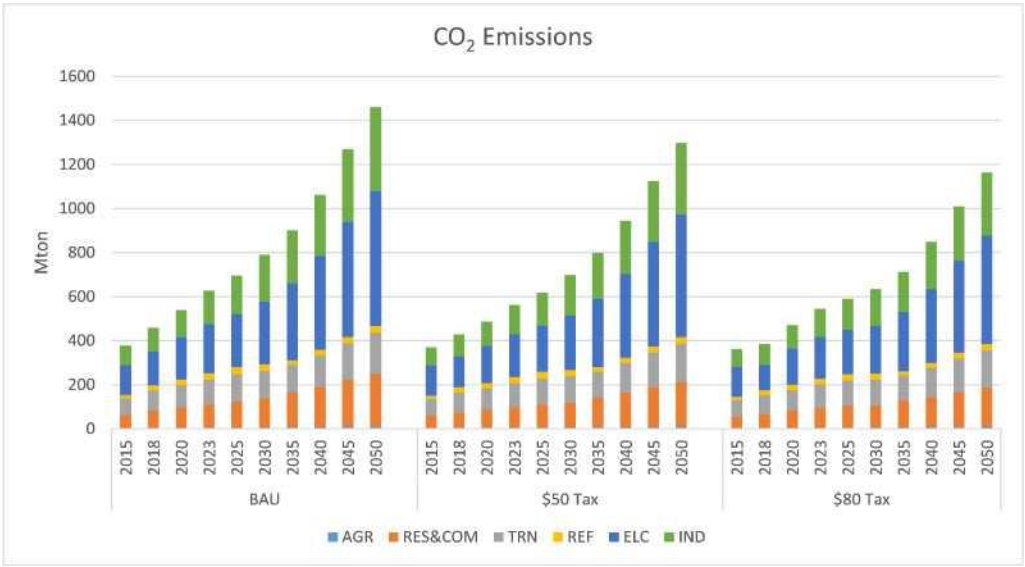


Figure 11: Sectoral CO2 Emissions in BAU and Tax Scenarios. AGR=Agriculture; RES&COM=Residential and Com- mercial; TRN=Transport; REF=Refinery; ELC=Electricity; IND=Industry.

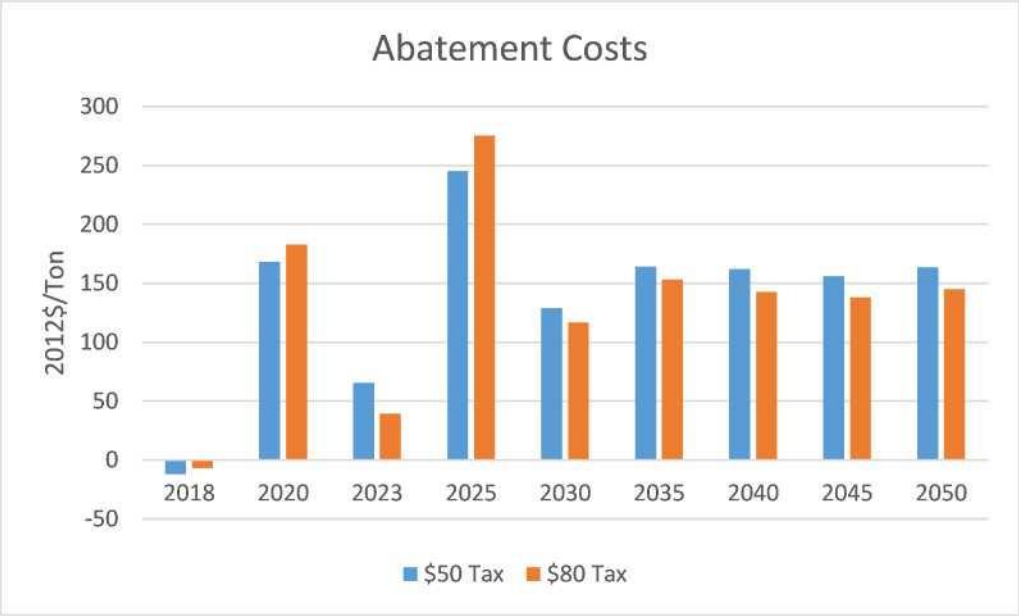


Figure 12: Abatement Costs in Tax Scenarios

GDP Loss

Figure 13 illustrates the percentage of GDP loss with respect to the base scenario for tax scenarios. By applying taxes in 2018, GDP starts to drop from 2020 onwards in these scenarios. As can be seen in Figure 13, GDP loss rate increases as the tax level goes up. The rate of GDP loss relative to the base scenario starts increasing from 2020 and, hits the lowest rate in 2023 and reaches the highest in 2025 and then decreases. GDP losses are greater when higher constraints are applied across the planning trajectory. In $50 tax scenario, GDP losses are between 0.36% and 0.82% except for the periods that have high resource costs and constraints on capacity levels of technologies, where losses are 1.47% in 2025 and 0.91% in 2035.

Emission Bound Scenarios and Emission Tax Scenarios

As Figures 4 and 9 indicate, energy consumption levels decrease in both bound and tax sce- narios. For instance, in 2030 the 21% bound scenario results in 10.12% reduction in consump- tion while the $50 tax results in 10.23% reduction and $80 tax, reduces energy consumption by 12.72%. The reason that consumption levels are lower in tax scenarios is that demands are generated endogenously based on energy prices and under taxation, the system prefers to de- crease demand levels rather than investing on more expensive low-emission technologies, and the amount of reductions in demand levels are higher in tax scenarios compared to emission bound scenarios.

As illustrated in figures 8 and 13, we can see that in bound scenarios, GDP falls as soon as the bounds are introduced in 2018. However, the macroeconomic impacts of emission taxes do not start until 2020, which indicates that initiation of taxation in earlier periods is required 15

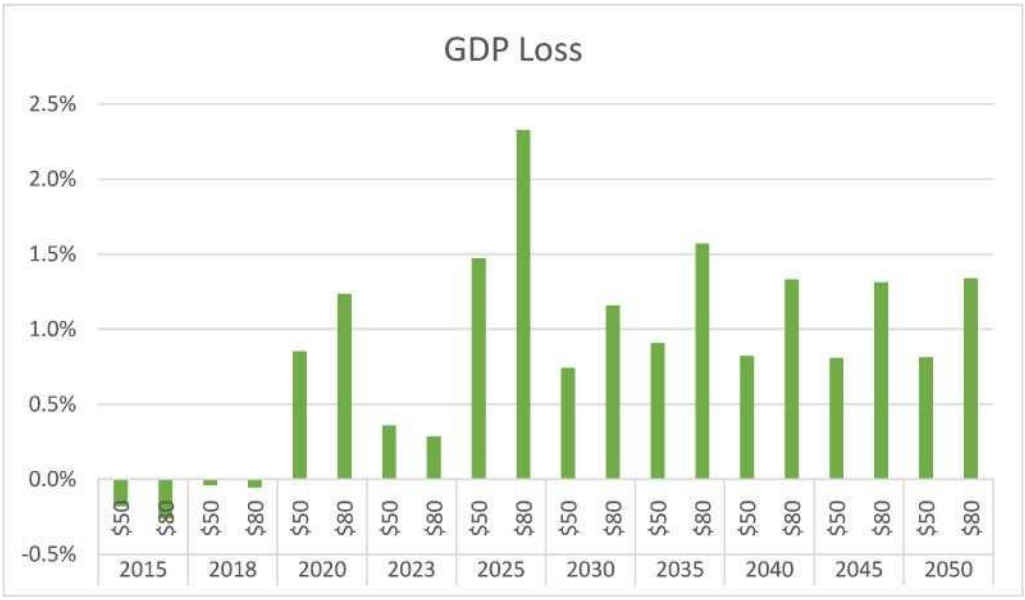


Figure 13: Percentage GDP Loss w.r.t BAU in Tax Scenarios

to restructure the energy system and the economy in order to achieve the desirable reduction in carbon emissions. The magnitude of GDP loss is greater in bound scenarios relative to tax scenarios until 2030 and from this period until the end of the planning horizon, GDP losses are greater in tax scenarios. The reason is that high demand levels in later periods lead to increase in emission levels and the system prefers to reduce economic growth during these periods in order to pay less for taxes. As depicted in Figure 5 and Figure 10, electricity generation is decreased in all scenarios. One major reason is the diminished demand for electricity. Both scenarios reduce electricity generation from coal, however the reduction amount in tax scenarios is less than the emission bound scenarios. The 21% emission bound scenario has approximately the same electricity gen- eration levels as the $80 tax scenario, though $80 tax produces almost the same generation levels by using more coal. This latter generation of electricity, which makes use of coal, might indicate that emission bound scenarios are more effective than tax scenarios.

By comparing Figure 6 and Figure 11, we can observe that emission bound scenarios cut down emissions to the specified levels, 10% and 21% below the CO2 levels in the BAU scenario. Tax scenarios also lower emission levels, majorly in later periods. However, only under the high $80 tax, emission levels approach those in the 21% emission bound scenario.

Sensitivity Analysis

A sensitivity analysis is carried out as a result of the uncertainty associated with the MACRO model parameters. This sensitivity has been examined to analyze changes in main assumptions which is considering higher energy prices. The model runs that have been developed in this 16

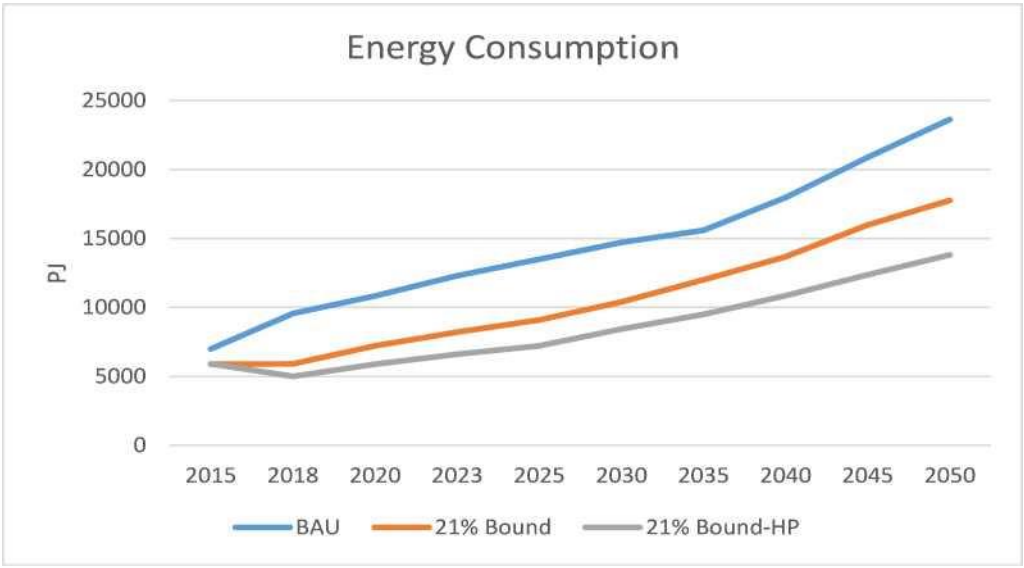


Figure 14: Energy Consumption Levels in BAU, 21% Bound and 21% Bound-HP Scenarios

section, examine 21% emission reductions throughout the model horizon. The ”21% Bound” scenario assumes 21% emission bound with respect to the base scenario starting from 2018 and ”21% Bound-HP” scenario is the ”21% Bound” scenario, except higher resource prices have been assumed in the TIMES model. Figure 14 compares energy consumption levels in 21% bound scenario and 21% bound-HP scenario that has higher resource costs. In 21% bound-HP scenario, that energy resource costs are doubled in the base case in TIMES, consumption levels are less than 21% bound scenario, where energy demand is lower as a result of higher resource costs. The higher resource price scenario (21% Bound-HP) has lower consumption levels compared to the other case (21% Bound), as expected, since the higher resource prices triggers the response from end-use demands and lowers the level of consumption.

Figure 15 illustrates the impact of higher resource costs on the electricity generation sector. High resource price scenario (21% Bound-HP), further cuts base case electricity generation by an overall shift to using more efficient technologies and also as a result of demand response, reflecting higher energy costs.

Figure 16 illustrates marginal abatement costs in 21% emission bound scenarios and the scenario in which the same emission bound is applied along with assuming higher energy prices compared to the prior scenario. As can be seen in the figure, the 21% Bound-HP scenario in which higher resource prices are assumed, has higher abatement costs.

As can be seen in Figure 17, in the 21% emission bound scenario, GDP losses are between 0.44% (the minimum percentage loss) and 3.01%(the maximum percentage GDP loss) except for the high resource price scenario, where GDP losses increase and are between 1.2% and 6.74% respectively.

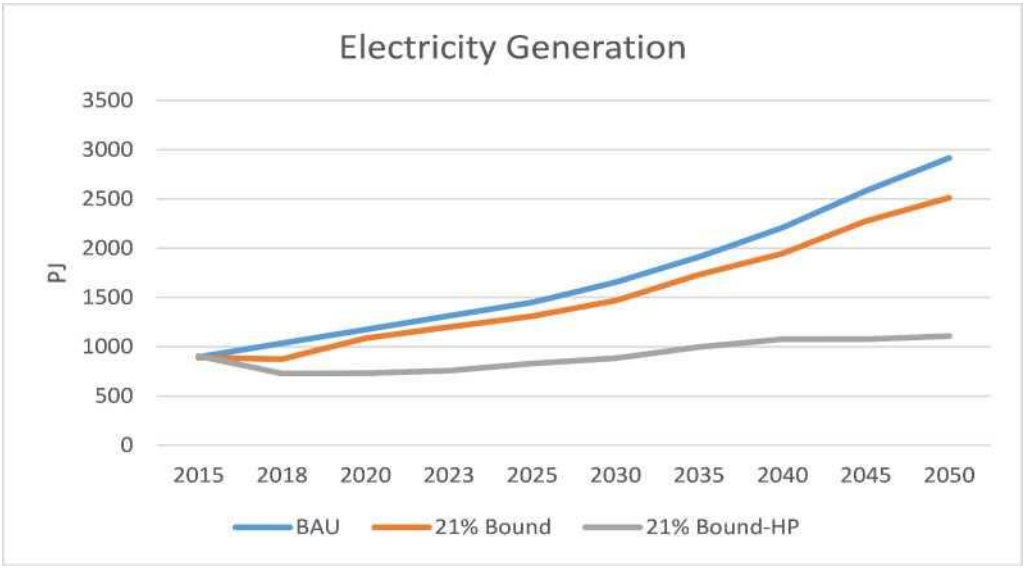


Figure 15: Electricity Generation Levels in BAU, 21% Bound and 21% Bound-HP Scenarios

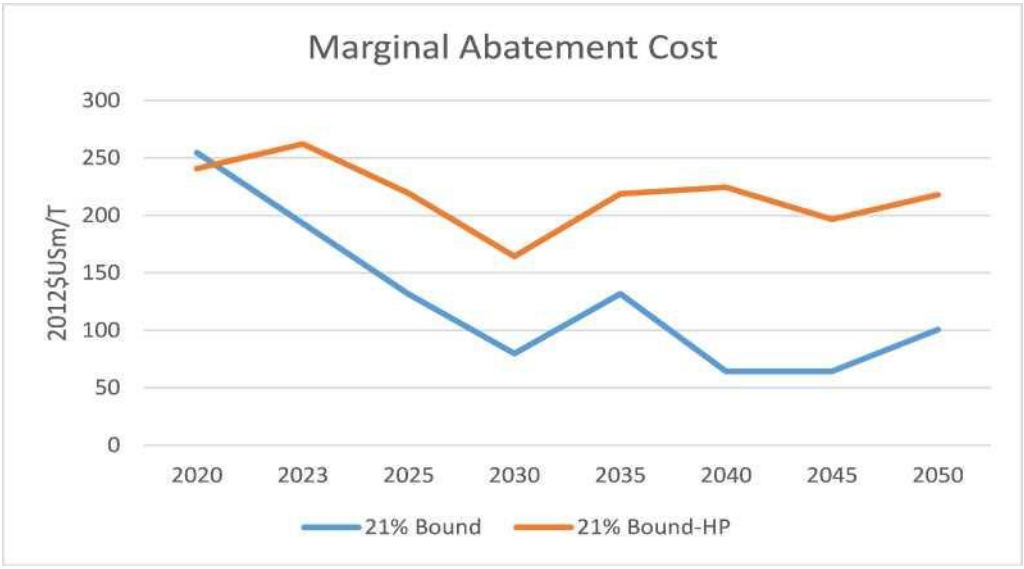


Figure 16: Marginal Abatement Costs in 21% Bound and 21% Bound-HP Scenario

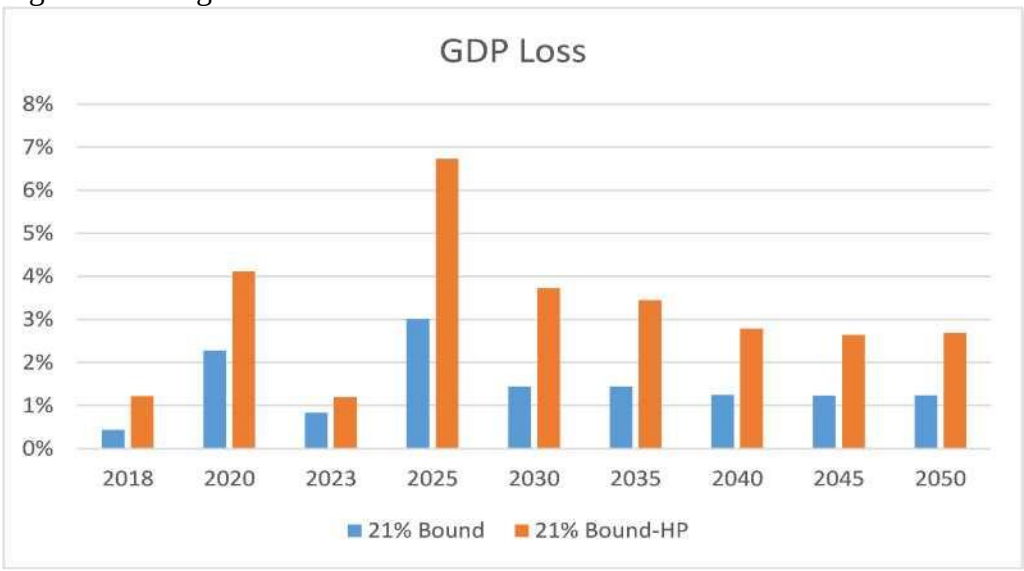


Figure 17: Percentage GDP Loss compared to Baseline in 21% Bound and 21% Bound-HP Scenarios

Conclusions

In this paper, the economic implications of restricting CO2 emissions in Turkey have been evaluated under different scenarios using the TIMES-MACRO energy-economy modelling frame- work. In order to limit emissions either by introducing emission constraints or applying emission taxes, a shift towards low-carbon energy sources and technologies is needed. The technological change is associated with increased energy system costs, although it becomes obvious that these costs can be lowered in both the supply and demand sides of the energy sector. The modelling framework that has been employed in this study, has been calibrated to represent the whole Turk- ish energy system in a technologically detailed manner along with its interactions with the entire economy in an optimization framework which makes least-cost choices based on a system-wide infrastructure. More specifically, it measures the advantages of each option by considering the characteristics of technologies, fuel costs, supply and conversion costs, alternative technologies and demand sectors, and effects on the environment and the macroeconomy.

It is found that in the BAU scenario, i.e. in the absence of environmental constraints and externality costs, the model prefers to use coal as the dominant fuel as it emerges as the cheapest primary energy source. Due to the limited availability of low-cost solar, wind and geothermal power generation and backup requirements for supply security, renewable energy sources are not able to dominate power generation and cut down the demand for coal to reasonable levels. Natural gas starts to compete with coal in the supply combination and maintains its share in the medium term. In the emission reduction scenarios energy demands are determined endogenously based on the energy prices, leading to the fact that demand levels are reduced in these scenarios. By comparing emission cap scenarios with emission tax ones, it is found that an emission cap is more effective than emission taxation. Total energy supply levels are lower in the emission reduction scenarios which indicates investment into more efficient technologies. The abatement costs of emission reduction in the emission bound scenarios, in terms of GDP loss, are found to be in the range of 45-265 $/ton CO2 while high costs are observed to occur in early periods and stabilize in the long run at about 100 $/ton for 10% reduction and 130 $/ton for 21% reduction. In tax scenarios, the GDP loss remains below 2% of GDP with similar behavior as observed in emission bound scenarios. The abatement costs in terms of GDP loss in the emission tax scenarios are found to be less than 100 $/ton CO2 in the long run for tax rates up to 20 $/ton CO2. The $80 tax scenario, which produces emissions similar to the 21% reduction scenario, implies a cost of up to 275 $/ton CO2 being more expensive than the bound scenarios. As such, the cap-and trade policy option appears to be a more rational choice for emission reduction in Turkey when compared to taxation.

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