The General Equilibrium Impacts of Carbon Tax Policy in China: A Multi-model Assessment

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Abstract

The purpose of this modeling exercise is to conduct a multi-model comparison of carbon tax policy in China to examine the potential impacts in both near-term 2020, medium-term 2030 and distant future 2050. Though Top-down CGE models have been applied frequently on climate or other environmental/energy policies to assess emission reduction, energy and economic wide general equilibrium outcomes in China, different models often vary greatly across models. In this paper, we examine and compare a range of Chinese CGE models with different characteristics, to look at a plausible range of carbon tax scenarios, examine and compare the model differences by focusing on a common set of carbon tax policies (low, medium and high carbon tax scenarios), with same socio-economic drivers such as population and labor input projections, GDP projections, foreign energy price shocks and etc. We found the overall impacts of carbon tax to achieve China's 2030 NDC target is similarly on macro-level indicators across the selected China CGE models: low and medium tax pricing regime can help China reach its NDC target with limited negative impacts economic-widely. However, models differ substantially in terms of impacts on detail structure of GDP, price impacts, quantity impacts at sectoral level, as well as energy and carbon intensity reductions.

Keywords: multi-model assessment, CGE model, carbon tax, China

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1. Introduction

China has committed to the Paris Agreements and set its own Nationally Determined Contribution (NDC) target to cut CO_2 emissions per unit of GDP by 60 to 65 percent by 2030, compared to 2005 levels. A more recent debate is to discuss whether China can decarbonize to carbon neutral in 2050, if so, by how much effects on its economic development. A central issue for China's future climate change policy and updated NDC target relies on the cost benefit analysis or cost-effectiveness analysis of new climate/energy policies, especially what climate policies will curtail China's greenhouse gas emissions, and at how much costs?

Given the long-time scale of climate change policies, top-down CGE models are often used to analyze impacts of such carbon pricing policies, such as carbon tax or cap-and-trade policies. These economy-wide models are often multi-sector, general equilibrium, include energy or environmental modules, satisfying market-clearing conditions. It is important to apply multisector model on climate policies because most of the carbon pricing policy would affect major energy sectors, while these are often upstream or major energy inputs for other sectors, leading to larger general equilibrium effects. With a multi-sector model, the inter-sector linkages can be examined thoroughly from the policies implemented at the upstream energy sectors or major energy-using sectors to less energy-using sectors. The general equilibrium analysis is needed for such analysis because the time scale of carbon policies is often by annual terms, and such models have simpler temporal aspects than macroeconomic models that focus on short-run disequilibrium effects. The general equilibrium aspect is also important to shed some light on macro-level economic impacts, so that most CGE models did not depict sectoral technology details as detail as most bottom-up models.

Though Top-down CGE models have been applied frequently on climate or other environmental/energy policies to assess emission reduction, energy and economic wide general equilibrium outcomes in China, different models often vary greatly across models. In fact, not only model structures such as recursive dynamic, perfect foresight dynamic could matters a lot on different theoretical growth models, major assumptions and future projections would also differ substantially, thereby it is very difficult to understand why models predict different results.

In this paper, our goal is to evaluate major Chinese CGE model on their applications on carbon pricing policies, to assess how likely a future carbon pricing regime would mitigate carbon emissions, as well as general equilibrium effects at economy-wide for China. To evaluate this possibility, the Chinese Energy Modeling Forum (CEMF) Working Group focused on carbon tax policy simulations and policy effects based upon simulations provided by 8 dynamic recursive CGE models for China. Whenever possible, our modeling teams have used similar assumptions to represent the base case without carbon pricing and three counterfactual carbon tax policy scenarios (low, medium, high carbon tax rate trajectories).

The use of consistent assumptions on key parameters and projections in this study offer us a unique opportunity to understand both broad conclusions about this group of models simulation of carbon tax on energy use, emission reduction and impacts on GDP, but also potential to examine why model's unique characteristics may deliver different outcomes either by their structure, parameters or simulation strategies with more insights they offer. This special issue of energy economics provides us an opportunity for participating CGE modeling teams to discuss the key insights from their own model in considering various carbon tax policy scenarios. We also draw some conclusion from the 8 CGE model simulation exercises to shed some lights on future carbon pricing policy reform in China. Due to space limitations, our paper only provides a summary of these 8 CGE model in section 2. We do not provide comprehensive model documentation nor complete discussion of their detail model assumptions.

In order to compare these 8 CGE models set and focus on key model characteristics, we impose constraints on a common platform of basic CGE model assumptions, such as population, labor input projections, calibrating a common trend of GDP growth till 2050, and a common set of carbon tax policy scenarios (low, medium and high scenarios) with carbon tax rate set for each year. Given these common model assumptions, we run eight major Chinese CGE models, examine and compare these different models, to examine whether a plausible range of carbon tax impacts exist, and how different models predict different results that we can attribute to its own model characteristics by adding common CGE projection assumptions.

Our study considers the effects of three sets of carbon taxes started to be imposed in 2020 and gradually increase over years. The tax ranging from low tax rate (roughly 5 yuan per ton of carbon dioxide in 2020 to 84 yuan/tCO_2 in 2030, and 283 yuan/tCO_2 in 2050), medium tax rate (roughly 10 yuan/tCO_2 in 2020, to 167 yuan/tCO_2 in 2030, and 567 yuan/tCO_2 in 2050), to high tax rate (roughly 20 yuan/tCO_2 in 2020, to 334 yuan/tCO_2 in 2030, and 1134 yuan/tCO_2 in 2050). In most models, tax revenues are recycled back to reduce other tax rates, while some did not keep neutral tax assumptions. Some models simulate China's carbon tax within a global model, but most models here are national China model or China regional/province CGE models. Are

There are a few EMF modeling comparison projects undertaken by many modeling groups, such as the Stanford EMF projects, focusing on energy-economy models, or integrated assessment models (IAMs), or partial equilibrium bottom-up models (Sugiyama et. al, 2019; Huntington, 2013; Stanford EMF Projects on the Energy Journal Special issue of volume 32 and other EMF reports). There are also a few Chinese modeling analysis for the bottom-up models. However, there are none of these modeling exercises explored the CGE model comparison of China's energy and environmental policies.

The paper is constructed as follows. We first provide a summary of these eight Chinese CGE models in Section 2. In Section 3, we compare major base case projections across these eight models, such as GDP level and growth rate, GDP structure, energy consumption and structure, carbon emission trajectories, energy price and others in the base case when there is no carbon tax policy in place. In Section 4, we compare how these key variables change from base case to counterfactual carbon tax policy case, and Section 5 draw some conclusions of this top-down model comparison analysis.

2. Summary of eight Chinese CGE models for model comparison project

2.1 Participating Models

In order to prepare for model comparison, we sent invitations to major CGE modeling groups in China. We first draft a modeling template with pre-determined common CGE model assumptions, and ask for these models to rerun their model according to our common trajectory of base case population, labor input, GDP and world energy prices, then in the counterfactual policy case, all the models exert a common set of carbon tax policies on upstream energy producers, and in each year the carbon tax rate is fixed so that all the models would implement the same counterfactual carbon tax policy. Finally, eight Chinese CGE model groups participate in this model comparison project.

These models are all recursive dynamic CGE models, most models are single country models, except C-GEM model is a global CGE model putting in China characteristics separately to simulate for Chinese domestic policies. Six models are based on GAMS platform and two models are based on GEMPACK platform. We summarize the basic characteristics of these eight CGE models in table 1 (ordered alphabetically).

Table 1. Summary of eight Chinese CGE Models for Model Comparison Exercises

Model Name	Institution	Model Team	Software Platform	Model Use	Model version	Major Applications	Note on Data and Parameters
1. China-in-Global Energy Model，C-GEM	Tsinghua Univ., MIT	Zhang Xiliang, Huang Xiaodan, Qi tianyu, Weng Yuyan	GAMS	2010s - now	Model 2011(base Year 2011)	National and Global Carbon Market, Environmental Tax, Energy Policies, Renewable Policies	Global Data is based on GTAP 9; China's Energy Data is calibrated to energy data of 2011 in Chinese Energy Statistical Yearbook 2014; Reference: Zhang et. al (2016)
2. CHEER|CGE Model	Tsinghua Univ.	Wenjia Cai, Can Wang	GAMS	2001-now	Model 2012 (Base Year 2012)	National Model and Regional Model; used for intergration with atmospheric model, health models	2012 benchmark year National IO and energy balance sheet, natural capital as share of capital input is based on GTAP 9 data base; Reference: Mu et. al (2018)
3. CHINAGEM	Institutes of Science and Development, CAS	Yu Liu	GEMPACK	2006-now	National Model (Base Year 2012)	Energy Policy, Carbon Tax, Emission trading and environmental tax	2012 National IO data Reference: Zhang et. al (2019)

4. DRC CGE	Development Research Council	Shantong Li, Jianwu He	GAMS	90s - now	National Model (Base Year 2015)	Energy, Climate and Development Policies	2015 National IO data, projection 2019-2050 Reference: Vennemo, He and Li (2014)
5.DREAM (Dynamic Regional Economy-Energy-Environment Analysis Model)	Fudan Univ.	Libo Wu, Haoqi Qian, Weiqi Tang, Ying Zhou	GAMS	2011-now	Global Model 2011 (Base Year 2011)	Energy Policies, Climate carbon pricing policies, Renewable policies	Apply GTAP-POWER+GTAP-E Structure, energy part refer to GTAP-EG setting[1] Reference: Qian et. al (2017, 2018)
6. HTCGE(Harvard-Tsinghua CGE)	Harvard Univ. Tsinghua Univ.	Jing Cao, Mun Ho, Dale Jorgenson	GAMS	90s - now	National Model 2014 (Base Year 2014)	Energy and Climate Policies, Environmental Tax Reform and integration with spatial sectoral emission inventory, atmospheric, and health models	2014 SAM data based on 2012 National IO table, empirically estimated parameters in consumption module, Reference: Cao and Ho (2017), Cao et. al (2016)
7.IMED|CGE Model	Peking Univ.	Hancheng Dai, Yang Xie	GAMS/MPSGE	2009-now	Global Model (2002), National and	Environmental Energy and Climate Policy Analysis, IAM as integration with	China National and Provincial Model use 2012 National and Provincial IO tables, Global CGE use

[1] various elasticities across different electricity technologies based on Papageorgiou & Saam (2015) and Elbakidze & Zaynutdinova (2016): set substitute elasticity between transmission and other electricity as zero, renewable and fossil as 1.84, elasticities within fossil energy is 0.8.

					Provincial Model (2012)	atmospheric, hydrology and crop yield models	2002 data based on GTAP 6 database and IEA energy balance sheet Reference: Xie et. al (2016)
8. SICGE(State Information Center General Equlibrium Model)	State Informati on Center	Li Jifeng, Cai songfeng	GEMPAC K	2007-now	Model 2012 (Base Year 2012)	Macroeconomic Policies, Energy and Environmental Policies	2012 National IO table Reference: Li et. al (2014)

2.2 Suggested Common Assumptions

In order to set up a series of standard assumptions, so base projections on key parameters are uniform for all 8 CGE models, we standardize the major social-economic drivers, such as the future population growth, urbanization rate, and labor input participations in this study, by adopting NDC growth assumptions (Table 2). Consider some models do not differentiate the quantity and quality aspect of labor input, we only provide quantity index of labor input for these models. Some models such as HTCGE actually has both quantity index and quality index based on their micro-level household education, aging and payoff matrix, so they conduct both quantity aspect labor input growth as well as quality index with foreseen improvements on education and continuing urbanization.

Table 2. Basic Assumptions on Population Growth, Urbanization and Labor Input Projections

	2015	2020	2025	2030	2035	2040	2045	2050
Population(mil.)	1375	1411	1426	1428	1418	1395	1366	1331
Urban	771	869	943	998	1032	1045	1042	1033
Rural	603	542	483	430	386	351	323	298
Urbanization Rate (%)	56.1	61.6	66.1	69.9	72.8	74.9	76.3	77.6
Labor input (mil.)	775	768	764	731	702	673	654	632

We did not provide annual GDP estimates, but provide DRC growth forecast on the level of GDP, labor productivity, potential capital growth rate, TFP growth rate, primary sector, secondary sector and tertiary sector projections, as well as decomposition of GDP into consumption, capital formation and net export (Table 3, 4, and 5).

Table 3. GDP growth rate projection and decomposition on labor input, capital formation and TFP

	2015~2020	2020~2025	2025~2030	2030~2035	2035~2040	2040~2045	2045~2050
GDP growth rate	6.5	5.5	4.5	4.0	3.4	3.4	2.9
Decomposed into:							
Labor input growth rate	-0.2	-0.1	-0.9	-0.8	-0.8	-0.5	-0.7
Capital formation growth rate	9.7	7.2	5.7	4.5	3.5	3.2	2.9

TFP	1.7	2.0	2.1	2.2	2.1	2.1	1.8

Table 4. Decomposition of the Projection of China's GDP at sectors

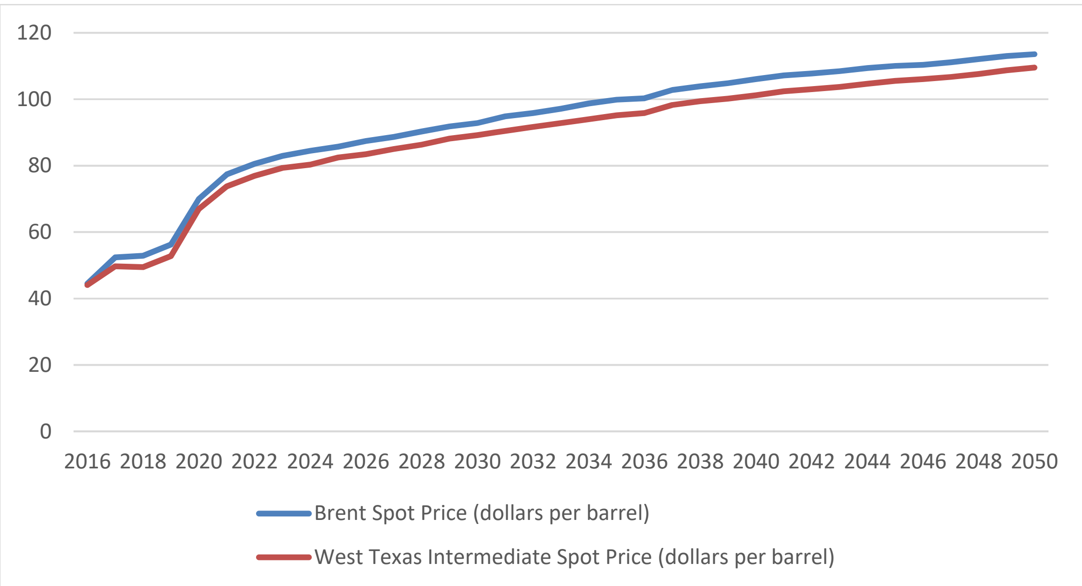
	2015	2020	2025	2030	2035	2040	2045	2050
Primary Sector	8.8	6.7	5.8	4.5	3.7	2.8	2.3	1.8
Secondary Sector	40.9	35.6	31.3	29.1	26.2	24.4	22.6	21.0
Tertiary Sector	50.2	57.5	62.8	66.2	70.0	72.7	75.0	77.1

Table 5. Decomposition of China's Future GDP (Final Demand Approach)

	2015	2020	2025	2030	2035	2040	2045	2050
GDP:								
Household Consumption	38.0	45.5	49.9	50.8	55.0	56.1	57.1	58.2
Government Consumption	13.8	14.7	15.5	16.1	16.6	17.1	17.7	18.3
Capital Formation	44.7	39.8	34.5	33.1	28.3	26.7	25.2	23.6
Net Export	3.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0

In the base case, we also assume the same oil import price to keep common import price shock (figure 1).

Figure 1: Projected Oil Price Forecast (EIA)



Source: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-aeo2017&cases=ref2017~ref_no_cpp&sourcekey=0; collected on January 19, 2019

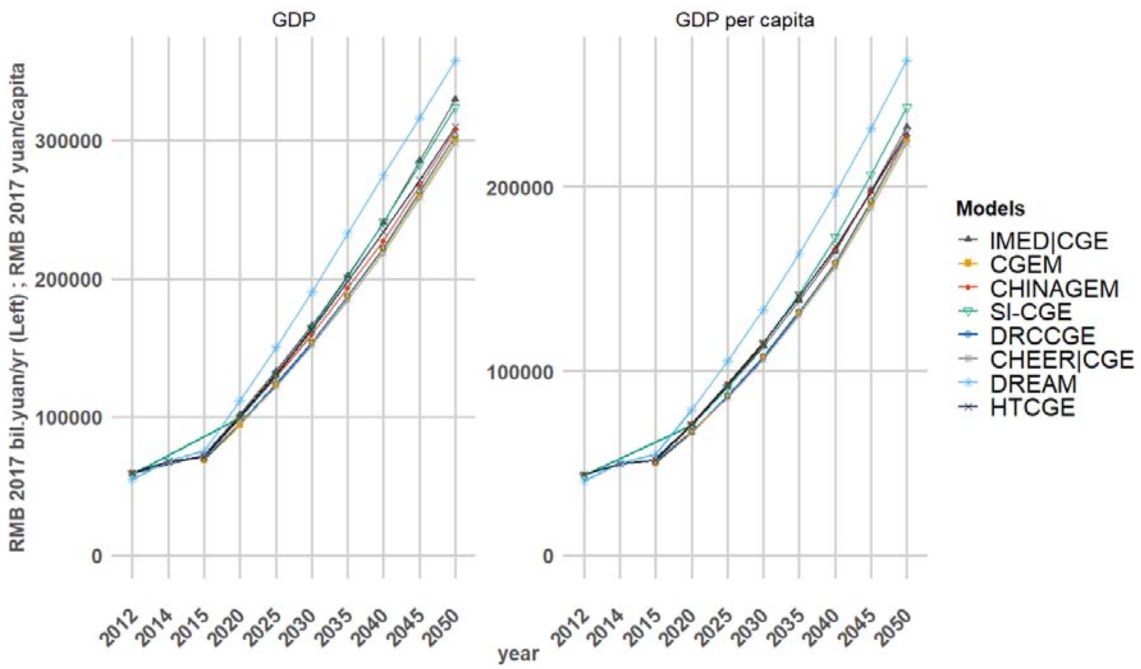
The above economic forecast information was provided to all 8 CGE modeling teams in advance to help them re-calibrate their model. It is not surprising that not all constraints would be satisfied, since models often were based on very different structure and parameters, but we ask them to calibrate their modelled economic trajectory as close as possible to the above assumptions.

3. Base Case Simulations

3.1 Base Case Economic Performance

Given our suggestions on common GDP growth trajectory in section 3.1, all models deliver very similar GDP growth and per capita GDP growth across years from 2012 to 2050 (Figure 2), except DREAM model predict a relatively faster GDP growth than other models.

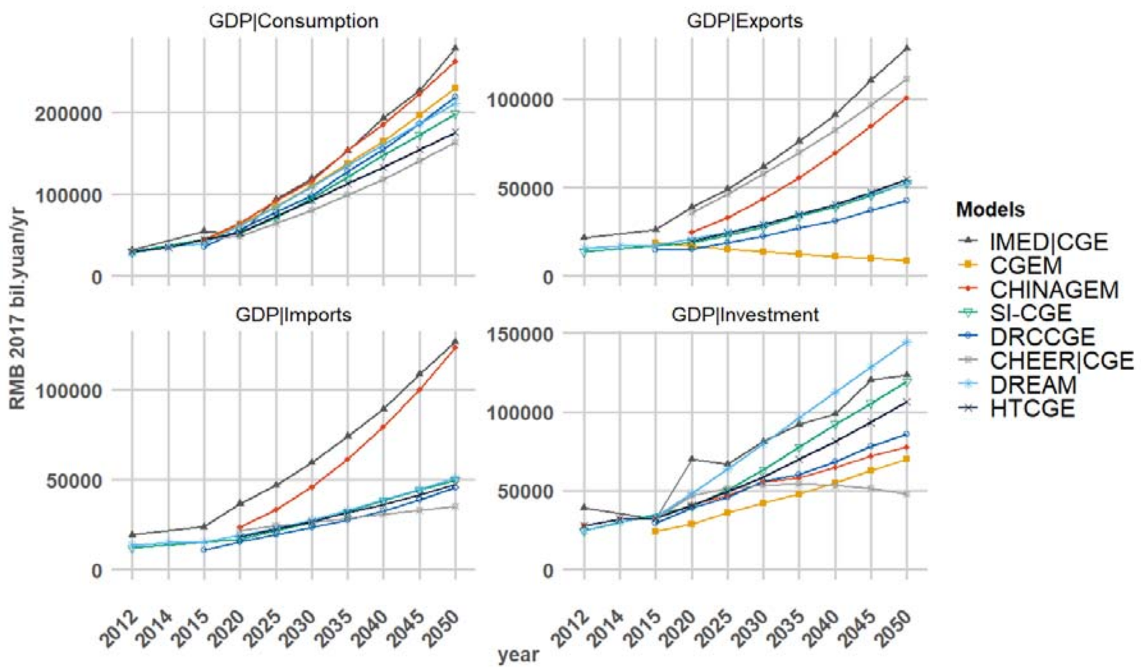
Figure 2. GDP and GDP per capita Projections (2012 – 2050)



Given different model structure, it is relatively easier to calibrate aggregate GDP growth than detail GDP components: consumption, investments, exports and imports. Figure 2 gives the base case model comparison of the GDP decomposition. Overall, all models predict consumptions and imports would grow gradually from 2012 to 2050, some models predict China's future export and investment will decline over time. The differences across models mainly lie in different model assumptions upon whether China's high investment tendency will continue or not, and whether export tendency vary across time with complex international trading circumstances.

Figure 3 shows IMED|CGE shows higher growth pattern on all consumption, investment, export and import than other models. ChinaGEM also shows relatively high consumption, import, and import, but lower projection of investment growth. Although IMED|CGE and ChinaGEM predict higher export and import, the net export is similar and partly offsets the higher consumption pattern, so that the aggregate GDP growth in figure 1 is not as different as other models. The discrepancies of higher import group (IMED|CGE, ChinaGEM) mainly lie in its different assumption of rest of the country assumption and trade parameters. In terms of investment, all models predict a gradual increasing trend, of which IMED|CGE, DREAM and SI-CGE have relatively higher growth rate, CHEER|CGE has an inverted U-shape with peak around 2030, IMED|CGE has a much t peak of 2020 but then slow down; the other models all show a close to linear growth pattern.

Figure 3. GDP Decomposition: Consumption, Investment, Export and Imports

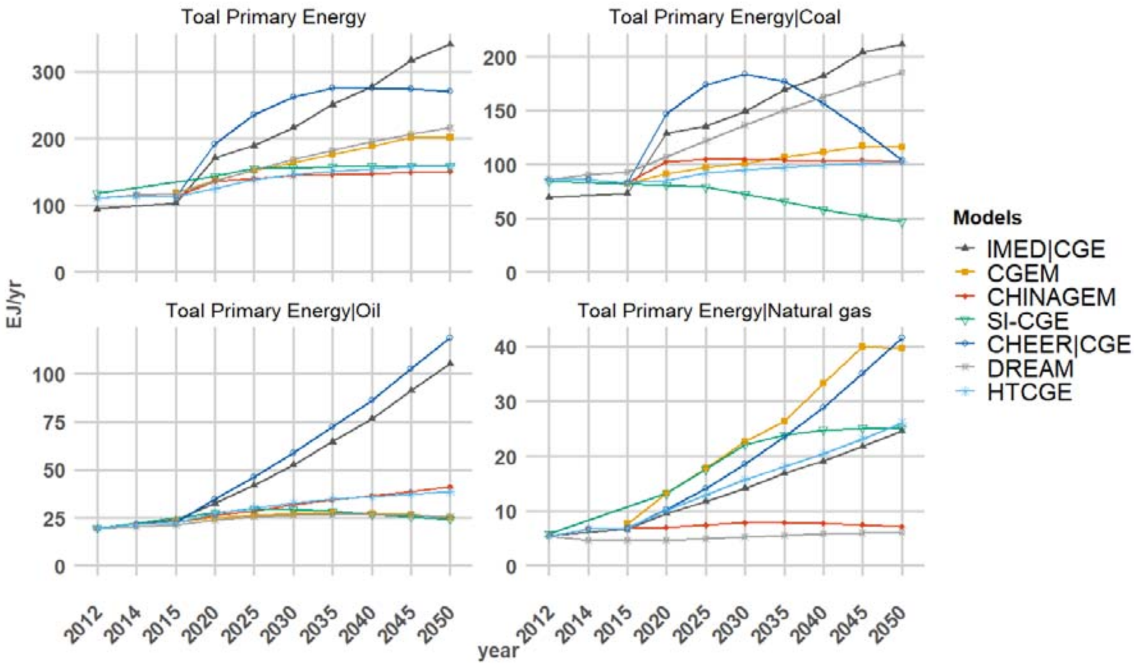


3.2 Primary Energy Use and Structure

Figure 4 shows the projection results of all 8 models in terms of total primary energy (TPE) use, and the relative share of coal, oil and natural gas. The initial year primary energy of IMED|CGE is slightly lower than other models, but then it grows faster. CHEER|CGE peaks the primary energy around 2035, then gradually stabilize with small decline after 2035, thus presenting an inverted U shape. This is mainly driven by an inverted-U shape coal growth, which bend the total primary energy use even though in fact its oil and gas growth are also higher than other groups. It suggests that, even at the base case which no climate policies in place, there are either other energy policies in place so that coal use are restricted. It is not clear why CHEER|CGE suddenly increase coal use around 2030. The rest models such as CHINAGEM, HTCGE and SI-CGE are very similar, with small growth till 2050.

Except the inverted U shape of CHEER|CGE model and SI-CGE with consistently declining patterns, IMED|CGE and DREAM assume a higher growth of coal and oil, which may be driven by the high growth rate of major economic performances discussed in Session 3.1. CGEM project the highest natural gas usage in the base case, compared to all other models. In terms of natural gas, DREAM and CHINAGEM predict very stable natural gas usage (around 6EJ/yr.) till 2050, while all other models a steady growing trend except SI-CGE peak around 2030 then decline over time.CGEM and CHEER|CGE predict natural gas would achieve about 40 EJ/yr in 2050, while SI-CGE, HTCGE and IMED|CGE achieve about 25 EJ/yr..

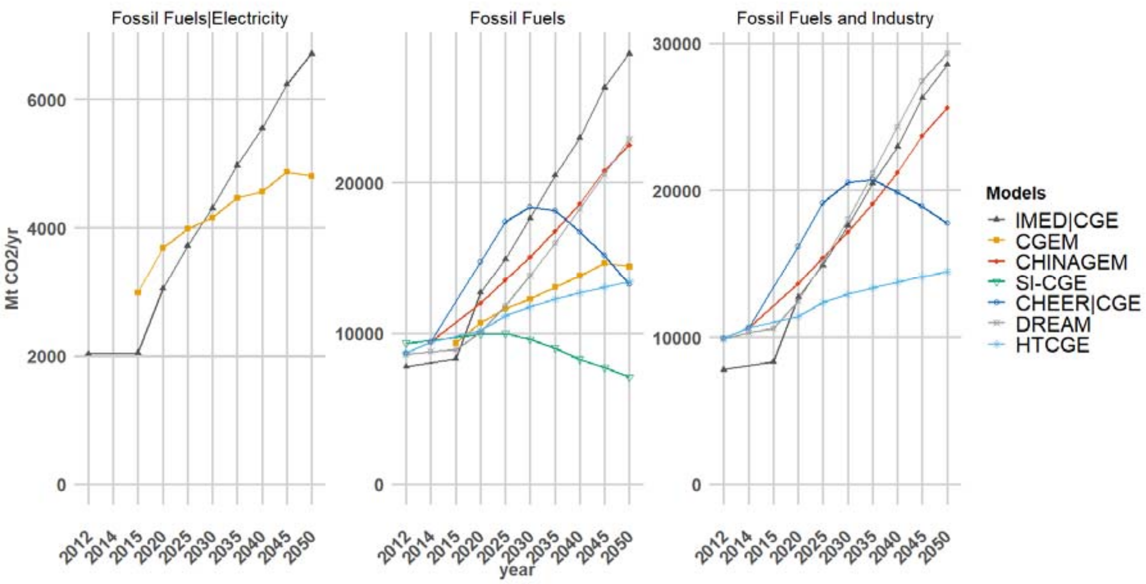
Figure 4. Base Case Projection of Total Primary Energy, Coal, Oil and Gas



3.2 Carbon Emissions

Since majority of carbon emissions in China are from combustion of fossil fuels, the pattern of carbon emissions across models present similar pattern as the primary energy or coal use (Figure 5). Only CHEER|CGE and SI-CGE peak carbon at 2030 and 2025 respectively in the base case, while other models simulate increasing growth of carbon emissions for both fossil fuel combusted or both fossil combusted + processed emissions mainly from cement sector. IMED|CGE and DREAM has higher growth of carbon emissions, which is consistent with their higher energy use and economic performances. HTCGE and CGEM have similar pattern on fossil carbon emissions, roughly half of IGEM|CGE and DREAM predictions. SI-CGE shows a declining pattern of carbon emissions from fossil fuels, right after peaking around 2025 in the base case, this may suggest even without carbon pricing policies, some other policies would have affect the coal use in their base case. HTCGE predict lower fossil fuel combusted emissions as well as processed emissions, which is due to their energy performance calibrated to recent IEA report, with very little growth on coal use. Only IMED|CGE and CGEM report the fossil-fuel combusted carbon emissions from electricity sector only, which shows similar patterns as their fossil fuel emission patterns.

Figure 5. Carbon Emissions Projection in Base Case



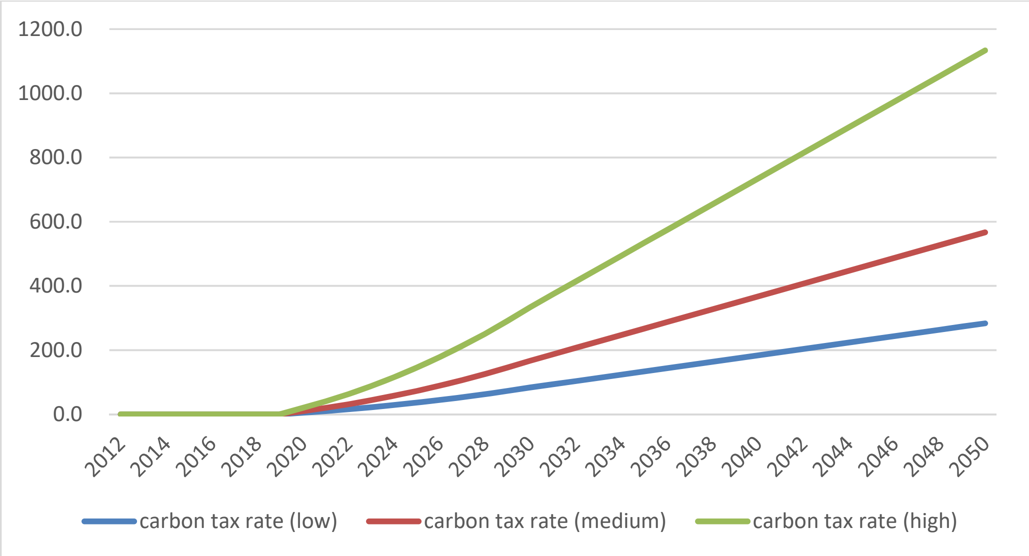
4. Counterfactual Carbon Tax Policy and Simulation Results

4.1 Carbon Tax Scenario

For this multi-model carbon tax simulation assessment, we analyze the following three scenarios with gradually increasing carbon tax rate imposed on upstream energy producers such as mine mouth of coal, oil and natural gas mines (Figure 6). Though we harmonize the socioeconomic drivers such as population/labor and aggregate GDP growth, each model still did not harmonize at other specific economic and energy use drivers, such as TFP and induced technology change as well as production/consumption function forms and relevant substitution elasticities and etc.

1) Low carbon tax: 5 yuan/tCO_2 from 2020 to 84 yuan/tCO_2 in 2030, and 284 yuan/tCO_2 in 2050;
2) Medium carbon tax: 10 yuan/tCO_2 from 2020 to 167 yuan/tCO_2 in 2030, and 567 yuan/tCO_2 in 2050;
3) High carbon tax: 20 yuan/tCO_2 from 2020 to 334 yuan/tCO_2 in 2030, and 1134 yuan/tCO_2 in 2050;

Figure 6. Carbon Tax Rate Schedule (2020-2050)



The tax revenue can be used to reduce pre-existing taxes or simply lump transfer to household, these two options were left to the individual modeling groups' choice. For instance, HTCGE choose to cut pre-existing value added tax, corporate income tax and etc. Some models such as CHEER|CGE did not keep revenue neutral assumption, so the government size would be potentially larger than the base case.

4.2 Results: Impacts of Carbon Tax Policies

1) Impacts on Macroeconomic Indicators:

Figure 7 presents the impacts of carbon tax policies on GDP level. The results of CHINAGEM is not drawn on this graph, since its GDP impacts are roughly -5% to over 40% in 2050, much larger than the results of other modeling teams, which are all below 10%. CHEER|CGE predict a double dividend of carbon tax, which is higher for high carbon tax scenario, but in later years also causing big drops of GDP. At low carbon tax scenario, the impacts of GDP would reach -10%. Except CHEER|CGE and SICGE, all the other model predicts much less GDP loss, all below 4%. Since the population data is harmonized across all the modeling teams, so impacts on per capita GDP has the same pattern.

Figure 7. Impact of Carbon Tax Policies on GDP (% change, compared with Base Case)

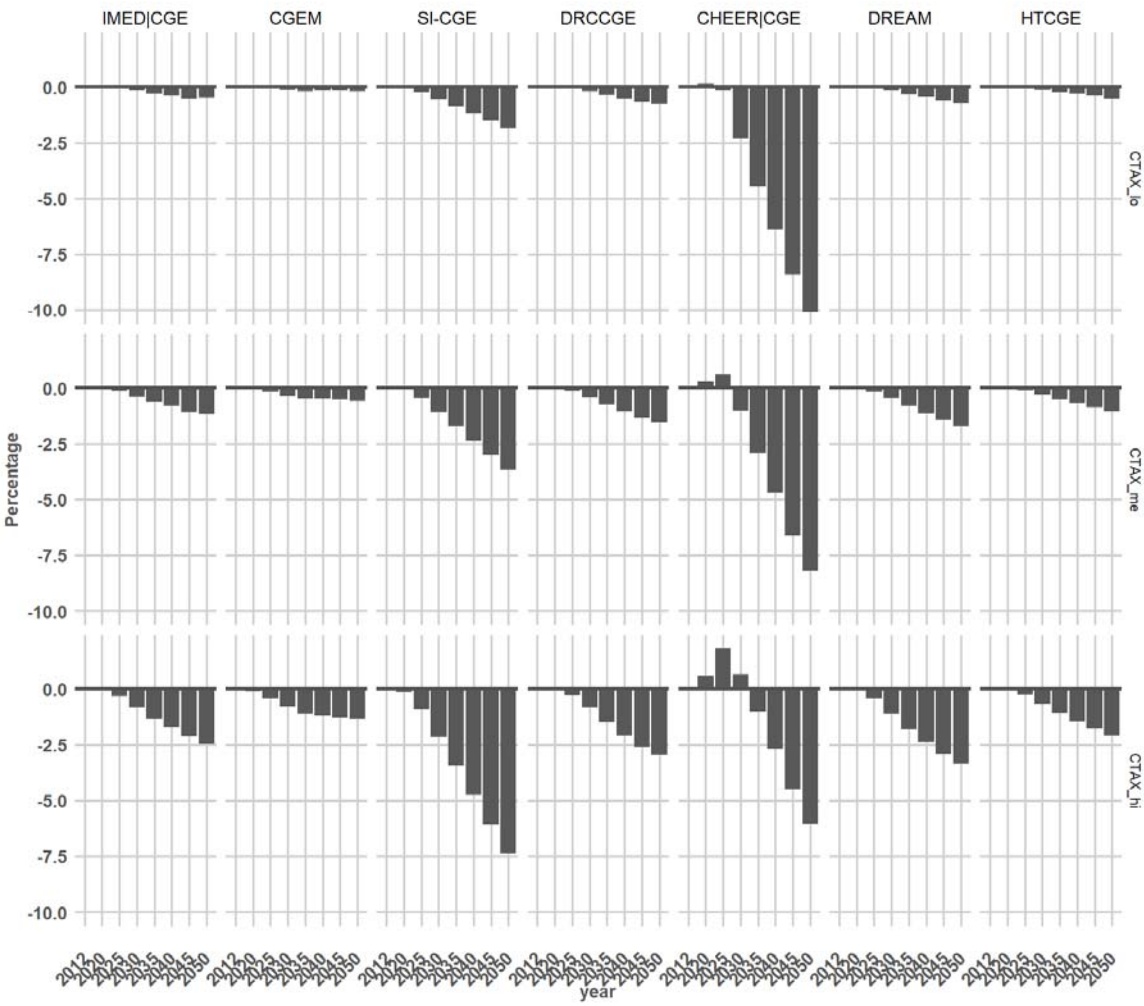


Figure 8, 9, 10 and 11 presents the impacts of carbon tax on consumption, exports, imports and investments. Consider the big GDP effects of CHINAGEM, we did not include CHINAGEM results here.

Considering the consumption aspect, only CHEER|CGE has a positive impact on consumption, export and investment, this may be related to its revenue recycling assumption, since this model does not assume revenue neutral in the counterfactual carbon tax case. The positive impacts are consistent with the double dividend result, but the impacts on imports are negative and much larger than other groups, this after 2030 offsets the positive impacts on consumption, export and investment, causing a net loss on GDP. Interestingly, IMED|CGE, SI-

CGE, DREAM and HTCGE predict similar impacts of less than 2% impact on consumption for low carbon tax scenario, 2-3% impact for medium carbon tax scenario, and 3-5% impact for high carbon tax scenario. All models have bigger and negative impacts on exports except CHEER|CGE, ranging from 2.5-4% for low carbon tax scenario, about 3% - 5.5% for medium carbon tax scenario, and 6% - 8% for high carbon tax scenario. All models include CHEER|CGE have negative impacts on imports, and SI-CGE predicts very small impacts of less than 2%, while CHEER|CGE predict more than 10% impacts for high carbon tax scenario in 2050.

Figure 8. Impact of Carbon Tax Policy on Consumption (% change from Base Case)

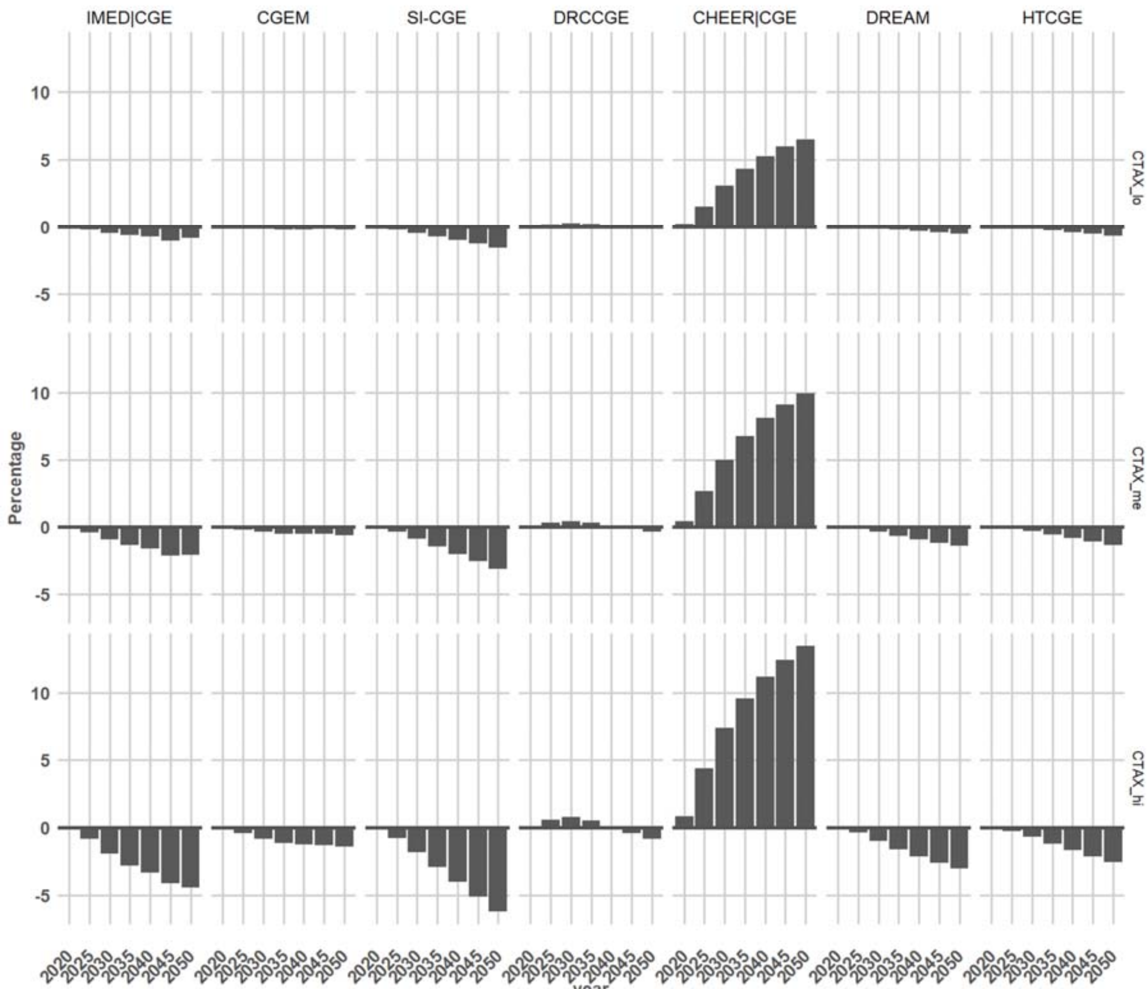


Figure 8. Impact of Carbon Tax Policy on Exports (% change from Base Case)

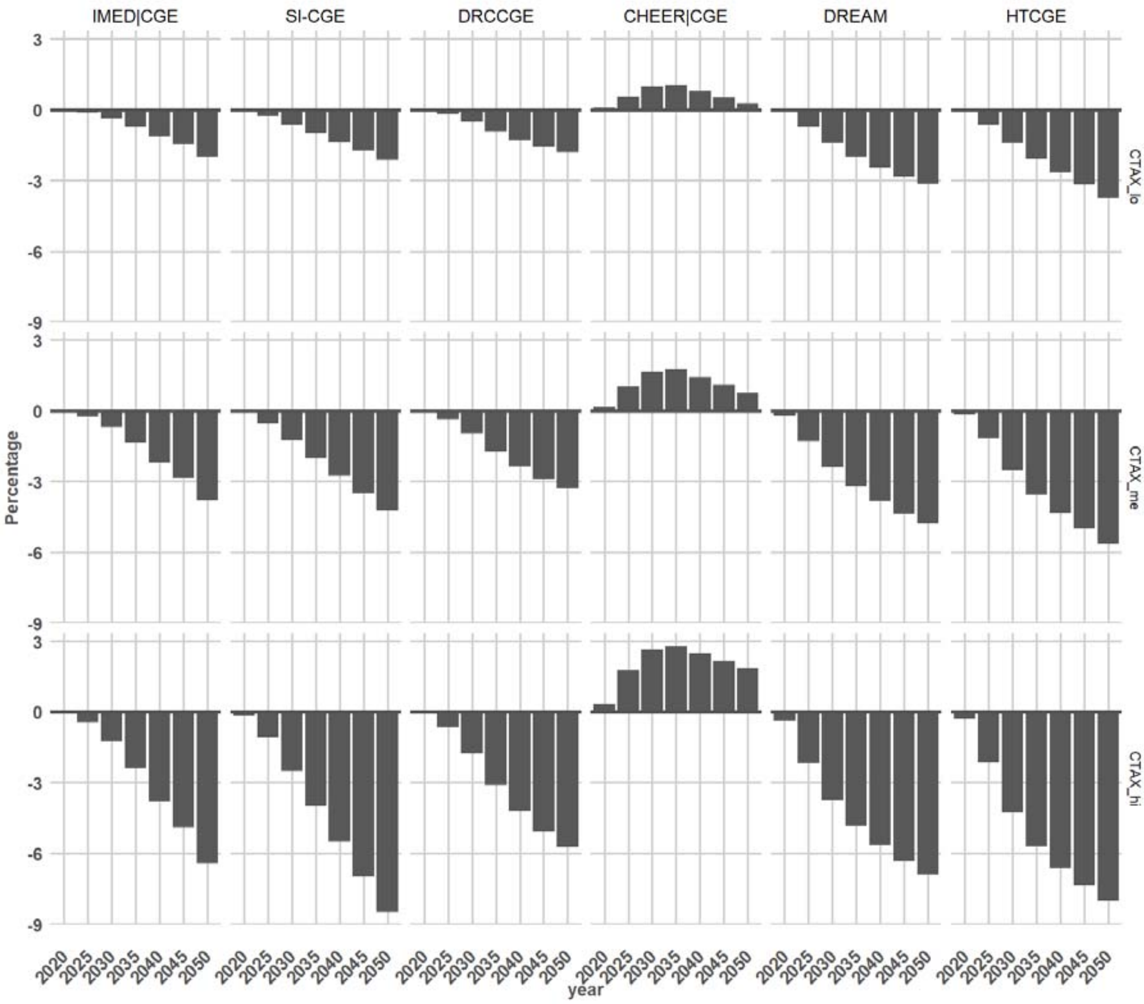


Figure 9. Impact of Carbon Tax Policy on Imports (% change from Base Case)

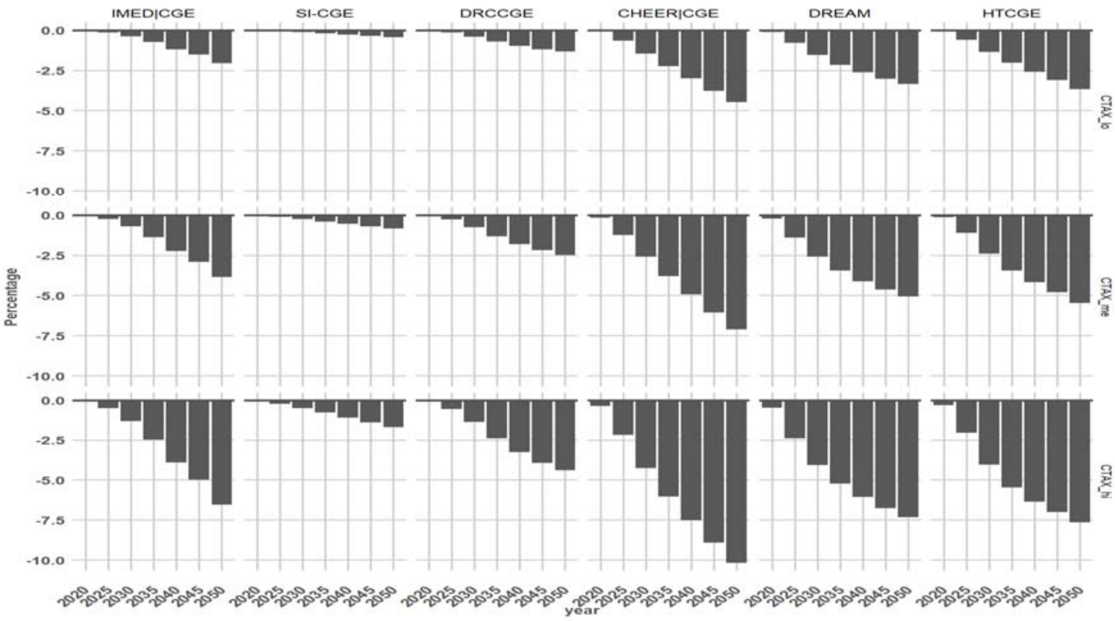
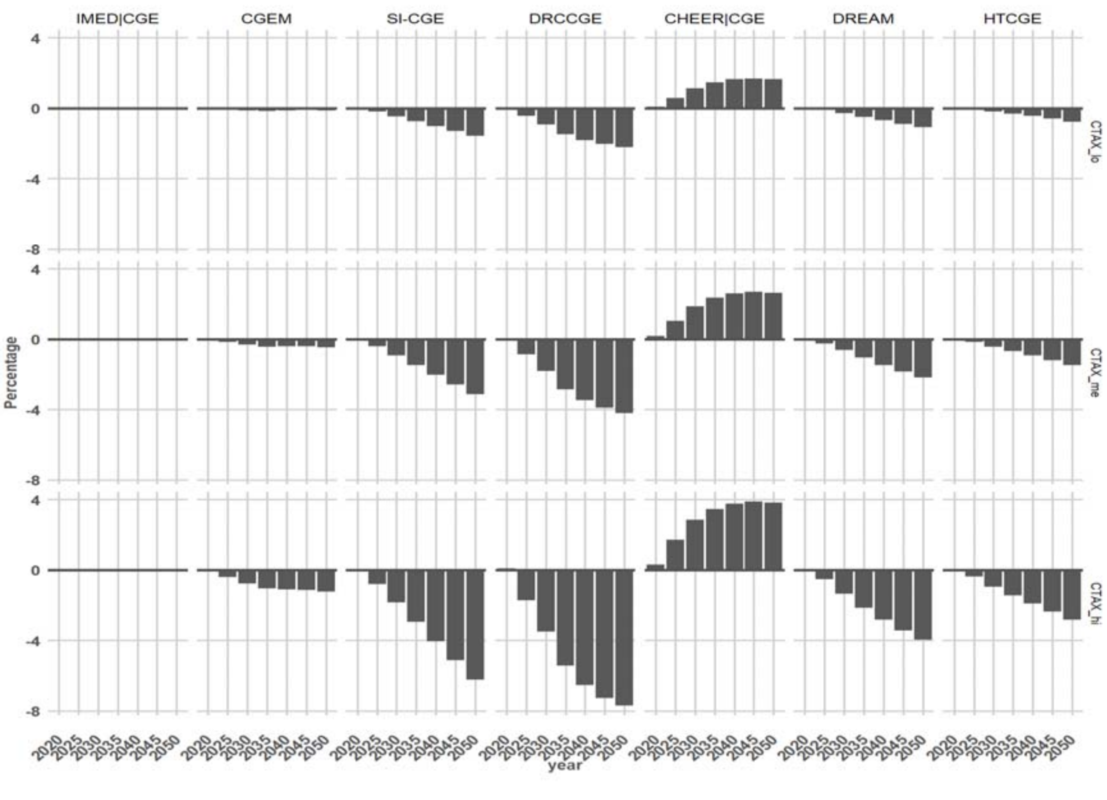


Figure 10. Impact of Carbon Tax Policy on Investment (% change from Base Case)



2) Impacts on Energy Use and Carbon Emission Reductions

As for total energy use, most models found similar impacts of carbon tax, for instance in the last year of 2050, roughly 10% - 20% for low carbon tax, 12% - 30% for medium carbon tax, and 25-40% for high carbon tax. CHEER|CGE has relatively higher impacts than rest models, such as reaching 60% total primary energy for high carbon tax in 2050. SI-CGE on the other hand has lowest impacts, even for the high carbon tax scenario the total primary energy only drop by 9% in 2050.

Figure 11. Impact of Carbon Tax Policy on Total Primary Energy (% change from Base Case)

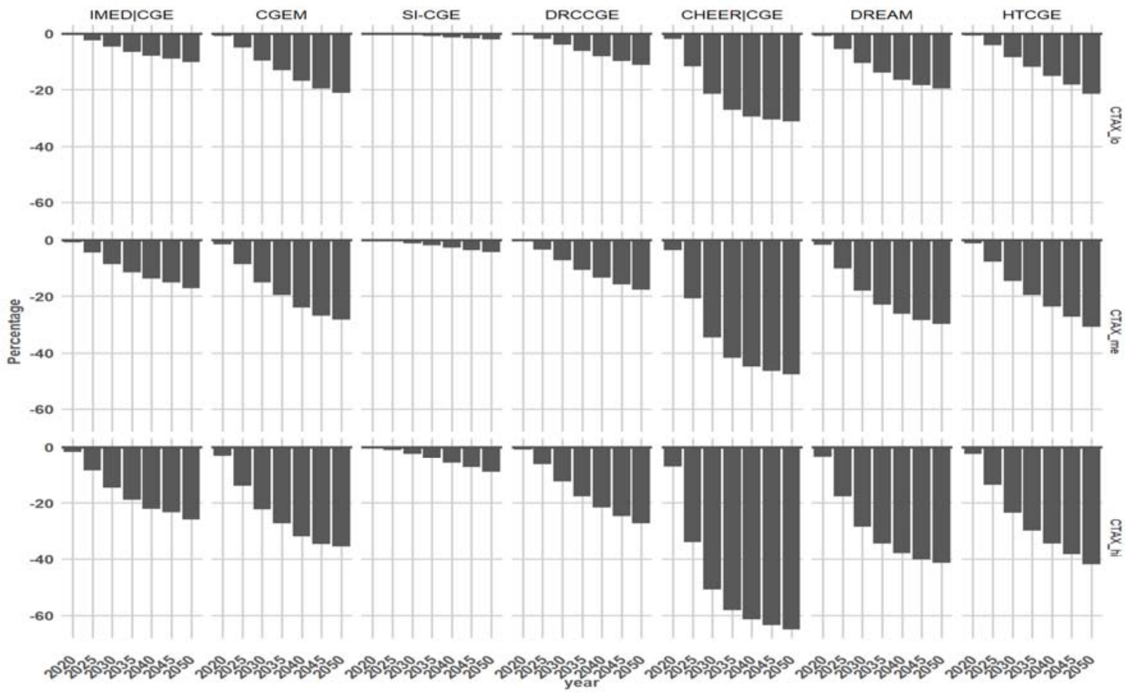


Figure 12 provides impacts of carbon tax on coal use, and the patterns have similar patterns except SI-CGE has larger drops on coal use than on primary energy use, and also more sensitive, though less impacts for low carbon tax scenario but higher impacts for high carbon tax scenario. This is partly due to the higher energy substitution than other models within the primary energy mix, when coal and oil are constrained, natural gas would increase, so less impacts on total primary energy. CHEER|CGE still decrease faster than other models; and reach -60% in the high carbon tax scenario compared to the base case.

Figure 12. Impact of Carbon Tax Policy on Total Coal Use (% change from Base Case)

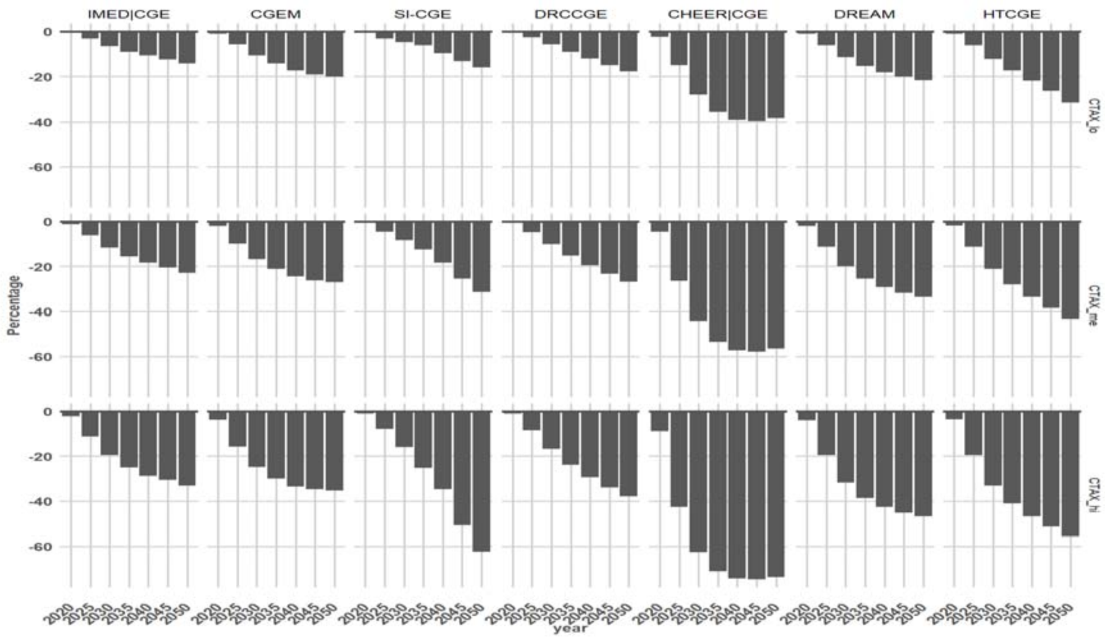


Figure 13. Impact of Carbon Tax Policy on Total Oil Use (% change from Base Case)

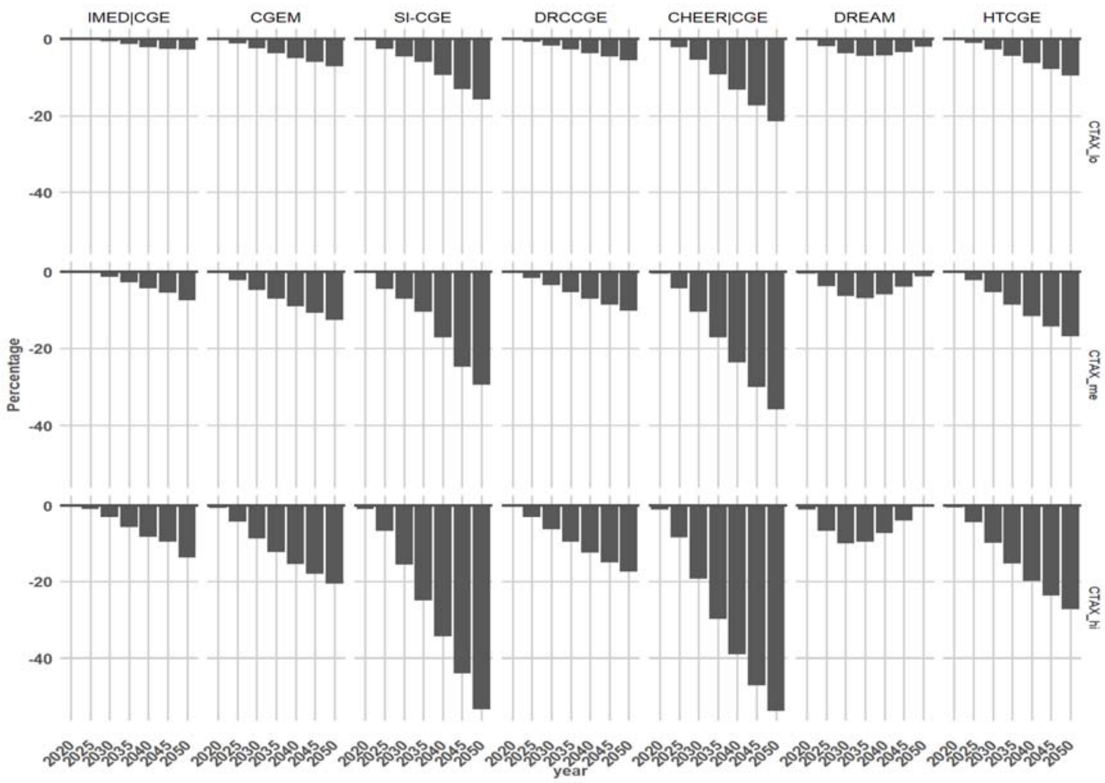
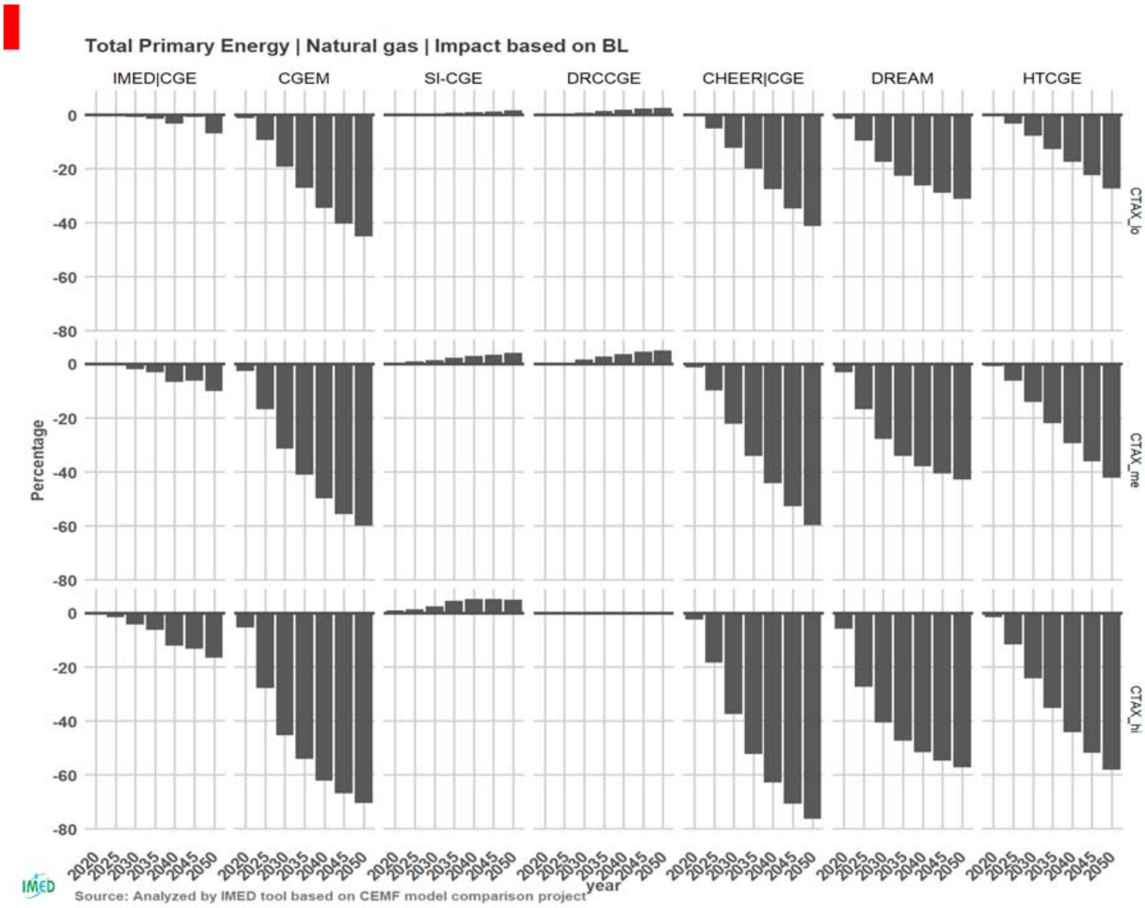


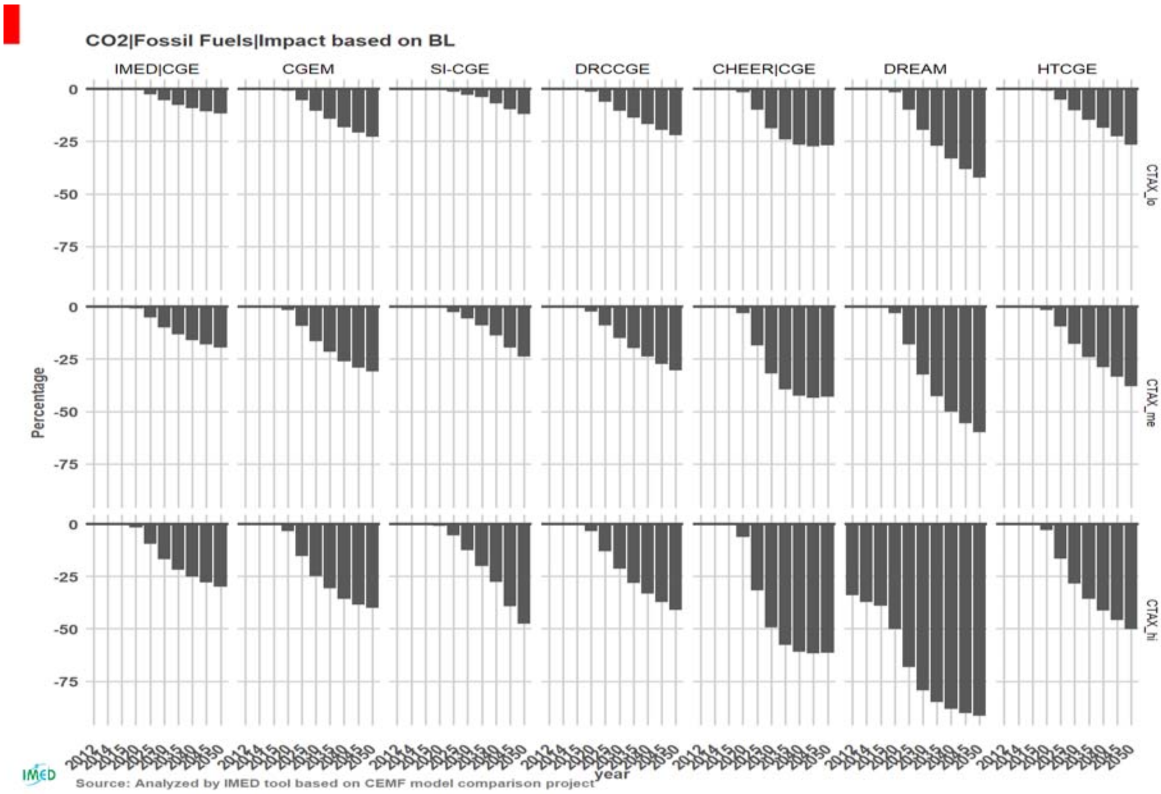
Figure 14. Impact of Carbon Tax Policy on Natural Gas Use (% change from Base Case)



Only SI-CGE and DRCCGE predict increased natural gas use under the carbon tax, CGEM, CHEER|CGE, DREAM and HTCGE predict very similar magnitude of the impacts on natural gas use, IMED|CGE simulates less impacts.

In terms of the carbon emission outcome, we can see all models predict similar impacts of carbon tax in all three scenarios, except DREAM and CHEER|CGE have larger decline of carbon emissions than other models.

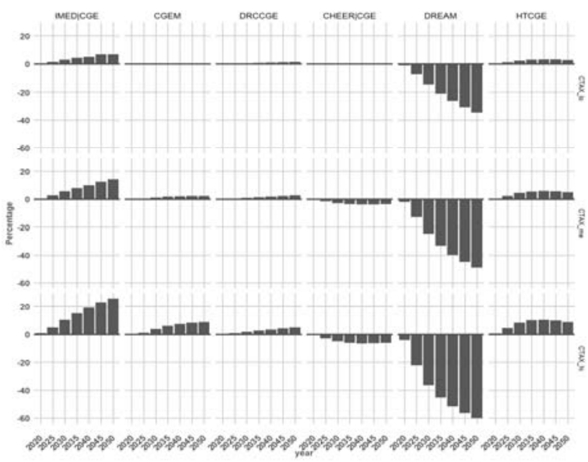
Figure 15. Impact of Carbon Tax Policy on Fossil-fuel combusted Carbon Emissions (% change from Base Case)



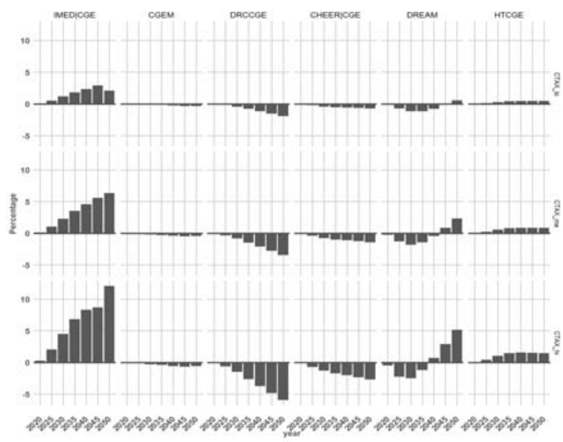
3) Impacts on Coal, Oil, Natural Gas and Electricity Price

Figure 16. Impact of Carbon Tax Policy on Coal, Oil, Natural Gas and Electricity Price (% change from Base Case)

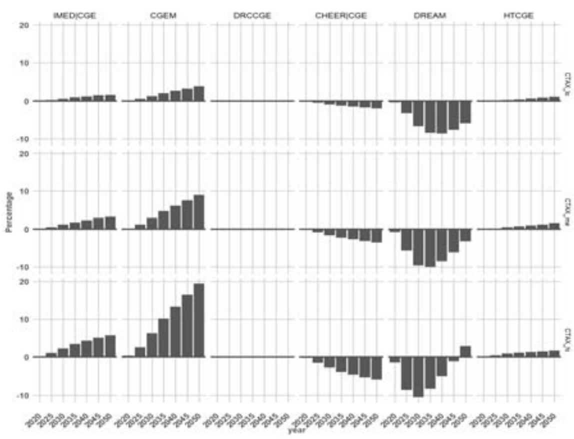
Coal Price



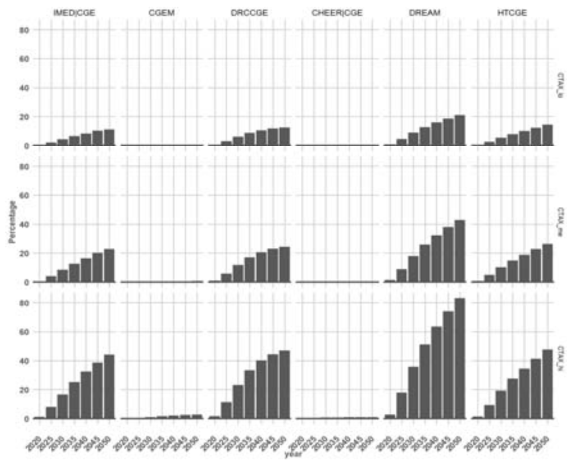
Oil Price



Natural Gas Price



Electricity Price



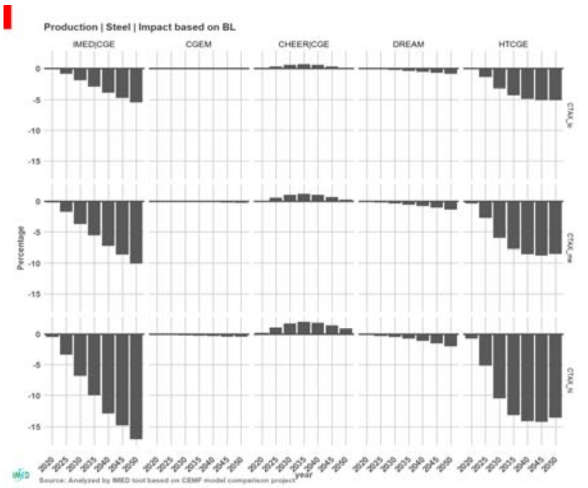
Although impacts on fossil fuel and coal use are similar across models, the impacts on coal, oil and natural gas prices are very divergent. Most models have positive price impacts on coal use except DREAM and CHEER|CGE, since carbon contents of the fossil fuels were charged with increasing carbon tax rates over time. However, impacts on oil, natural gas is unclear, some models may have declining price as substitute, such as DRCCGE, CHEER|CGE and DREAM also have negative price impacts. All models have positive impacts on electricity price, and only CGEM and CHEER|CGE have ignorable impacts on pricing. CGEM is mainly due to the facts that most renewables are replacing the fossil fuel combusted power generation, so very little change on electricity price.

4) Impacts on Outputs

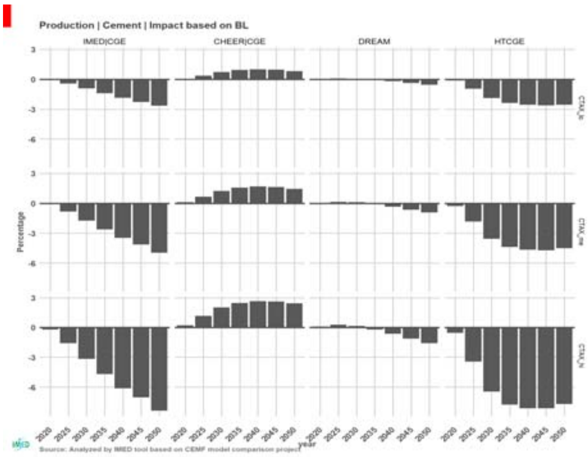
Though the price effects are relatively similar across different models, output impacts are very different across models. Figure 17 provides the impacts of six models on the output of steel, cement, electricity and EITE sectors. Imposing carbon tax would cause the price of energy intensive sectors to increase, thus often driving down the output. However, in the CHEER|CGE, carbon tax in all energy intensive sectors increase the output. For other models, though the impacts are all negative, the magnitude also varies largely across different CGE models. For instance, for the high carbon tax scenario in 2050, the output impact for IMED|CGE can reach -17%, while only -0.4% in CGEM. DREAM model has less impacts on steel, cement and EITE sectors, but highest impacts on electricity use. CGEM model under carbon tax policy increase electricity output, which may due to its unique technology mix that a carbon tax lead to induce technology change especially on renewable technologies, which even offset the decline of output in the conventional coal-fired power generation, so leading to an increase in overall electricity output.

Figure 17. Impact of Carbon Tax Policy on Output of Steel, Cement, Electricity and EITE Sectors (% change from Base Case)

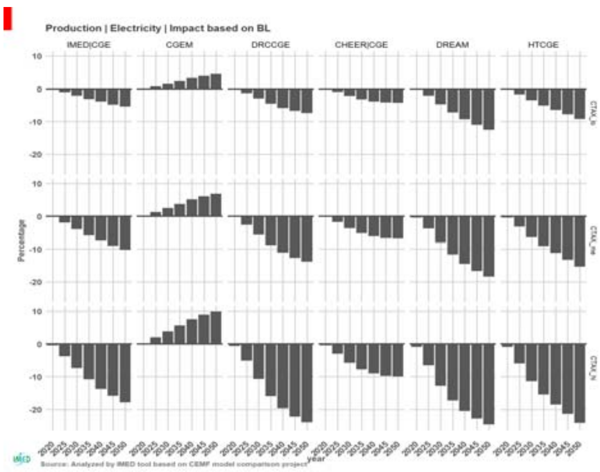
Steel



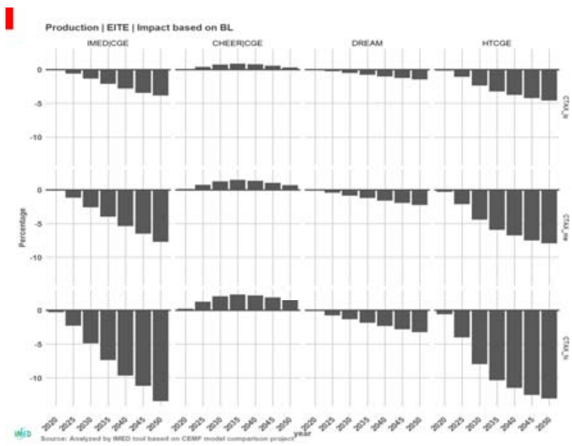
Cement



Electricity



EITE Sectors

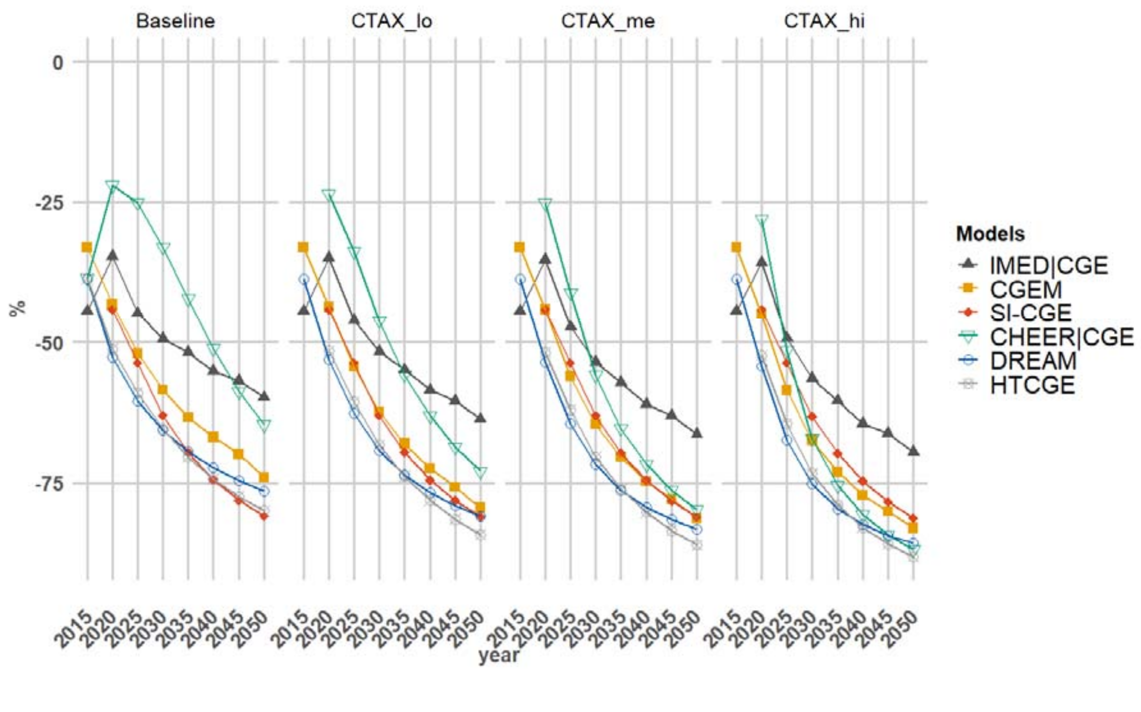


3) Comparison with China's NDC target

We also compared how different models predict the energy and carbon intensity reduction with China's NDC targets for 2020 and 2030. Since all intensity outcomes need to compare with 2005 benchmark level, we compiled the 2005 energy and carbon intensity target using *China's Energy Statistical Yearbook* and *BP-World Energy Statistical Yearbook*.

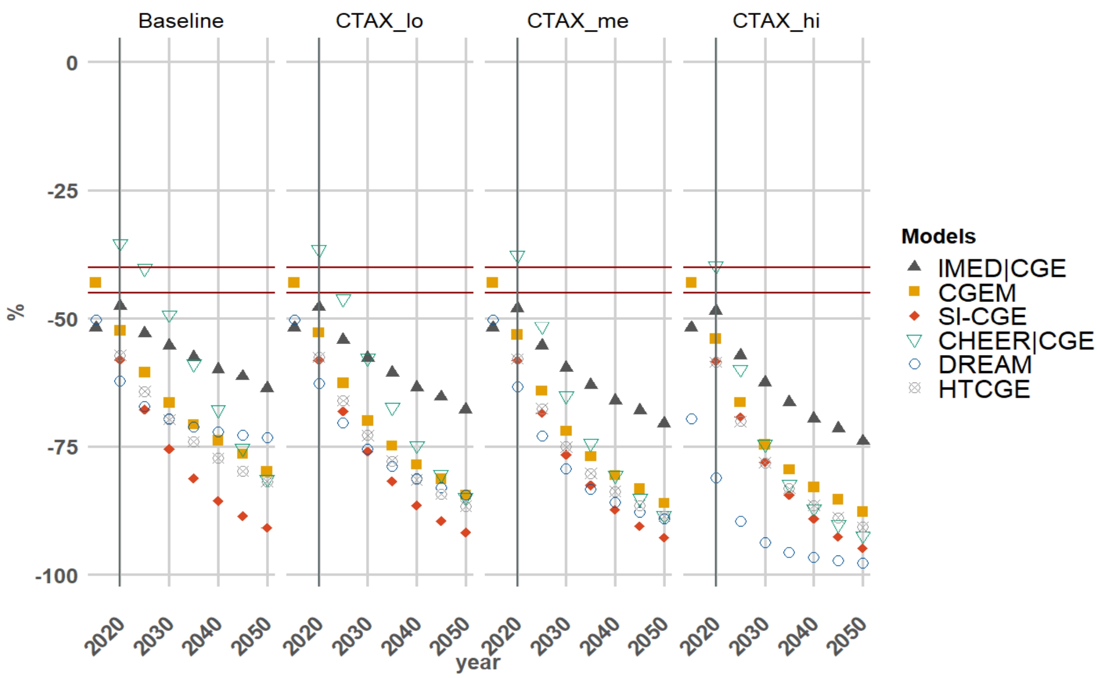
Figure 18 gives the results of three carbon tax policies on energy intensity from 2015 to 2050. All models suggest the intensity is gradually declining in the base case where there is no carbon tax, while the intensity drop more faster under carbon tax scenarios. IMED|CGE and CHEER|CGE shows China's energy intensity will peak at 2020, suggesting even in the base case some policy is working for this transition to happen, all other models have consistent assumptions before and after 2020.

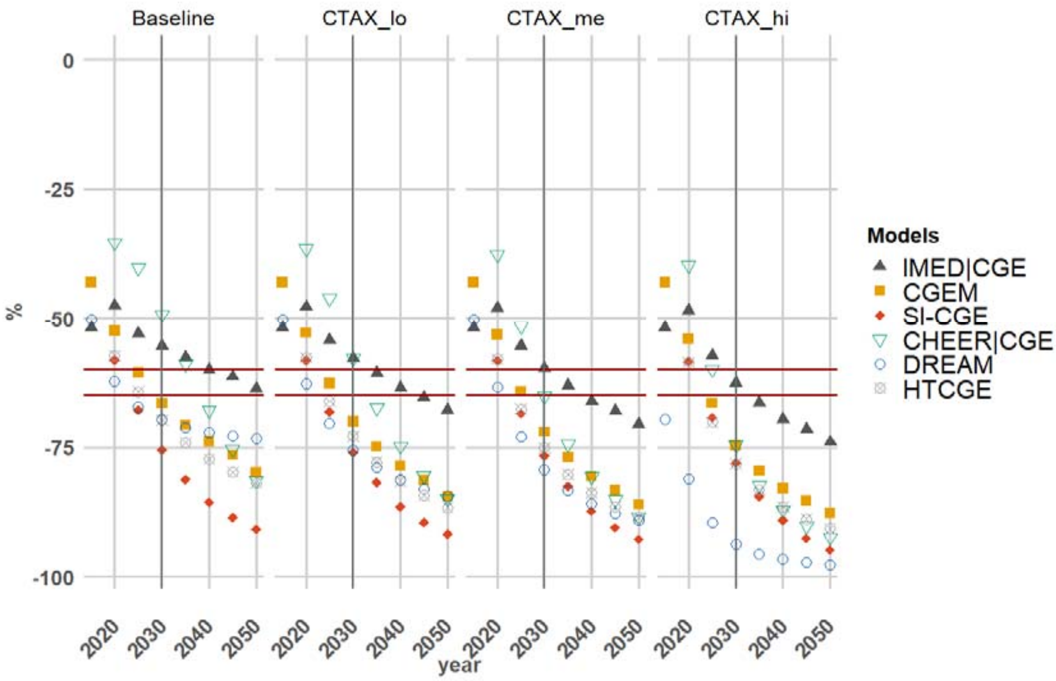
Figure 18. Impact of Carbon Tax Policy on Energy Intensity (Compared with 2005 Benchmark)



The carbon intensity tends to have similar pattern as their energy intensity. Four models out of six models predict the low carbon tax rate can reach China's NDC 60-65% target, while two models – IMED|CGE and CHEER|CGE – can only reach the NDC target under medium and high carbon tax scenario. As for China's NDC 2020 target – that is to reduce China's carbon intensity by 40-45% below 2005 level, most models can achieve such target except CHEER|CGE just meet the lower bound 40% target under the high carbon tax scenario. The high carbon tax scenario exercises shows 5 out 6 models would predict China's carbon intensity would decline by roughly 80% to 90%, however, given a higher GDP level in 2050, the absolute carbon emissions is still roughly high. Let us take a very crude estimation, our estimated 2005 carbon intensity baseline is roughly 0.21, use HTCGE model as an example, since the GDP in 2015 is roughly 68905 bil. RMB at 2015 RMB value, with our harmonized GDP growth for this multi-model exercises, GDP in 2050 is roughly getting tripled. By best estimate that carbon intensity can be reduced by 90%, then the carbon intensity in 2050 is roughly 0.021, then the calculated carbon emissions would be 6000 mil tons, about 54% of the 2015 level. Therefore, without dramatic technology breakthrough, even the best optimal model with the high carbon tax scenario in our exercises cannot reach carbon neutral in China.

Figure 19. Impact of Carbon Tax Policy on Carbon Intensity (Compared with 2005 Benchmark)





6. Conclusions and Policy Implications

6.1 Summary and Study Limitations

We have described the results of a multi-model comparison to analyze a near-term 2020, mid-term 2030 and 2050 carbo then tax policy of China, which can be used to inform the ongoing debates about China's future climate target and committed efforts. Our present study confirms many of the findings made in other studies about how China meet its NDC target. Our multi-model analysis revealed the peculiarities of China's situation. Models show that given a low or medium carbon tax regime alone, China can firmly fulfill its 2020 and 2030 NDC target. However, if targeting at more stringent policies such as carbon neutral in 2050, then all models suggest it would be not possible even under high carbon tax scenarios.

There are many caveats to this paper, and some of those are also quite common for other EMF exercises. First, our results are not predictions but built upon scenarios and general equilibrium simulations. Moreover, although we tried to harmonize the major drivers of the social-economic factors, still some models are not calibrated to produce the same pattern of the growth on population and GDP levels. The harmonized socio-economic drivers are exogenous set to align all models, which may deviate from the future reality, thus potentially leading to some base line errors. We also did not specify how revenue recycling regimes in different models would cause what kind of difference regarding household's burden or industrial burden.

Given our first pilot trial on multi-CGE-model analysis, we did not conduct systematical uncertainty or ambiguity analysis on the lower and higher bound of the carbon tax analysis. Also since we only have one regional model and one global model, we did not compare how these regional, global model differ from the rest national models.

6.2 Policy Implications

Our analysis points to the likelihood of using low level of carbon tax regime to achieve short-term and medium-term NDC target. Our multi-model analysis suggests that even though models may exert different revenue recycling assumptions, the overall negative impact on GDP and other macro indicators are limited. However, even at very low carbon tax regime since our models are adopting an increasing growing tax rate schedule, we still did not find any double dividend in most models. This means in the current pre-existing tax system, the potential space for "double dividend" is limited, so the benefits mainly lie in the carbon reduction and ancillary environmental benefits.

The distributional analysis suggests most burden of carbon tax imposed on energy intensive sectors, though one model CGEM assumed higher within technology mix substitution, that carbon tax brings stronger induced renewable technology progress, driving electricity output even higher than base case, which suggest how the technology models are simulated under the CGE model is especially important for understand these key variables. Unfortunately, most models did not have bottom-up structures to show how technologies shifting with carbon tax policies.

Our carbon tax policy is a simple exercise, which may never happen in China's institutional framework. However, national carbon trading, energy tax reform, or potential resource tax reform would impose similar higher prices on upstream fossil fuels, so our analysis would shed some light on how carbon pricing would work, and in what kind of potential magnitude in China.

References

Cao, Jing and Mun Ho. 2017. "Appendix A. Economic-Environmental Model of China (version 18)," Harvard China Project Working Paper.

Cao, Jing, Li Gao, Mun Ho, Chris Nielsen, Yuxuan Wang, Yu Zhao. 2016. "Resource Taxes, Carbon Taxes and Fiscal Reform in China," Harvard China Project Working Paper.

Haoqi Qian, Libo Wu, Weiqi Tang, 2017, " "Lock-in" effect of emission standard and its impact on the choice of market based instruments", Energy Economics, 63: 41-50.

Haoqi Qian, Ying Zhou, Libo Wu, 2018, "Evaluating various choices of sector coverage in China's national emissions trading system (ETS)", Climate Policy, 18(S1): 7-26.

Hillard Huntington, 2012. Energy Efficiency and Climate Change Mitigation. Stanford EMF 25 Report, https://emf.stanford.edu/publications/emf-25-energy-efficiency-and-climate-change-mitigation

Hillard Huntington, 2013. Changing the Game? Emissions and Market Implications of New Natural Gas Supplies, Stanford EMF 26 Report, https://emf.stanford.edu/projects/emf-26-changing-game-emissions-and-market-implications-new-natural-gas-supplies-0

Li Jifeng, Xin Wang and Yaxiong Zhang, 2014. A CGE Assessment of Carbon Pricing with Regulated Electricity Price in China, 2014 GTAP Conference Paper, presented at the 17th Annual Conference on Global Economic Analysis, Dakar, Senegal. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4410

Sugiyama Masahiro, Shinichiro Fujimori, Kenichi Wada, Seiya Endo, Yasumasa Fujii, Ryoichi Komiyama, Etsushi Kato, Atsushi Kurosawa, Yuhji Matsuo, Ken Oshiro, Fuminori Sano, Hiroto Shiraki, 2019. Japan's long-term climate mitigation policy: Multi-model assessment and sectoral challenges, Energy 167, pp.1120-1131.

Vennemo Haakon, Jianwu He, Shantong Li, 2014. Macroeconomic Impacts of Carbon Capture and Storage in China, Environmental and Resource Economics 59(3), pp. 455-477.

Weyant John, Leon ClarkeAllen Fawcett, 2014. U.S. Technology and Climate Policy Strategies, Stanford EMF 24 Report, https://emf.stanford.edu/publications/emf-24-us-technology-and-climate-policy-strategies

Xu Zhang, Tianyu Qi, Xunmin Ou, Xiliang Zhang, 2016. The Role of multi-region integrated emissions trading scheme: A computable general equilibrium analysis, Applied Energy, Volume 185, part 2, pp. 1860-1868.

Yang Xie, Hancheng Dai, Huijuan Dong, Tatsuya Hanaoka, Toshihiko Masui, 2016, Economic Impacts from $PM_{2.5}$ Pollution-Related Health Effects in China: A Provincial-Level Analysis, Environmental Science & Technology, 50(9), pp. 4836-4843.

Yaqian Mu, Wenjia Cai, Samuel Evans, Can Wang, David Roland-Holst, 2018. Employment impacts of renewable energy policies in China – a decomposition analysis based on a CGE modeling framework. Applied Energy 210, pp. 256-267.

Zhang Xuebiao, Yawen Liu, Yu Liu, Qi Cui, Lingyu Yang, Xiaohong Hu, Jialin Guo, Jinzhu Zhang, Shunxiang Yang, 2019. Journal of Cleaner Production, Vol. 230, pp. 150-161.