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Understanding the Interactions between Emissions Trading Systems and Renewable Energy Standards Using a Multi-Regional CGE Model of China

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Abstract

Many countries have introduced policy measures, such as carbon pricing, greenhouse gas offsetting mechanisms, renewable energy standards, and energy efficiency improvements, to achieve their climate change mitigation targets. However, in many instances, these measures overlap in ways that may dilute each policy's greenhouse gas reduction potential. This study examines how a renewable energy standard in the power sector would interact with a national emission trading scheme that is introduced to achieve a greenhouse gas mitigation target. Using a static, multiregional computable general equilibrium model of China to simulate policy measures, the study finds that the addition of a separate renewable energy standard policy would increase the economic cost for achieving a target level of greenhouse gas mitigation. The study concludes that although renewable energy standard policies promote the use of renewable energies, they are an economic burden from the perspective of reducing greenhouse gas emissions if a carbon pricing mechanism is in place.

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Understanding the Interactions between Emissions Trading Systems and Renewable Energy Standards Using a Multi-Regional CGE Model of China[1]

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1. Introduction

Different policy instruments are being introduced in both developed and developing countries for greenhouse gas (GHG) mitigation. Initially, GHG mitigation options such as energy technology mandates (e.g., renewable energy utilization requirements) and energy efficiency standards were the focus under climate change mitigation initiatives. While various policy options including fiscal incentives and regulatory mandates now are common in both developed and developing countries to promote lower-carbon energy use and efficient consumption of energy, market based mechanisms for climate change mitigation, such as the clean development mechanism (CDM) and other GHG offset mechanisms, also played a crucial role in the deployment of these measures. More recently, particularly after the Paris Agreement, carbon pricing has emerged as a key policy instrument in several countries, including developing countries, to achieve their nationally determined commitment (NDC) agreed in the Paris Agreement.

One issue often raised by policy makers is how to address the economic burden to tax payers that could arise due to potential overlapping of various policy options. This issue arises when multiple policies (e.g., carbon pricing, renewable energy mandates and energy efficiency standards) are implemented at the same time. This study aims to address that question in the context of energy and GHG mitigation policies in China.

Like other countries, China has proposed various policy options to meet its NDC, including a national emission trading system (ETS) and a mandate for use of non-fossil fuels to meet a given fraction (20%) of the total primary energy supply.[3] While the national ETS is expected to be introduced in 2017, renewable energy standards (RES) policies are already in place since 2006. The ETS has been already tested through seven pilot schemes at the provincial and city levels since 2013.

A rich literature exists on the design issues of both ETS and RES separately (see e.g., Lesser and Su, 2008; Langniß et al., 2009; Couture and Gagnon, 2010; Schallenberg-Rodriguez and Haas, 2012; Hübler et al., 2014; Ouyang and Lin, 2014; He et al., 2015). Understanding of interactions between these measures also is critical for the successful implementation of each policy.

Applying a theoretical model to understand the interactions between emissions trading and other policy instruments, Fankhauser et al. (2010) argue that renewable energy obligations within a capped area might have undermined the carbon price and increased the mitigation costs. Using a partial equilibrium model to explore the interactions between emission trading and three renewable electricity support schemes, Böhringer and Behrens (2015) suggest that policy makers should address the implications of the overlap between emission caps and different RES policy instruments. Using a CGE model to analyze the interactions between a renewable portfolio standard and a cap-and-trade policy in the United States, Morris (2009) finds that the renewable energy portfolio increased the welfare costs of cap-and-trade policy. Some studies blamed the renewable energy mandate in the EU for causing the plummeting of CO_2 permits prices under the EU ETS between 2008 and 2013, because

[3] China has set a target of reducing its emission intensities 60% to 65% below its 2005 level by 2030; it has also planned to supply 20% of total energy consumption in 2030 from non-fossil fuel sources.

the mandate curtailed the demand for CO_2 permits (Van den Bergh et al., 2013; Weigt et al., 2013). Examining the relationship between the EU-ETS permit price drop and renewable policies in the EU, Koch et al. (2014) finds that the growth of wind and solar power generation under the EU mandate robustly explains the EU-ETS permit price dynamics.

Some literature (Nordhaus,2011; Böhringer et al., 2009; Tsao et al., 2011; Morris, 2009) also suggests that a separate renewable energy mandate might adversely affect low carbon economic development that could be encouraged by broader carbon pricing policies. This is because favoring a particular technology (here renewable energy) would depress the carbon price and associated investments on other lower carbon technologies. For example, Nordhaus (2011) argues that depressed carbon prices caused by the additional RES policy are not likely to provide sufficient incentives for investments in low-carbon technologies. Newell (2015) stresses technology policies, such as renewable portfolio standards, could raise rather than lower the societal costs of climate mitigation; on the other hand, carbon pricing policies, such as a carbon tax with part of the tax revenue recycled to research and development of clean technologies, would be the most cost efficient option for climate change mitigation.

One could argue that adoption of clean and renewable energy would not only help reduce GHG emissions, they would have other benefits, such reduction of local air pollution. If the benefits from local air pollution are quantified and accounted for in the analysis, it might be possible that a policy that considers both emission trading and renewable portfolio standards simultaneously is more economic as compared to an emission trading scheme alone. However, quantification of air pollution benefits is complex and accounting for these intangible benefits in a social accounting matrix, the main database for a CGE model is further complicated.

Against this background, our paper uses a static, multi-regional CGE model to analyze the interactions between ETS and RES policies in China by comparing their economywide impacts both at national and provincial levels. We simulated three cases: (i) a base case in the absence of the ETS and RES policies; (ii) an ETS case which considers a national emission trading scheme to reduce national CO_2 emissions by 10% from the base case; and (iii) an ETS-cum-RES case where a separate RES policy is introduced on top of the ETS to achieve the same level of emission reduction target. Our simulation results show that an additional RES policy would further reduce GDP and increase the welfare loss associated with the ETS.

The paper is organized as follows. Section 2 describes the CGE model used, and how ETS and RES policies are implemented in this model. Section 3 presents the data and policy scenarios. Section 4 presents the economy-wide implications effects of ETS alone and in combination with RES. Finally, key conclusions are drawn in Section 5.

2. Methodology

This research is implemented in the CEEP Multi-Regional Energy-Environment-Economy Modelling System (CE^3MS), which is based on a multi-regional static CGE model for China (Wu et al., 2016). The CE^3MS includes 30 regions in accordance with the administrative structure of mainland China (excluding Tibet due to a lack of data).

Each region has independent institutions as production sectors, rural and urban households, a representative enterprise, and a local government; and, meanwhile, has relevant economic activities such as production, consumption, savings, and investment. Each region has 17 representative production sectors: one agricultural, five energy, seven non-energy industrial, and four service sectors (Table 1). The CE^{3}MS database derives from the China 2007 regional social accounting matrices (SAMs).

Table 1. Sector declarations and descriptions.

Sector codes	Description
Agri	Agriculture, forestry, animal husbandry and fishery
Coal	Coal
Coil	Crude oil and natural gas
Mine	Mining
Fpap	Manufacture of foods, beverage, tobacco, textile, wearing, apparel, leather, wood, paper and publishing
Petro	Coking, gas and processing of petroleum
Chem	Chemical industry
Nmm	Manufacture of nonmetallic mineral products
Metal	Manufacture and processing of metals and metal Products
Omf	Other manufacture
Ele	Production and supply of electric, heat power
Gas	Production and supply of gas, water
Cons	Construction
Trans	Transport, storage, post, information transmission, computer services and software
Wsale	Wholesale and retail trades, hotels and catering services
Esta	Real estate, leasing, business services and financial intermediation
Ots	Other services

Export and import provides the linkages between each region and the rest of the world. Most importantly, a multi-regional model differs from a national model in its interregional linkages among all regions, including commodity trading, and the mobility of labor and capital. Unlike developed countries, the central government plays a quite important role in development decisions in China; therefore, a central government is described at the national level in this model. The basic modules of CE^{3}MS are production module, emissions trading module, commodity trading module, institution module, labor mobility module, and macro closure, of which the key features are outlined below.

2.1 Production module

The model assumes that all sectors are characterized by constant returns to scale and are traded in perfectly competitive markets. Constant elasticity of substitution (CES) functions and nesting structures are used to characterize the production technologies for all sectors. In the production of non-electricity sectors, energy is treated as a special resource rather than an intermediate input and is combined with value-added. Thus, energy can be substituted by other energy or intermediate input.

$$QA_{j,r} = \alpha_{j,r} \left[\delta_{j,r} QVAE_{j,r}{}^{\rho_{j,r}} + \left(1-\delta_{j,r}\right) QINTA_{j,r}{}^{\rho_{j,r}} \right]^{\frac{1}{\rho_{j,r}}} \tag{1}$$

$$\frac{PVAE_{j,r}}{PINTA_{j,r}} = \frac{\delta_{j,r}}{1-\delta_{j,r}} \left(\frac{QINTA_{j,r}}{QVAE_{j,r}} \right)^{1-\rho_{j,r}} \tag{2}$$

$$PA_{j,r} QA_{j,r} = PVAE_{j,r} QVAE_{j,r} + PINTA_{j,r} QINTA_{j,r} \tag{3}$$

where $PA_{j,r}$ and $QA_{j,r}$ are the producer price and output of sector *j* in region *r*, $PINTA_{j,r}$ and $QINTA_{j,r}$ are the price and quantity of intermediate input, $PVAE_{j,r}$ and $QVAE_{j,r}$ are the price and quantity of value added and energy input. $\alpha_{j,r}$ and $\delta_{j,r}$ are the efficiency parameter and share parameter of the CES function, and $\rho_{j,r}$ is the substitution elasticity parameter. The combination of intermediate input is presented by Leontief functions as Equation 4 and Equation 5:

$$QINT_{i,j,r} = ica_{i,j,r} QINTA_{j,r} \tag{4}$$

$$PINTA_{j,r} = \sum_{i} ica_{i,j,r} PQ_{i,r} \tag{5}$$

where $QINT_{i,j,r}$ is the quantity of commodity *i* as intermediate input of sector *j* in region *r*, $PQ_{i,r}$ is the price of commodity *i* in region *r*, $ica_{i,j,r}$ is the coefficient of intermediate input. The combination of value added and energy input is described in Equations 6-11.

$$QVAE_{j,r} = \alpha_{j,r}^{vae}\left[\delta_{j,r}^{vae} QVA_{j,r}^{\rho_{j,r}^{vae}} + \left(1-\delta_{j,r}^{vae}\right) QVE_{j,r}^{\rho_{j,r}^{vae}}\right]^{\frac{1}{\rho_{j,r}^{vae}}} \tag{6}$$

$$\frac{PVA_{j,r}}{PVE_{j,r}} = \frac{\delta_{j,r}^{vae}}{1-\delta_{j,r}^{vae}}\left(\frac{QVE_{j,r}}{QVA_{j,r}}\right)^{1-\rho_{j,r}^{vae}} \tag{7}$$

$$PVAE_{j,r} QVAE_{j,r} = PVA_{j,r} QVA_{j,r} + PVE_{j,r} QVE_{j,r} \tag{8}$$

$$QVA_{j,r} = \alpha_{j,r}^{va}\left[\delta_{j,r}^{va} QLD_{j,r}^{\rho_{j,r}^{va}} + \left(1-\delta_{j,r}^{va}\right) QKD_{j,r}^{\rho_{j,r}^{va}}\right]^{\frac{1}{\rho_{j,r}^{va}}} \tag{9}$$

$$\frac{WL_{j,r}(1+tval)}{WK_{j,r}(1+tvak)} = \frac{\delta_{j,r}^{va}}{1-\delta_{j,r}^{va}}\left(\frac{QKD_{j,r}}{QLD_{j,r}}\right)^{1-\rho_{j,r}^{va}} \tag{10}$$

$$PVA_{j,r} QVA_{j,r} = (1+tval) WL_{j,r} QLD_{j,r} + (1+tvak) WK_{j,r} QKD_{j,r} \tag{11}$$

where $PVA_{j,r}$ and $QVA_{j,r}$ are the price and quantity of value added, $PVE_{j,r}$ and $QVE_{j,r}$ are the price and quantity of total energy input, $WL_{j,r}$ and $QLD_{j,r}$ are the price and quantity of labor, $WK_{j,r}$ and $QKD_{j,r}$ are the price and quantity of capital input. $tval$ and $tvak$ are value added tax rates of labor and capital. Equations 12-17 present the structure of energy input of sector *j* in region *r*.

$$QVE_{j,r} = \alpha_{j,r}^{ve}\left[\delta_{j,r}^{ve} QVEE_{j,r}^{\rho_{j,r}^{ve}} + \left(1-\delta_{j,r}^{ve}\right) QNELE_{j,r}^{\rho_{j,r}^{ve}}\right]^{\frac{1}{\rho_{j,r}^{ve}}} \tag{12}$$

$$\frac{PVEE_{j,r}}{PNELE_{j,r}} = \frac{\delta_{j,r}^{ve}}{1-\delta_{j,r}^{ve}}\left(\frac{QNELE_{j,r}}{QVEE_{j,r}}\right)^{1-\rho_{j,r}^{ve}} \tag{13}$$

$$PVE_{j,r} QVE_{j,r} = PVEE_{j,r} QVEE_{j,r} + PNELE_{j,r} QNELE_{j,r} \tag{14}$$

$$QNELE_{j,r} = \alpha_{j,r}^{nele}\left[\delta_{j,r}^{nele} QVEC_{j,r}^{\rho_{j,r}^{nele}} + \left(1-\delta_{j,r}^{nele}\right) QVENC_{j,r}^{\rho_{j,r}^{nele}}\right]^{\frac{1}{\rho_{j,r}^{nele}}} \tag{15}$$

$$\frac{PVEC_{j,r}}{PVENC_{j,r}} = \frac{\delta_{j,r}^{nele}}{1-\delta_{j,r}^{nele}}\left(\frac{QVENC_{j,r}}{QVEC_{j,r}}\right)^{1-\rho_{j,r}^{nele}} \tag{16}$$

$$PNELE_{j,r}QNELE_{j,r} = PVEC_{j,r}QVEC_{j,r} + PVENC_{j,r}QVENC_{j,r} \tag{17}$$

where $PVEE_{j,r}$ and $QVEE_{j,r}$ are the price and quantity of electricity input, $PNELE_{j,r}$ and $QNELE_{j,r}$ are the price and quantity of non-electricity input. $QVEC_{j,r}$, $PVEC_{j,r}$, $QVENC_{j,r}$, $PVENC_{j,r}$ are the coal input and non-coal input and the corresponding prices, respectively.

To implement the RES policy in CE^{3}MS, electric power generation is represented by eight generation technologies: coal (*Coa*), natural gas (*Ngs*), petroleum (*Pet*), nuclear (*Nuc*), hydropower (*Hyd*), wind (*Win*), solar (*Sol*), and other renewable technologies (*Oth*). The structure of electricity production is given in Figure 1. In particular, coal, natural gas, and petroleum are raw material inputs of coal-, natural gas-, and petroleum-powered generation and thus are considered as intermediate inputs rather than value-added or energy inputs for coal-, natural gas-, and petroleum-powered generation.

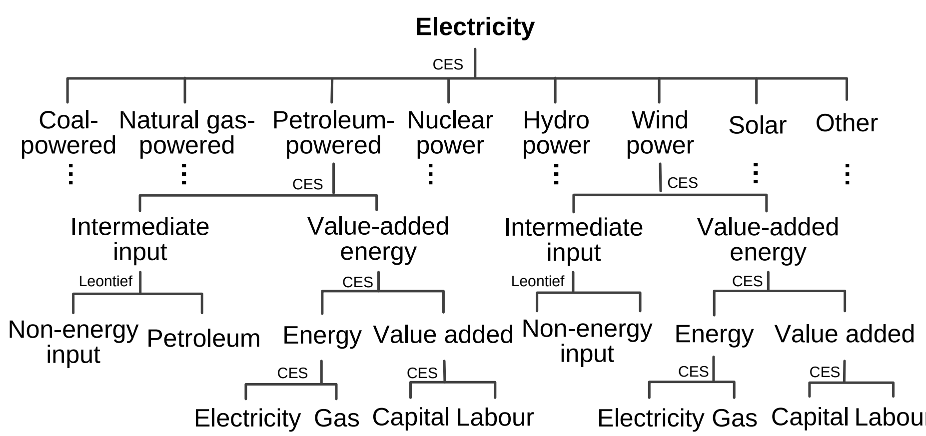


Figure 1. Structure of electricity production

The total electricity output aggregation shows imperfect substitution of electricity from different generation technologies, which reflects the reality that various power generation technologies coexist while having differing generation costs. The substitution elasticity of different generation technologies is set to 2 in this study, with reference to the MIT-EPPA model (Paltsev et al., 2005; Sue Wing, 2006). The RES policy is implemented by a production subsidy, and the subsidy cost is passed to final consumers via a tax on electricity consumption.

$$QA_{k,r}^{et} = \alpha_r^{-1}\left(\delta'_{k,r} / PA_{k,r}\right)^{\frac{1}{1-\rho_r}} \left(\sum_k \delta'^{\frac{1}{1-\rho_r}}_{k,r} PA_{k,r}^{\frac{-\rho_r}{1-\rho_r}} \right)^{\frac{1}{\rho_r}} Qele_r \tag{18}$$

$$Pele_r Qele_r = \sum_k PA_{k,r} QA_{k,r}^{et} \tag{19}$$

where k denotes different power generation technologies, $PA_{k,r}$ and $QA_{k,r}^{et}$ are the on-grid price and output of electricity by technology k, $Pele_r$ and $Qele_r$ are the composite price and total output of electricity in region r. ρ_r is the parameter of substitution elasticity of different generation technologies.

The RES policy is implemented through a production subsidy for renewable electric power generation in this model, which is described in Equation 22. With a subsidy, the on-grid price of renewable power will be lower and leads to a substitution of renewable power for fossil-derived power. In this analysis, we assume that the subsidy cost is passed through to consumers by an electricity consumption tax.[4]

$$QA_{k,r}^{et} = \alpha_{k,r}^{et} \left[\delta_{k,r}^{et} QINTA_{k,r}^{et^{\rho_{k,r}^{et}}} + (1-\delta_{k,r}^{et}) QVAE_{k,r}^{et^{\rho_{k,r}^{et}}} \right]^{\frac{1}{\rho_{k,r}^{et}}} \tag{20}$$

[4] This tax is similar to a situation in which all of the additional cost of the renewable electricity is passed forward to all electricity users like in the case of a feed-in tariff. Different approaches would be possible to generate government revenue to finance a renewable energy subsidy. Landis and Timilsina (2015) increase VAT to subsidize wind power in Brazil. Timilsina and Landis (2014) increase tax on fossil fuels to subsidize renewable energy in Morocco. The general equilibrium results would be slightly different across these approaches. Since the electricity sector in China is a large sector, a small tax on electricity to subsidize renewable energy is not expected to distort the sector much.

$$PP_{k,r}QA^{et}_{k,r} = PINTA^{et}_{k,r}QINTA^{et}_{k,r} + PVAE^{et}_{k,r}QVAE^{et}_{k,r} \tag{21}$$

$$PA_{k,r} = \frac{PP_{k,r}}{1+r_{sub}}, \quad k \in Win, Sol, Oth \tag{22}$$

$$r_{sub}\sum_{k,r} PA_{k,r}QA_{k,r} = r_{tax}\sum_{r} Pele_{r}Qele_{r}, \quad k \in Win, Sol, Oth \tag{23}$$

$PP_{k,r}$ is the producer price of electricity by technology k in region r, $PINTA^{et}_{k,r}$ and $QINTA^{et}_{k,r}$ are the price and quantity of intermediate input by technology k. r_{sub} is the subsidy rate and r_{tax} is the added electricity consumption tax rate.

2.2 Emissions trading module

We assume there is a single, national ETS in which emitters from different regions all participate. We employed a "grandfathering" approach where initial quotas are distributed for free.[5] Under trading scheme, each trading sector determines its actual emission reductions and trading volume under the objective of minimizing the total cost by comparing its marginal abatement cost and carbon price. This is described in Equations 24-25 below:

$$Min\ TC_{tj,r} = C_{tj,r}(\overline{COE}_{tj,r} - COEE_{tj,r}) + CP_1 \times (COEE_{tj,r} - \overline{COQ}_{tj,r}) \tag{24}$$

$$s.t. \quad \sum_{tj,r} COEE_{tj,r} = \sum_{tj,r} \overline{COQ}_{tj,r} \tag{25}$$

where $TC_{tj,r}$ is the total cost which includes the abatement cost and trading cost of sector tj in region r. $COEE_{tj,r}$ is the actual emissions under the ETS policy, while $\overline{COE}_{tj,r}$ is the emissions in the benchmark. $\overline{COQ}_{tj,r}$ is the initial emission quota allocated to sector tj in region r, and CP_1 is the CO_2 price under ETS.

[5] Note that a province's total emission quota is equal to the sum of sectoral quotas of that province; we have not applied any other rule to allocate the national quota to provincial quotas.

The decision of emissions reduction in trading sectors will directly affect their production as the total production costs in these sectors change. Therefore, the equation of production costs in trading sectors will change from Equation 3 to Equation 26 as below:

$$PA_{tj,r}QA_{tj,r} = PVAE_{tj,r}QVAE_{tj,r} + PINTA_{tj,r}QINTA_{tj,r} + TC_{tj,r} \quad (26)$$

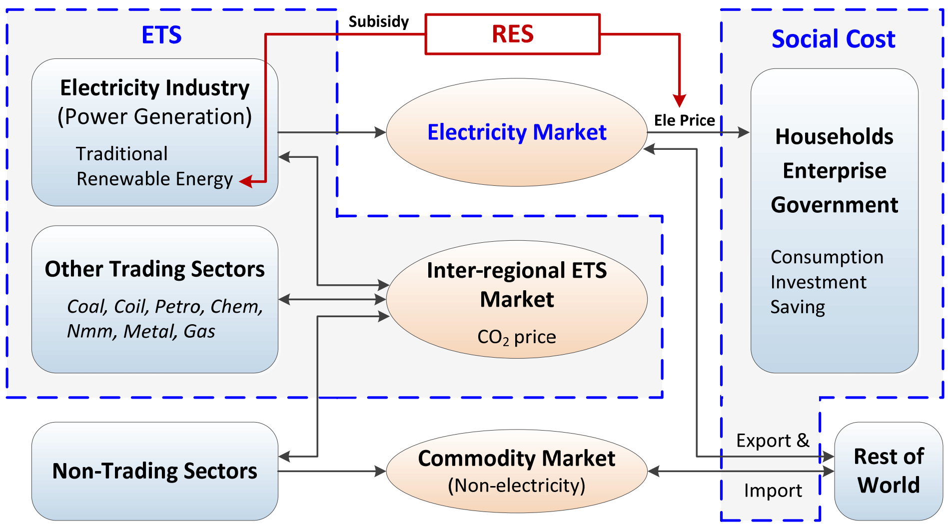


Figure 2. Framework for combination of ETS and RES policies in CE³MS

Figure 2 shows the framework for combination of ETS and RES policies in CE³MS. According to the existing empirical experience from seven pilot ETSs, eight industries (five energy sectors and three energy-intensive sectors) are considered as emissions trading sectors in the nationwide carbon market in China. Under the ETS policy, each trading sector will decide on emissions reductions by comparing its marginal abatement costs with the carbon price. Please see Figure 3 for these marginal abatement cost curves across the region and sectors.

2.3 Commodity trading module

Commodity trading in the model includes import, export, and transferring among regions. The output of production sectors in each region not only supplies the local market, but also other regions in China and the rest of world, which are presented in Equations 27-35.

$$QA_{j,r} = \alpha_{j,r}^{cet}\left[\delta_{j,r}^{cet} QDS_{j,r}^{\rho_{j,r}^{cet}} + \left(1-\delta_{j,r}^{cet}\right) QE_{j,r}^{\rho_{j,r}^{cet}}\right]^{\frac{1}{\rho_{j,r}^{cet}}},\ \rho_{j,r}^{cet} > 1 \quad (27)$$

$$\frac{PDS_{j,r}}{PE_{j,r}} = \frac{\delta_{j,r}^{cet}}{1-\delta_{j,r}^{cet}}\left(\frac{QE_{j,r}}{QDS_{j,r}}\right)^{1-\rho_{j,r}^{cet}} \quad (28)$$

$$PA_{j,r} QA_{j,r} = PDS_{j,r} QDS_{j,r} + PE_{j,r} QE_{j,r} \quad (29)$$

$$PE_{j,r} = pwe_{j,r} \cdot (1+te_j) \cdot EXR \quad (30)$$

Equations 27-30 describe the allocation of commodity *j* between domestic market ($QDS_{j,r}$) and export ($QE_{j,r}$), which is decided by the commodity price ($PDS_{j,r}$) in domestic market and the export price ($PE_{j,r}$). $pwe_{j,r}$ is the free on board price of commodity *j* and te_j is its export tax rate. EXR is the exchange rate. Equations 31-35 describe how the supply of commodity *j* in region *r* in the domestic market will be allocated among region *r* and other regions in China.

$$QDS_{j,r} = \alpha_{j,r}^{ds}\left[\delta_{j,r}^{ds} QRRE_{j,r}^{\rho_{j,r}^{ds}} + (1-\delta_{j,r}^{ds}) QRD_{j,r}^{\rho_{j,r}^{ds}}\right]^{\frac{1}{\rho_{j,r}^{ds}}},\ \rho_{j,r}^{ds} > 1 \quad (31)$$

$$\frac{PRRE_{j,r}}{PRD_{j,r}} = \frac{\delta_{j,r}^{ds}}{1-\delta_{j,r}^{ds}}\left(\frac{QRD_{j,r}}{QRRE_{j,r}}\right)^{1-\rho_{j,r}^{ds}} \quad (32)$$

$$PDS_{j,r} QDS_{j,r} = PRRE_{j,r} QRRE_{j,r} + PRD_{j,r} QRD_{j,r} \quad (33)$$

$$QRR_{j,r,s} = irre_{j,r,s} QRRE_{j,r} \quad (34)$$

$$PRRE_{j,r} = \sum_{s} irre_{j,r,s} PQ_{j,r} \quad (35)$$

$QRD_{j,r}$ and $QRRE_{j,r}$ are the supply of commodity *j* in region *r* and the total supply to other regions, respectively. $PRD_{j,r}$ and $PRRE_{j,r}$ are corresponding prices. $QRR_{j,r,s}$ is the supply of commodity *j* in region *r* to region *s*, and $irre_{j,r,s}$ is the Leontief coefficient.

Composite commodities will be ultimately used for intermediate input, governmental and residential final consumption, fixed assets investment and inventory investment. Both of the total supply and demand of commodities are represented by nested CES function and the supply function follows constant elasticity of transformation (CET) function while the demand function follows the Armington assumption.

2.4 Household and institution module

The households' income is composed of labor payment, part of capital compensation and transfer payments from local government. The utility function of households is assumed as a Cobb-Douglas function in this model, which can derive the households' consumption for different commodities as the following equations:

$$YH_{h,r} = shifl_{h,r} WLR_r QLSR_r + shifkh_{h,r} WKR_r QKSR_r + transfrgtoh_{h,r} \quad (36)$$

$$PQ_{j,r} QH_{h,j,r} = shrh_{h,j,r} mpc_{h,r} (1 - ti_h) YH_{h,r} \quad (37)$$

where $YH_{h,r}$ is the total income of household *h* in region *r*, $QLSR_r$ and $QKSR_r$ are the supply of labor and capital in region *r*, WLR_r and WKR_r are the average wage and capital return in region *r*, $QH_{h,j,r}$ is the households' consumption of commodity *j*. $transfrgtoh_{h,r}$ is the regional government transfer payment in region *r*. $shifl_{h,r}$, $shifkh_{h,r}$, $shrh_{h,j,r}$ are share parameters, and $mpc_{h,r}$ is the households' propensity to consumption. ti_h is the income tax rate.

The regional enterprise income includes capital compensation and local government transfer payments. And the income excluding the enterprise income tax will totally transform to savings.

The regional government income consists of proportional[6] local tax revenues and the central government transfer payments. The expenditure includes transfer to local households and commodity consumption which is also determined by the Cobb-Douglas utility function.

3. Scenarios

The following scenarios are adopted to assess the impact of combining RES policy with an ETS policy (Table 2). A benchmark scenario, S0, represents a situation in the absence of ETS and RES policies to reduce GHG emissions. An 'ETS' scenario refers to a nationwide trading of carbon emission permits where emitters with surplus permits sell to those who needs them to meet their emission reduction targets. The total CO_2 emissions allowed on the part of the covered sectors is 10% below the benchmark, a purely hypothetical target for scenario comparison.[7] In the ETS-cum-RES scenario, a separate RES mandate is introduced on top of the ETS and both the ETS and RES policies together are set to achieve the 10% emission reduction target.[8] The RES policy

[6] The proportions of tax allocation between regional governments and the central government are from the tax law.

[7] Please note that any hypothetical target would be fine here to compare these two policies. We selected 10% because an earlier study (Cao et al. 2016) found that meeting China's INDC entails reduction of average emission for the period 2015-230 by 9.8% from the baseline, where the baseline includes all existing policies (e.g., policies included in 13th 5 Year Plan).

[8] Note that we are not comparing here ETS and RES policy instruments to achieve the same emission reduction target. Instead, we aim to compare the ETS system with and without the presence of a separate RES policy. Under both cases, the emission reduction target is the same.

under the ETS-cum-RES scenario is implemented through a RES production subsidy rate of 50%[9], and the emissions trading target is lowered such that the RES subsidy and the emissions price achieve the desired 10% emissions reduction relative to benchmark. Considering that hydropower has the lowest generation cost and high competitiveness compared with other renewable energy technologies in China, it is not included in the RES policy in this study. The technologies included are solar, biomass, and wind.

Table 2. Scenarios under different policies.

Scenario	RES subsidy rate	CO_2 intensity decrease
S0: Benchmark scenario without any policies	0	0
Scenario ETS: ETS policy only	0	10%
Scenario ETS-cum-RES: ETS policy and RES policy	50%	10%

For simplicity of presenting the results, the 30 regions are classified into three areas (eastern, central, and western) based on the regional divisions used by the National Bureau of Statistics of China. Table 3 shows the classification of regions.

Table 3. Classification of regions.

Category	Regions
Eastern regions	Beijing (BJ), Tianjin (TJ), Hebei (HB), Liaoning (LN), Shanghai (SH), Jiangsu (JS), Zhejiang (ZJ), Fujian (FJ), Shandong (SD), Guangdong (GD), Hainan (HN)
Central regions	Shanxi (SX), Jilin (JL), Heilongjiang (HL), Anhui (AH), Jiangxi (JX), Henan (HeN), Hubei (HuB), Hunan (HuN)
Western regions	Inner Mongolia (IM), Guangxi (GX), Chongqing (CQ), Sichuan (SC), Guizhou (GZ), Yunnan (YN), Shaanxi (SaX), Gansu (GS), Qinghai (QH), Ningxia (NX), Xinjiang (XJ)

4. Results

Because this is a static long-term analysis, the results shown in this section do not

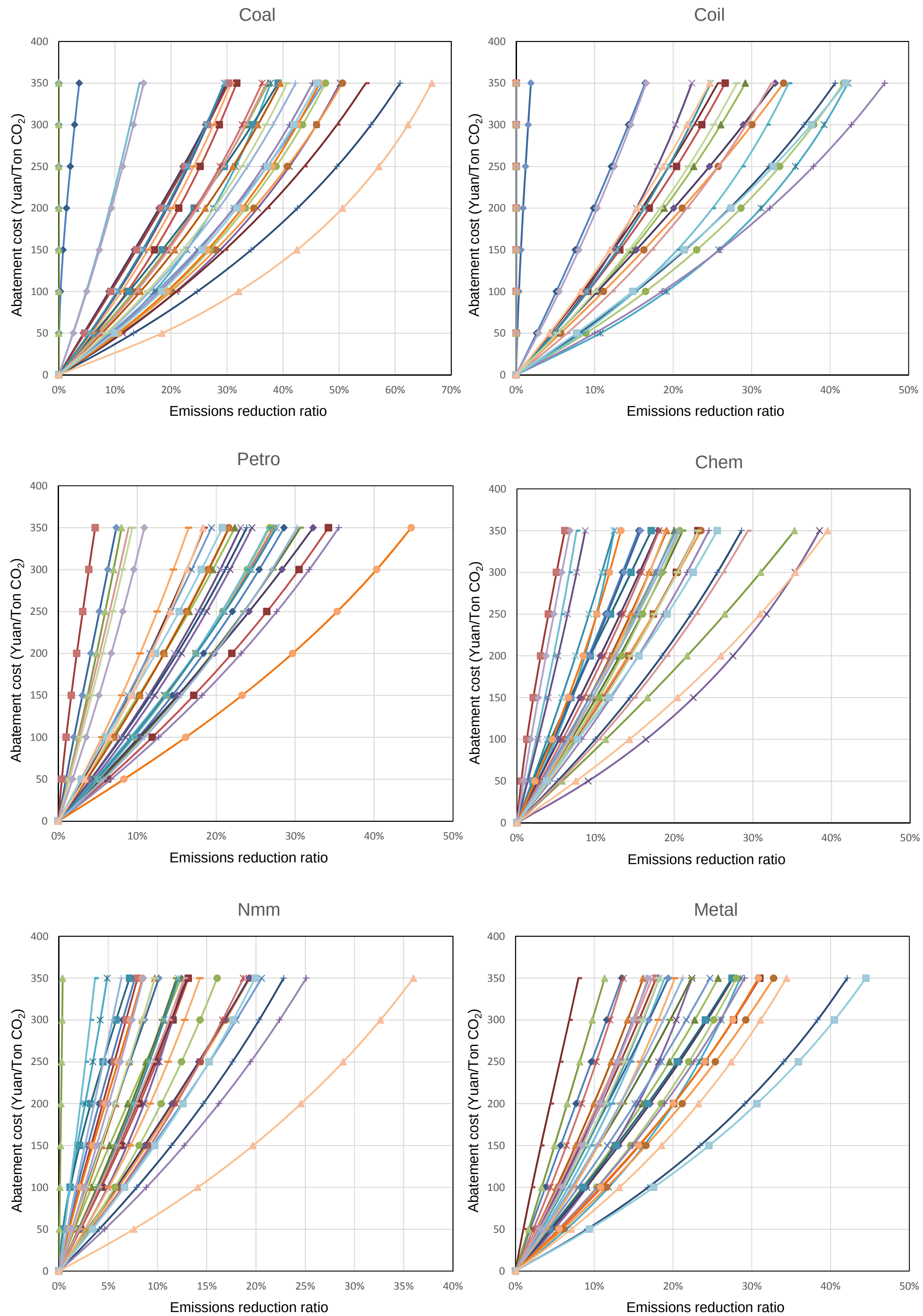
[9] The subsidy rate is determined based on data on levelized costs for power generation from various sources and current electricity generation mix. A 50% price subsidy means reduction of the long-run marginal cost of the renewable energy aggregate (excluding hydro), which is the price of electricity from those sources in the model, by 50%.

explicitly pertain to any specific year. We can think of them implicitly as reflecting an equilibrium situation after fully deploying the policy instruments being studied. Note that the results measure changes in key variables (GDP, sectoral outputs, international trade) due to ETS and ETS cum RES as compared to the situation in the absence of ETS and RES. They do not represent any particular year although we used SAM of 2007.

4.1 Marginal abatement costs by sectors and regions

The starting point for any emission trading study is to understand the marginal costs of CO_2 abatement of various sectors in various regions. This is the basis of trade between the sectors and also among the regions. A sector with marginal abatement cost higher than market clearing CO_2 permit price buys CO_2 permits whereas a sector with marginal abatement cost lower than market clearing CO2 permit price sells CO_2 permits. Figure 3 shows the marginal abatement cost (MAC) curves of energy and energy-intensive sectors in the base case (i.e., before the emission trading). For a given sector, the marginal abatement cost are significantly different across the regions representing how expensive it would be to reduce CO_2 emissions from that sector in a region. In most regions, the electricity sector has lower marginal abatement cost as compared to other sectors due to more flexibility to produce electricity from different sources. For example, due to its utilization of an abundant endowment of fossil energy resources, Inner Mongolia offers the highest CO_2 emission mitigation potential from electricity generation, and coal and oil mining, for a given abatement cost. More generally, western resource abundant regions, such as Shanxi, Inner Mongolia, and

Ningxia, offer lower abatement cost compared to eastern industrialized regions.



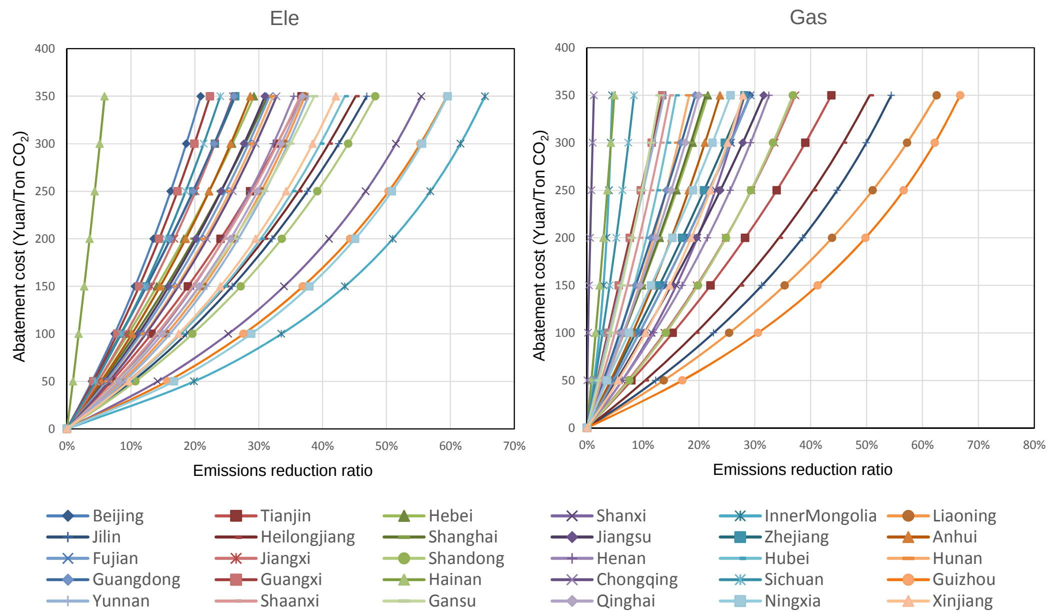


Figure 3. Marginal abatement cost curves of energy and energy-intensive sectors in the absence of ETS

4.2 Carbon market under the policy scenarios

Figure 4 presents trade of CO_2 mitigation between the sectors and across the regions under the ETS (S1) and ETS-cum-RES (S2) scenarios. Under the ETS scenario, the total trading volume of CO_2 mitigation was 173.38 million tons to achieve a target of reducing 10% CO_2 emissions from the base case (i.e., in the absence of these policies). The equilibrium market price of CO_2 price 47.43 yuan/ton (or US$7.1 with exchange rate of 0.15 US$ for one yuan).

If the separate renewable energy mandate for electricity generation is imposed on top of the ETS for the same target of CO_2 mitigation (i.e., 10% below the base case), with 50% subsidies for solar, wind, and biomass, the volume of emission trade slightly decreases, by 1.5%, to170.82 million tons. As a result, the equilibrium CO_2 price also decreases, by 3.5%, to 45.74 yuan/ton. The reduction in trade volume and CO_2 price is caused by the reduction in electricity sectors' demands for emission allowances due to the renewable energy mandate.

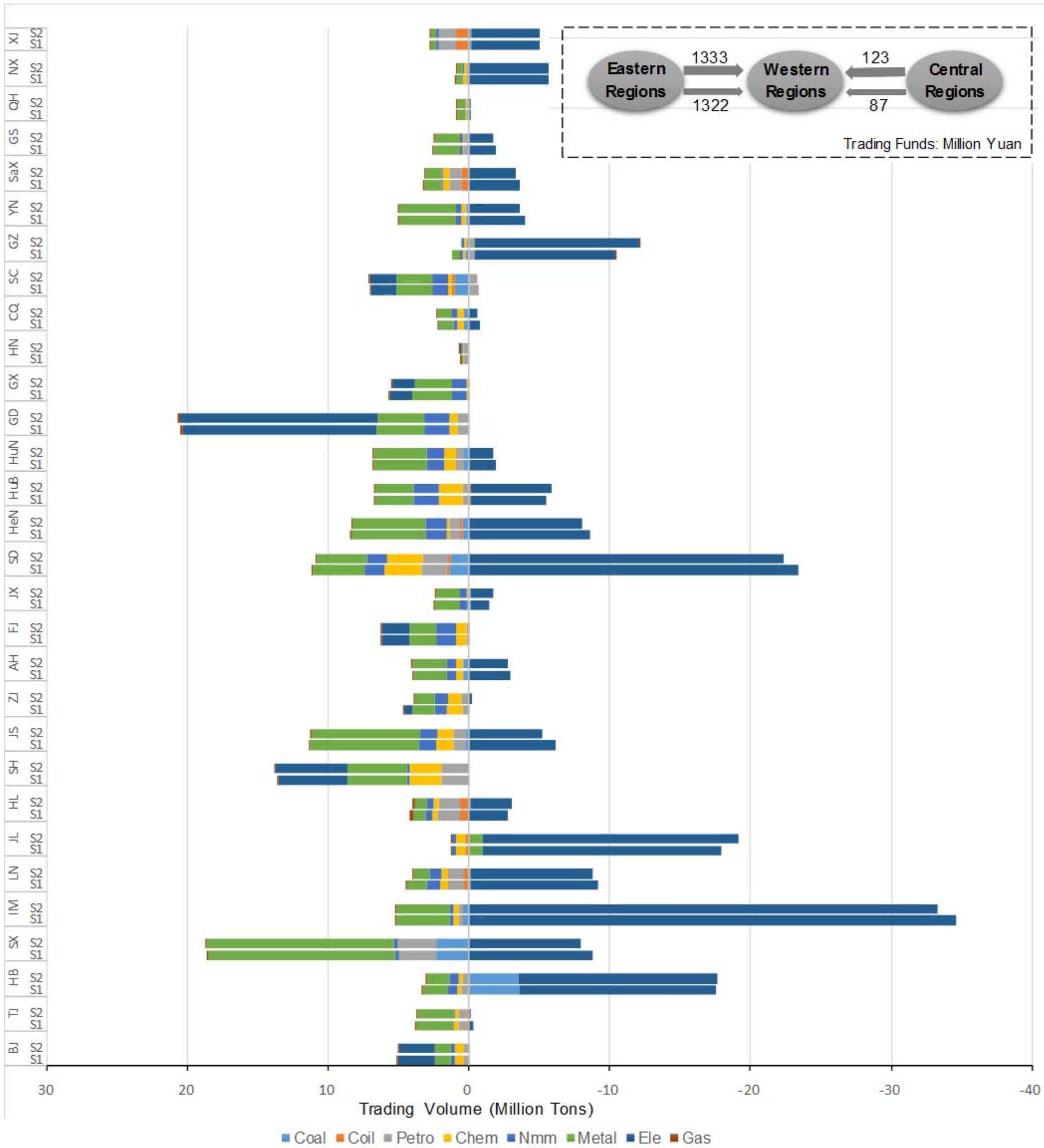


Figure 4. Inter-regional emissions trading under ETS and ETS-cum-RES cases

Although the impacts of renewable energy mandate on CO_2 emissions trade is small at the national level, it is significant to some provinces. For example, the inter-regional transfer of funds from central region to western region under the ETS decreases by 29% from 123 million yuan to 87 million yuan as the renewable energy mandate causes the size of ETS market to shrink. This is a clear disadvantage to the Western poorer region of adding a separate renewable policy on top of the ETS. The inter-regional transfer of funds from eastern region to central region, however does not change much; it gets reduced by less than 1% from 1,333 million yuan to 1,322 million yuan.

Although the electricity sectors in most regions choose to sell fewer allowances under the ETS-cum-RES case, the electricity sectors in Hebei, Jilin, Heilongjiang, Jiangxi, Hubei, and Guizhou will get higher income by selling more allowances compared to the ETS case. This is because reduction of CO_2 in these regions is more economic despite the shrinkage of the overall carbon market due to higher flexibility of CO_2 reduction from their power sectors. In other words, although the RES policy lowers the CO_2 price and total trading volume, the marginal abatement costs of electricity sectors in these regions are still less than the CO_2 price.

4.3 Economic impacts

Table 4 presents the impacts on key economic variables of the ETS and ETS-cum-RES policies. Model simulations reveal that ETS would cause less than 0.1% (20 billion Yuan) reduction in Chinese GDP. However, due to the very large size of Chinese national GDP, the percentage reduction in GDP appears to be very small. Due to the expansion of clean infrastructure caused by the ETS policy, there would be a net increase in total investment by 5 billion Yuan.

Table 4. Economic impacts (changes from the base case)

	ETS	ETS-cum-RES
GDP (million yuan)	-20152 (-0.073%)	-28105 (-0.101%)
Welfare (million yuan)	-10442	-13820
Investment (million yuan)	5037 (0.042%)	4221 (0.035%)
-Eastern regions (million yuan)	-183 (-0.003%)	-334 (-0.005%)
-Central regions (million yuan)	4301 (0.145%)	3833 (0.129%)
-Western regions (million yuan)	918 (0.038%)	723 (0.030%)

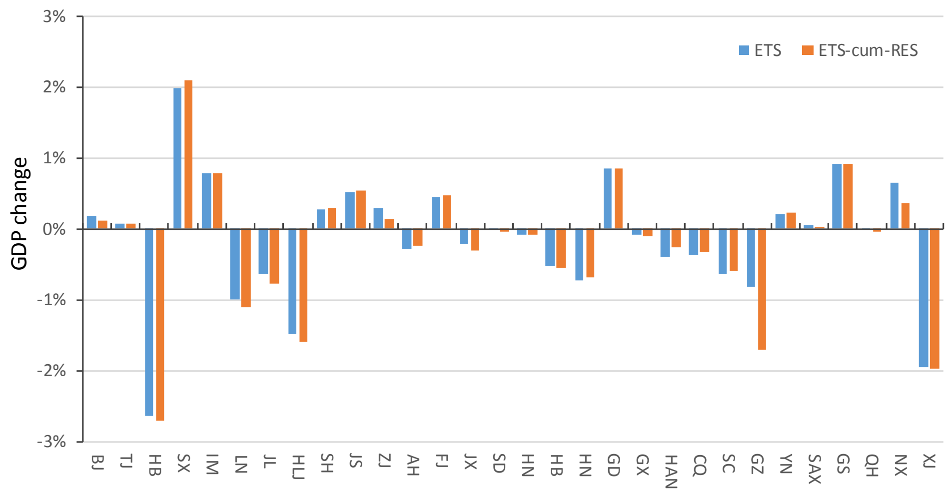


Figure 5a. GDP change in regions under ETS and ETS-cum-RES cases

Figure 5b. Welfare change in regions under ETS and ETS-cum-RES cases

In comparing the economic impacts between the ETS and ETS-cum-RES policy, we find as expected that the renewable energy mandate plus ETS policy would lead to a larger GDP loss than the ETS alone (though by only about 8 billion, a very small percentage difference in GDP loss). This is because the RES mandate would have diverted some of the cheaper reduction that can be achieved through the emission trading to relatively expensive reduction mandated by the RES policy.

Note that renewable energy sources are supported through subsidy. Necessary budget to finance the renewable electricity subsidy under the ETS-cum-RES policy is collected through an additional tax on electricity consumption. The increased electricity price would reduce the real income of households and thus directly contribute to reduced household welfare. It also would increase prices of sectoral outputs, especially of electricity intensive industries and thereby causing reductions in domestic consumption as well as exports of those goods and ultimately causing the GDP to decrease. For example, household electricity consumption decreases by 0.58% from the base case due to the additional RES policy on top of the ETS scheme to meet 10% CO_2 emission reduction target in China.

4.4 Impacts on economic structure

4.4.1 Industrial structure

Tables 5 show the changes in sectoral outputs from the base case under ETS and ETS-cum-RES scenarios. For example, the output of coal industry, the main source of CO_2 emission in China, would drop by 9% under ETS scenario from the base case. Similarly, sectoral outputs of coal fired electricity generation industry would decrease by 3%. When the RES policy is added in the presence of the ETS policy, the energy and energy-intensive industries would experience further output losses. This is because the

RES imposes a substitution of fossil fuel based electricity generation with renewable electricity and would cause reduction of fossil fuel demand for power generation and thereby fossil fuel supply. Moreover, it also increases electricity prices and causes outputs of electricity intensive industries to decrease further.

Table 5 Sectoral output change in regions under ETS and ETS-cum-RES cases (%).

	Agri		Coal		Coil		Mine		Fpap		Petro	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Total	-0.20	-0.21	-8.96	-8.90	-2.98	-3.09	-5.49	-5.48	0.64	0.61	-2.88	-2.92
BJ	-0.08	-0.19	-0.50	-0.78	-9.43	-9.18	-0.58	-0.90	0.05	-0.06	-5.89	-6.28
TJ	0.05	0.02	1.99	1.58	-1.83	-1.95	-4.28	-4.39	0.71	0.65	-1.71	-1.82
HB	-0.68	-0.75	-17.48	-17.25	-3.24	-3.44	-16.90	-16.75	-1.05	-1.18	-5.96	-6.15
SX	-15.36	-14.99	-9.60	-9.14	-5.71	-4.78	-62.52	-61.86	-7.83	-7.53	-0.36	-0.14
IM	1.31	1.34	-5.59	-5.42	1.14	1.02	2.20	2.24	0.99	1.08	-4.85	-4.73
LN	-0.20	-0.25	-12.71	-12.59	-1.76	-2.05	-10.16	-10.33	0.48	0.43	0.34	0.03
JL	-0.05	-0.08	-9.63	-9.81	-3.33	-3.46	-2.54	-2.87	0.86	0.69	-11.14	-10.81
HLJ	-0.59	-0.62	-13.17	-13.60	-3.67	-3.84	-5.43	-5.37	-0.61	-0.65	-3.92	-4.10
SH	-0.11	-0.12	0.00	0.00	-1.80	-1.69	0.00	0.00	1.10	1.11	-3.73	-3.66
JS	0.27	0.28	-5.00	-4.94	-3.26	-3.35	-1.18	-1.18	0.52	0.53	-1.33	-1.43
ZJ	0.05	-0.02	-1.33	-1.60	0.00	0.00	-2.49	-2.83	0.41	0.27	-4.21	-3.89
AH	-0.35	-0.34	-7.30	-7.17	0.00	0.00	-4.76	-4.55	-0.28	-0.25	-4.03	-4.00
FJ	0.29	0.30	-5.18	-5.22	0.00	0.00	-1.44	-1.34	0.45	0.46	-0.22	-0.29
JX	0.28	0.23	-8.47	-8.72	0.00	0.00	-2.52	-2.87	1.07	0.97	-12.27	-12.34
SD	1.08	1.07	-9.06	-9.13	-4.88	-5.06	-5.35	-5.43	2.72	2.69	-4.61	-4.67
HN	-0.43	-0.42	-8.92	-8.85	-2.41	-2.52	-1.17	-1.10	-0.52	-0.49	-3.27	-3.31
HB	-0.94	-0.91	2.73	2.25	-26.76	-26.10	-7.89	-7.62	0.12	0.12	-3.81	-3.89
HN	-0.70	-0.67	-8.84	-8.75	0.00	0.00	-3.19	-3.09	-0.71	-0.67	-2.16	-2.19
GD	0.42	0.41	0.00	0.00	0.42	0.47	0.12	0.15	1.02	1.00	-0.16	-0.14
GX	-0.02	-0.02	-1.57	-1.94	0.00	0.00	-2.93	-2.94	-0.12	-0.11	4.55	4.12
HAN	0.41	0.47	0.00	0.00	0.00	0.00	-1.88	-1.64	0.87	1.02	-3.21	-2.97
CQ	-0.14	-0.13	-9.43	-9.21	-30.19	-29.73	-10.21	-9.78	-0.36	-0.32	-11.16	-10.82
SC	-0.17	-0.15	-10.26	-10.11	-5.07	-5.03	-5.97	-5.69	0.21	0.25	-21.41	-20.89
GZ	-0.35	-0.67	-10.46	-11.32	0.00	0.00	0.89	-0.28	0.78	0.92	-23.46	-22.77
YN	-0.09	-0.06	-9.95	-9.75	0.00	0.00	-1.54	-1.42	0.01	0.09	-9.22	-8.94
SAX	-0.22	-0.21	-4.35	-4.36	-0.37	-0.42	0.05	0.03	0.16	0.15	-0.85	-0.91
GS	0.64	0.65	-3.65	-3.65	-1.03	-1.06	-1.32	-1.32	0.75	0.78	-0.80	-0.76
QH	-0.03	-0.02	-0.55	-0.81	-1.02	-1.11	-3.56	-3.50	-0.37	-0.35	-0.04	-0.17
NX	0.05	-0.02	-8.19	-8.32	-2.88	-3.32	0.00	-0.47	0.12	0.08	-2.82	-3.03
XJ	-0.95	-0.98	-18.46	-18.48	-3.90	-3.94	-6.72	-6.59	-0.70	-0.77	-3.02	-3.05

Table 5 (continue). Sectoral output change in regions under ETS and ETS-cum-RES cases (%).

	Chem		Nmm		Metal		Omf		Ele		Gas	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Total	-1.17	-1.23	-1.98	-1.98	-4.84	-4.81	-0.77	-0.77	-3.02	-3.31	-0.87	-1.19
BJ	-1.21	-1.39	-0.92	-1.01	-1.39	-1.46	0.47	0.39	-3.22	-4.28	-0.95	-1.26
TJ	-0.09	-0.11	-0.31	-0.26	-2.33	-2.23	-0.04	-0.01	-1.77	-1.61	0.44	0.11
HB	-1.30	-1.54	-3.64	-3.67	-10.04	-9.96	-4.33	-4.38	-6.56	-7.02	-4.29	-4.71
SX	-36.28	-35.36	-9.14	-8.92	-25.32	-24.96	-12.19	-11.82	0.92	1.13	0.62	0.71
IM	5.16	4.91	2.12	2.12	-1.65	-1.57	0.12	0.09	-1.51	-1.47	0.17	0.15
LN	-0.40	-0.63	-1.55	-1.70	-12.27	-12.17	-1.43	-1.48	-6.12	-6.70	-8.50	-9.15
JL	-1.49	-1.92	-6.55	-6.59	-18.40	-18.11	-0.24	-0.27	-7.11	-9.10	-3.89	-5.25
HLJ	-2.08	-2.06	-2.81	-2.82	-5.36	-5.24	-1.04	-1.06	-5.31	-5.98	-6.38	-6.84
SH	-1.02	-0.99	0.14	0.18	-2.47	-2.34	0.25	0.25	-1.23	-1.01	-0.13	-0.30
JS	-0.08	-0.06	-0.77	-0.73	-0.55	-0.51	-0.54	-0.50	-1.61	-1.56	-0.14	-0.26
ZJ	-0.24	-0.53	-0.85	-0.95	1.68	1.30	-1.84	-1.95	-4.10	-4.86	0.11	-0.96
AH	-2.11	-2.03	-2.68	-2.60	-3.08	-2.91	-2.04	-1.93	-2.67	-2.68	-1.19	-1.32
FJ	-0.22	-0.19	-1.52	-1.46	-0.81	-0.74	0.22	0.24	-1.37	-1.47	0.70	0.46
JX	1.44	1.27	-2.92	-2.92	-5.59	-5.63	-0.77	-0.83	-5.25	-6.04	-0.02	-0.42
SD	-1.63	-1.73	-2.30	-2.40	-8.61	-8.52	-2.22	-2.19	-2.85	-2.85	-1.34	-1.69
HN	-0.42	-0.40	-0.86	-0.81	-0.86	-0.81	-0.21	-0.21	-2.92	-3.03	-2.15	-2.28
HB	-7.25	-7.01	-4.75	-4.57	-10.21	-9.85	-0.87	-0.84	-5.03	-5.58	0.34	0.20
HN	-2.59	-2.53	-4.60	-4.46	-2.57	-2.49	-1.53	-1.49	-2.49	-2.49	-0.58	-0.71
GD	0.74	0.73	-0.29	-0.28	0.73	0.72	0.40	0.40	-1.08	-1.09	0.59	0.41
GX	0.10	0.05	-2.96	-2.93	-2.21	-2.22	-0.77	-0.78	-3.29	-3.67	-0.53	-1.28
HAN	-16.64	-15.81	-0.93	-0.81	-11.26	-10.57	1.25	1.36	2.21	2.48	0.01	0.15
CQ	-8.17	-7.84	-5.69	-5.42	-6.86	-6.62	-3.36	-3.25	-2.83	-2.60	0.42	0.19
SC	-0.60	-0.57	-3.09	-2.98	-8.34	-8.02	-2.98	-2.87	-2.52	-2.57	-0.83	-0.86
GZ	2.85	1.96	-1.68	-2.30	-9.49	-12.94	-0.29	-0.71	-8.02	-10.64	-18.20	-23.42
YN	0.01	0.03	-1.54	-1.47	-1.28	-1.17	-0.33	-0.26	-2.01	-2.04	-1.27	-1.25
SAX	-3.41	-3.29	-0.04	-0.06	0.83	0.78	-0.54	-0.57	-1.87	-1.86	-0.09	-0.27
GS	0.10	0.09	-2.07	-2.03	-1.82	-1.79	-0.56	-0.56	-1.37	-1.32	0.55	0.23
QH	-3.25	-3.27	-0.17	-0.16	-3.40	-3.39	0.46	0.51	-2.11	-2.26	-0.39	-0.49
NX	-1.20	-1.46	-2.78	-2.88	0.56	-0.29	0.44	0.11	-4.09	-4.83	-0.53	-1.10
XJ	-12.36	-12.30	-3.11	-3.10	-6.00	-5.91	-3.04	-3.09	-6.28	-6.56	-3.17	-3.36

Table 5 (continue). Sectoral output change in regions under ETS and ETS-cum-RES cases (%).

	Cons		Trans		Wsale		Esta		Ots	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Total	-0.16	-0.16	-1.43	-1.41	-0.75	-0.74	-0.99	-0.96	-0.50	-0.50
BJ	-0.06	-0.07	-0.32	-0.35	0.06	-0.01	-0.04	-0.07	0.10	0.04
TJ	-0.39	-0.40	-1.17	-1.10	-0.44	-0.40	-0.93	-0.86	-0.13	-0.12
HB	-0.23	-0.24	-3.77	-3.83	-3.02	-3.06	-3.91	-3.96	-2.72	-2.79
SX	-2.28	-2.23	-17.39	-16.82	-10.88	-10.52	-16.91	-16.47	-3.08	-2.90
IM	0.04	0.04	-1.31	-1.18	0.08	0.08	-1.05	-0.96	0.15	0.18
LN	-0.10	-0.10	-2.21	-2.24	-1.75	-1.80	-2.47	-2.47	-1.54	-1.58
JL	-0.19	-0.19	-0.93	-1.02	-0.50	-0.62	-1.22	-1.32	-0.79	-0.91
HLJ	-0.16	-0.16	-2.66	-2.67	-1.76	-1.79	-2.00	-2.02	-1.38	-1.45
SH	-0.06	-0.05	-0.52	-0.46	-0.23	-0.19	-0.27	-0.24	0.01	0.03
JS	-0.01	-0.01	-0.40	-0.35	-0.14	-0.11	-0.43	-0.37	0.07	0.10
ZJ	-0.04	-0.04	-0.69	-0.76	-0.27	-0.32	-0.35	-0.44	-0.32	-0.39
AH	-0.20	-0.19	-1.56	-1.47	-0.92	-0.86	-0.91	-0.84	-0.80	-0.75
FJ	0.01	0.01	-0.16	-0.12	0.13	0.16	-0.41	-0.34	0.13	0.16
JX	-0.08	-0.08	-2.59	-2.61	-1.03	-1.12	-0.96	-1.01	-0.59	-0.64
SD	-0.05	-0.05	-0.31	-0.24	1.06	1.07	-0.85	-0.82	0.15	0.14
HN	0.01	0.01	-1.05	-1.01	-1.16	-1.11	-1.08	-1.01	-0.70	-0.68
HB	-0.44	-0.43	-3.19	-3.09	-2.21	-2.14	-3.74	-3.63	-1.97	-1.91
HN	-0.66	-0.64	-1.56	-1.50	-1.33	-1.28	-1.48	-1.40	-0.99	-0.94
GD	0.07	0.05	0.49	0.51	0.58	0.60	0.49	0.50	0.46	0.47
GX	-0.24	-0.24	-0.67	-0.65	-0.78	-0.75	-0.70	-0.66	-0.30	-0.30
HAN	-0.02	-0.02	-1.21	-0.99	0.41	0.56	-0.98	-0.81	0.20	0.28
CQ	-0.27	-0.27	-1.77	-1.69	-1.99	-1.92	-1.68	-1.59	-0.60	-0.56
SC	-0.08	-0.07	-3.33	-3.21	-2.63	-2.52	-2.53	-2.42	-1.31	-1.25
GZ	0.01	-0.08	-3.32	-3.98	-2.09	-2.69	-3.78	-4.15	-0.83	-1.20
YN	-0.06	-0.06	-1.62	-1.51	-1.33	-1.22	-1.73	-1.59	-0.07	-0.02
SAX	0.38	0.39	-0.69	-0.68	-0.30	-0.31	-0.18	-0.17	-0.54	-0.55
GS	-0.61	-0.61	1.92	1.93	2.04	2.11	0.03	0.07	0.25	0.26
QH	-0.09	-0.09	-0.65	-0.65	-0.37	-0.37	-1.20	-1.19	-0.11	-0.12
NX	-0.02	-0.03	-1.60	-1.72	-1.18	-1.29	-1.80	-1.78	-0.05	-0.18
XJ	-0.13	-0.13	-2.83	-2.80	-1.51	-1.53	-2.53	-2.48	-1.99	-1.99

Note:

1. S1 and S2 denote ETS and ETS-cum-RES cases, respectively.
2. The value 0 in the table indicates zero output of that sector in the base case.

The results show that the outputs in transport, wholesale, real estate, and other services sectors under ETS-cum-RES case are more than the ETS case. This is because the RES policy would create more demand for goods and services to be produced from these sectors to support expansion of renewable energy industries in China.

4.4.2 Power generation mix

Table 6 presents the power generation mix under the various scenarios and percentage change in outputs of each power generation technology. Note that the drops in electricity outputs of from fossil fuel based technologies are higher under the ETS-cum-RES scenario are higher as compared to that in ETS scenario. This is because the RES policy causes substitution of fossil fuel based power generation with the renewable energy based electricity.

Table 6. Generation mix (%) under different scenarios along with percentage change in electricity outputs of different generation technologies

	S0	ETS		ETS-cum-RES	
	Proportion	Change	Proportion	Change	Proportion
Coa	84.870	-3.024	84.866	-3.591	84.335
Ngs	1.672	-2.938	1.673	-3.487	1.663
Pet	3.404	-3.615	3.383	-3.955	3.370
Nuc	1.648	-2.790	1.651	-3.413	1.640
Hyd	7.703	-2.790	7.721	0.045	7.943
Win	0.536	-2.790	0.537	44.559	0.799
Sol	0.127	-2.790	0.127	44.559	0.189
Oth	0.040	-2.790	0.041	44.559	0.060

Interestingly, electricity generation from renewable as well as fossil sources is decreasing under the ETS scenario. The reason is that the nesting structure used to model electricity generation technologies (Figure 1) does not allow different substitution possibility between the aggregate electricity generation from fossil fuels and aggregate electricity generation from renewable energy sources. Since the share of non-fossil share of total electricity generation is relatively small (< 10%) in China, this rigid nesting structure adopted in the model used for this study would not impact the result much for a small carbon price. However, the model structure must be changed to allow the substitution effect to work if carbon pricing level is high.

4.4.3 Impacts on residential consumption of goods and services

Table 7 presents the impacts of ETS and ETS-cum-RES scenarios on household consumption of goods and services. From the table, three observations can be made. First, under the both schemes, household consumption of fossil fuels and energy intensive products (non-metallic minerals, metals, chemicals) would drop by higher proportions than other goods and services. Second, the drops in household consumption of goods and services would be higher under ETS-cum-RES scenario than that of ETS scenario. The difference in drops of electricity consumption between the ETS and ETS-cum-RES scenario is noticeable as the adoption of RES policy increases the price for electricity consumption, and thus leads to significant decrease of electricity consumption, comparing with the ETS case. Third, the drops of household consumption of good and services are much higher in some provinces (e.g., Hebei, Liaoning, Heilongjiang, Guizhou, Hainan, Xinjiang) than in other provinces. This is because households in these provinces consume proportionally higher amounts of energy and energy intensive goods and services.

Table 7. Change in household consumption from the base case (%).

	Agriculture		Coal		Crude oil		Mining		Food, paper		Petroleum	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Total	-0.05	-0.07	-0.80	-0.80	-0.47	-0.49	-0.55	-0.54	-0.12	-0.14	-0.54	-0.54
BJ	0.18	0.13	-0.09	-0.12	0.00	0.00	0.00	0.00	0.17	0.12	-0.44	-0.47
TJ	0.15	0.15	-0.29	-0.26	0.03	0.05	0.34	0.32	0.11	0.11	-0.48	-0.46
HB	-2.35	-2.40	-3.40	-3.42	-2.67	-2.72	-1.84	-1.95	-2.50	-2.57	-3.18	-3.21
SX	1.81	1.89	0.27	0.39	0.00	0.00	0.00	0.00	1.74	1.82	0.08	0.23
IM	0.39	0.42	0.83	0.87	0.69	0.73	0.00	0.00	0.57	0.60	-0.21	-0.15
LN	-1.00	-1.07	-1.41	-1.45	-1.35	-1.41	0.00	0.00	-1.07	-1.15	-1.53	-1.58
JL	-0.40	-0.52	-0.62	-0.69	-0.50	-0.62	0.00	0.00	-0.52	-0.65	-1.17	-1.26
HLJ	-1.31	-1.38	0.14	0.13	-1.50	-1.56	0.00	0.00	-1.32	-1.40	-2.32	-2.35
SH	0.26	0.28	-0.14	-0.10	0.00	0.00	0.00	0.00	0.14	0.16	-0.61	-0.56
JS	0.40	0.42	0.03	0.07	0.00	0.00	0.00	0.00	0.50	0.52	-0.02	0.02
ZJ	0.19	0.09	-0.14	-0.23	0.00	0.00	0.00	0.00	0.18	0.05	-0.29	-0.39
AH	-0.29	-0.25	-0.76	-0.70	0.00	0.00	0.00	0.00	-0.37	-0.34	-1.11	-1.04
FJ	0.36	0.38	0.63	0.67	0.33	0.36	0.00	0.00	0.48	0.50	-0.10	-0.06
JX	-0.10	-0.15	-0.31	-0.35	-0.26	-0.33	0.00	0.00	-0.13	-0.21	-0.95	-0.99
SD	0.00	-0.02	-0.55	-0.55	0.00	0.00	0.20	0.13	0.07	0.04	-0.38	-0.39
HN	-0.18	-0.16	-1.45	-1.40	-0.57	-0.55	-0.56	-0.55	-0.21	-0.20	-1.25	-1.19
HB	-0.77	-0.74	-1.25	-1.20	0.00	0.00	-0.68	-0.68	-0.77	-0.75	-1.68	-1.62
HN	-0.50	-0.46	-1.69	-1.59	-1.04	-0.98	0.00	0.00	-0.74	-0.70	-1.52	-1.44
GD	0.86	0.86	0.47	0.48	0.78	0.79	0.90	0.88	0.85	0.84	0.52	0.53
GX	-0.05	-0.04	-0.36	-0.33	0.00	0.00	0.00	0.00	-0.06	-0.06	-0.60	-0.57
HAN	-0.21	-0.10	-0.40	-0.27	0.00	0.00	0.00	0.00	-0.17	-0.05	-0.64	-0.51
CQ	-0.24	-0.21	0.00	0.00	-0.71	-0.66	0.00	0.00	-0.35	-0.32	-1.15	-1.09
SC	-0.42	-0.39	-1.51	-1.41	-0.87	-0.81	0.00	0.00	-0.54	-0.50	-1.66	-1.57
GZ	-0.84	-1.40	-0.62	-1.10	-1.16	-1.90	0.00	0.00	-0.94	-1.64	-1.85	-2.47
YN	0.20	0.24	-0.53	-0.46	0.00	0.00	0.00	0.00	0.15	0.20	-1.12	-1.03
SAX	-0.03	-0.04	0.08	0.08	0.00	0.00	-0.12	-0.15	-0.10	-0.11	-0.69	-0.67
GS	0.78	0.79	1.07	1.10	0.00	0.00	1.06	1.05	0.88	0.88	0.50	0.52
QH	0.04	0.04	-0.32	-0.27	-0.59	-0.55	0.00	0.00	0.06	0.06	-0.06	-0.01
NX	0.40	0.24	0.21	0.13	0.23	0.05	0.00	0.00	0.50	0.31	-0.57	-0.71
XJ	-1.06	-1.08	0.32	0.32	-2.16	-2.15	0.00	0.00	-1.44	-1.48	-2.78	-2.75

Note:

1. S1 and S2 denote ETS and ETS-cum-RES cases, respectively.

2. The value 0 in the table indicates there is no household consumption of commodities in the base case.

Table 7b. Household consumption change in regions under ETS and ETS-cum-RES cases (%).

	Chemicals		Non metals		Metal		Other MF		Electricity		Gas	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Total	-0.42	-0.47	-0.86	-0.87	-1.09	-1.09	-0.26	-0.28	-0.05	-0.58	-0.39	-0.39
BJ	-0.11	-0.18	-0.25	-0.31	-0.75	-0.79	-0.06	-0.11	0.37	-0.67	0.18	0.11
TJ	-0.12	-0.12	-0.27	-0.28	-0.87	-0.85	-0.12	-0.11	0.45	0.08	-0.06	-0.04
HB	-2.84	-2.91	-2.69	-2.76	-3.85	-3.89	-2.97	-3.03	-2.76	-3.39	-2.46	-2.50
SX	0.80	0.91	0.64	0.74	-1.02	-0.86	1.21	1.30	1.46	1.47	1.31	1.40
IM	0.37	0.39	0.01	0.03	-0.36	-0.32	0.34	0.36	3.58	3.24	0.33	0.38
LN	-1.37	-1.45	-1.68	-1.77	-2.23	-2.28	-1.40	-1.47	-1.17	-2.25	-1.33	-1.39
JL	-0.77	-0.91	-1.28	-1.41	-1.58	-1.69	-0.79	-0.91	-0.01	-0.73	-0.81	-0.92
HLJ	-1.70	-1.79	-2.38	-2.46	-2.64	-2.70	-1.68	-1.76	-1.05	-1.82	-2.83	-2.93
SH	-0.12	-0.10	-0.12	-0.11	-0.40	-0.36	-0.02	0.01	0.50	0.22	-0.06	-0.03
JS	0.30	0.31	0.02	0.03	-0.31	-0.28	0.25	0.28	0.79	0.49	0.17	0.20
ZJ	-0.05	-0.18	-0.39	-0.52	-0.81	-0.91	-0.13	-0.25	-0.33	-1.08	0.01	-0.11
AH	-0.71	-0.67	-1.29	-1.25	-1.51	-1.45	-0.73	-0.68	-1.08	-1.33	-0.56	-0.52
FJ	0.21	0.23	-0.26	-0.24	-0.51	-0.47	0.24	0.26	1.10	0.79	0.25	0.25
JX	-0.24	-0.32	-0.72	-0.80	-1.13	-1.20	-0.30	-0.37	-0.22	-0.88	-0.25	-0.34
SD	-0.06	-0.09	-0.10	-0.12	-0.64	-0.65	-0.06	-0.09	0.97	0.55	-0.09	-0.12
HN	-0.50	-0.50	-0.71	-0.70	-1.32	-1.29	-0.64	-0.62	-0.74	-1.14	-1.28	-1.26
HB	-1.33	-1.30	-1.94	-1.89	-1.74	-1.70	-1.01	-0.99	-0.22	-0.74	-0.91	-0.88
HN	-1.28	-1.24	-2.11	-2.05	-1.89	-1.82	-1.16	-1.11	-0.57	-0.86	-0.97	-0.95
GD	0.69	0.68	0.36	0.35	0.24	0.24	0.67	0.67	0.88	0.59	0.67	0.68
GX	-0.26	-0.27	-1.66	-1.66	-1.24	-1.24	-0.36	-0.36	-0.10	-0.69	-0.25	-0.29
HAN	-0.39	-0.28	-0.59	-0.47	-0.76	-0.64	-0.37	-0.25	-0.27	-0.14	-0.37	-0.26
CQ	-0.75	-0.72	-1.08	-1.05	-1.27	-1.23	-0.66	-0.63	0.08	-0.30	-0.46	-0.42
SC	-0.75	-0.72	-1.36	-1.30	-1.60	-1.54	-0.86	-0.81	-1.16	-1.44	-0.72	-0.68
GZ	-1.16	-1.89	-1.58	-2.25	-1.96	-2.68	-1.23	-1.92	0.65	-1.44	0.49	0.35
YN	-0.08	-0.04	-0.94	-0.89	-1.01	-0.94	-0.16	-0.12	2.83	2.40	-0.36	-0.30
SAX	-0.42	-0.44	-0.53	-0.55	-1.04	-1.04	-0.40	-0.41	0.17	-0.19	-0.26	-0.25
GS	0.67	0.67	0.33	0.33	0.08	0.09	0.71	0.71	1.69	1.38	0.93	0.98
QH	-1.46	-1.47	-0.21	-0.20	-1.26	-1.33	-0.19	-0.18	1.40	0.91	-0.21	-0.19
NX	0.12	-0.10	-0.53	-0.72	-0.30	-0.54	0.23	0.03	2.77	1.79	0.36	0.22
XJ	-1.92	-1.95	-2.54	-2.57	-2.81	-2.81	-1.87	-1.89	-4.45	-5.12	-1.66	-1.70

Table 7c. Household consumption change in regions under ETS and ETS-cum-RES cases (%).

	Construction		Transport		Wholesale		Real Estate		Others	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Total	-0.52	-0.55	-0.03	-0.05	0.08	0.05	0.05	0.04	-0.11	-0.13
BJ	-0.21	-0.26	0.14	0.08	0.25	0.20	0.19	0.15	0.08	0.03
TJ	-0.25	-0.24	0.13	0.13	0.26	0.27	0.28	0.29	0.14	0.14
HB	-2.93	-3.00	-2.31	-2.39	-2.23	-2.29	-2.25	-2.31	-2.25	-2.33
SX	0.00	0.00	2.00	2.08	2.01	2.09	2.04	2.12	1.63	1.72
IM	0.27	0.30	0.66	0.69	0.75	0.77	0.79	0.82	0.64	0.66
LN	-1.49	-1.57	-0.99	-1.06	-0.78	-0.85	-0.71	-0.78	-0.82	-0.89
JL	-0.90	-1.03	-0.52	-0.65	-0.43	-0.56	-0.41	-0.53	-0.39	-0.52
HLJ	-1.85	-1.93	-1.32	-1.40	-1.30	-1.39	-1.22	-1.30	-1.22	-1.31
SH	0.00	0.00	0.17	0.19	0.27	0.30	0.24	0.28	0.12	0.14
JS	0.21	0.23	0.46	0.49	0.55	0.58	0.56	0.59	0.47	0.49
ZJ	-0.37	-0.49	0.15	0.04	0.24	0.13	0.24	0.14	0.17	0.06
AH	-0.80	-0.76	-0.41	-0.37	-0.30	-0.26	-0.36	-0.31	-0.35	-0.32
FJ	0.19	0.21	0.48	0.50	0.54	0.57	0.53	0.56	0.48	0.49
JX	-0.62	-0.71	0.07	-0.02	0.04	-0.07	0.11	0.04	0.13	0.05
SD	-0.15	-0.17	0.06	0.04	0.04	0.02	0.30	0.29	0.09	0.06
HN	-0.62	-0.61	-0.26	-0.24	-0.13	-0.11	-0.28	-0.26	-0.19	-0.19
HB	-1.32	-1.28	-0.49	-0.48	-0.41	-0.40	-0.21	-0.20	-0.42	-0.41
HN	-1.27	-1.22	-0.81	-0.76	-0.60	-0.56	-0.73	-0.68	-0.66	-0.62
GD	0.65	0.62	0.85	0.86	0.91	0.91	0.88	0.90	0.78	0.78
GX	-0.62	-0.62	0.02	0.02	0.04	0.04	0.02	0.03	0.01	0.01
HAN	-0.32	-0.19	-0.22	-0.10	-0.15	-0.02	-0.06	0.06	-0.24	-0.12
CQ	-0.83	-0.80	-0.31	-0.29	-0.25	-0.22	-0.20	-0.18	-0.35	-0.32
SC	-1.03	-0.98	-0.50	-0.45	-0.42	-0.38	-0.31	-0.27	-0.41	-0.37
GZ	-1.25	-1.99	-0.68	-1.36	-0.71	-1.40	-0.65	-1.30	-0.71	-1.37
YN	-0.36	-0.31	0.06	0.11	0.24	0.29	0.27	0.31	0.13	0.17
SAX	-0.46	-0.47	-0.11	-0.12	0.00	-0.01	0.14	0.13	0.03	0.02
GS	0.68	0.69	0.75	0.76	0.84	0.85	0.96	0.97	0.90	0.90
QH	-0.26	-0.26	0.11	0.12	0.13	0.13	0.17	0.17	0.09	0.08
NX	0.11	-0.09	0.57	0.38	0.64	0.46	0.64	0.46	0.53	0.35
XJ	-1.58	-1.61	-1.44	-1.47	-1.39	-1.41	-1.25	-1.27	-1.28	-1.31

4.4.4 Export and import

Figure 6 presents the impacts on export and import of total goods and services under ETS and ETS-cum-RES scenarios. Both ETS and ETS-cum-RES scenarios would cause exports of fossil fuels and energy intensive goods to decrease and exports of low emission intensive goods and services to increase. The magnitudes of changes in exports are lower under the ETS-cum-RES policy as compared to ETS policy.

The total import would also drop in China under ETS and ETS-cum-RES cases, respectively. The difference of import impacts between the ETS and ETS-cum-RES scenarios is not significant. As expected imports of fossil fuels would decrease under both scenarios. Note that although China is rich in coal resources, it is a net importer of coal due to much higher demand compared to domestic supply. While the reductions of imports of most commodities are less than 2%, the reductions of import of coal and mining products are more than 6%.

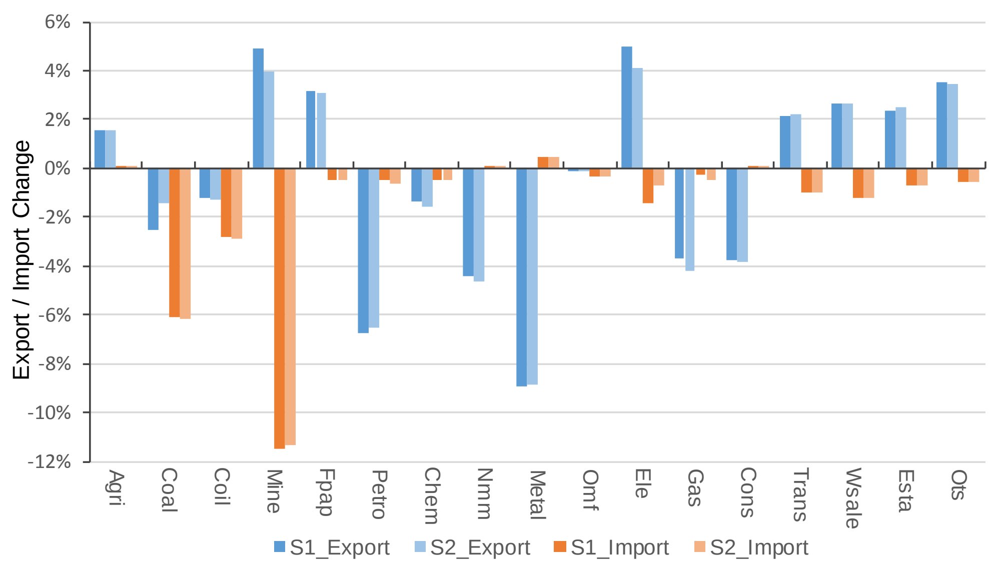


Figure 6. Changes of sectoral export and import under ETS and ETS-cum-RES cases

5. Conclusion

The emissions trading scheme and renewable energy mandates are two key elements in the climate change mitigation policy package that the government is implementing in China to achieve its nationally determined commitments under the Paris Agreement. In order to understand the interactions between these instruments, this study compares economy-wide impacts of ETS with and without a separate RES. These impacts are measured using a multi-regional computable general equilibrium model of China. Understanding these interactions would be helpful in designing the national emission trading scheme that China is going to introduce in 2017.

Our analysis shows that to achieve 10% reduction of CO_2 emissions in China from the base case, a national emission trading scheme would cause a slight loss of GDP and welfare. If a separate renewable electricity mandate is introduced on top of the ETS to achieve the same level of CO_2 mitigation, it would cause greater GDP and welfare losses. This would happen because an ETS allows the market to find and implement the cheapest GHG mitigation options. When a renewable energy mandate is imposed, it diverts resources into implementing the renewable energy technologies versus other GHG mitigation options which are cheaper than the renewable energy technologies.

The additional RES policy mandate would decrease the demand for emission allowances in trading sectors, thereby causing the size of the carbon market to shrink and the equilibrium carbon price to drop. This would lower the inter-provincial as well as inter-sectoral transfer of funds associated with emission trading. Our study shows that the inter-regional transfer of funds from the central region to the western region under the ETS decreases by 29% as the renewable energy mandate causes the size of the ETS market to shrink.

Despite the political appetite for mixing various GHG mitigation options to mitigate climate change, this study quantitatively demonstrates that relying on carbon pricing would be more efficient to achieve a given target of climate change mitigation.

While other policies such as renewable energy standards or energy efficiency mandates are promoted as well as GHG mitigation, their imposition is not necessary to achieve a climate change mitigation target if an emission trading scheme is already in place to meet the same objective.

It is important to note that a renewable energy policy together with an ETS would reduce more fossil fuels than the ETS policy alone and therefore help reduce more local air pollution than the latter. Considering the importance of local air pollution reduction in China, if the benefits from local air pollution are quantified and accounted for in the model, one could argue that the ETS cum RES policy might be more economic than the ETS policy alone. However, quantification of local air pollution reduction benefits in each of the 30 provinces in our model is itself huge task and beyond the scope of this study.[10] Moreover, the model needs substantial modification because its current welfare measure does not account for environmental benefits coming from CO_2 mitigation and local air pollution mitigation. These could be considerations for future studies.

It is also important to note that in practice emission trading schemes do not necessarily capture all potential emission sources. In such cases additional policy instruments can be helpful. Moreover, a separate renewable energy target may be needed if government, for whatever reasons, would like to see more deployment of renewable energy in addition to GHG mitigation.

[10] It is further complicated considering the trans-boundary nature of local air pollutants.

References

Böhringer, C., Behrens, M., 2015. Interactions of emission caps and renewable electricity support schemes. Journal of Regulatory Economics 48(1), 74-96.

Böhringer, C., Löschel, A., Moslener, U., et al., 2009. EU climate policy up to 2020: An economic impact assessment. Energy Economics 31, S295-S305.

Cao, J., Ho, M. and Timilsina, G.R. (2016). Impacts of Carbon Pricing in Reducing the Carbon Intensity of China's GDP, World Bank Policy Research Working Paper, WPS 7735. World Bank, Washington, DC.

Couture, T., Gagnon, Y., 2010. Analysis of feed-in tariff remuneration models: implications for renewable energy investment. Energy Policy 38(2), 955-965.

Fan Y., Wu J., Xia Y., et al., 2016. How will a nationwide carbon market affect regional economies and efficiency of CO_2 emission reduction in China? China Economic Review 38, 151-166.

Fankhauser, S., Hepburn, C., Park, J., 2010. Combining multiple climate policy instruments: how not to do it. Climate Change Economics 1(3), 209-225.

He, Y.X., Pang, Y.X., Zhang, J.X., et al., 2015. Feed-in tariff mechanisms for large-scale wind power in China. Renewable and Sustainable Energy Reviews 51, 9-17.

Hübler, M., Voigt, S., Löschel, A., 2014. Designing an emissions trading scheme for China—An up-to-date climate policy assessment. Energy Policy 75, 57-72.

Landis, F. and G.R. Timilsina (2015). The Economics of Policy Instruments to Stimulate Wind Power in Brazil, World Bank Policy Research Working Paper, WPS 7376, World Bank. Washington, DC.

Langniß, O., Diekmann, J., Lehr, U., 2004. Advanced mechanisms for the promotion of renewable energy—Models for the future evolution of the German Renewable Energy Act. Energy Policy 37(4), 1289-1297.

Lesser, J.A., Su, X.J., 2008. Design of an economically efficient feed-in tariff structure for renewable energy development. Energy Policy 36, 981-990.

Lin, W.B., Gu, A., Wang, X., et al., 2016. Aligning emissions trading and feed-in tariffs in China. Climate Policy 16(4), 434-455.

Morris, J.F., 2009. Combining a renewable portfolio standards with a cap-and-trade policy: a general equilibrium analysis. Massachusetts Institute of Technology.

National Development and Reform Commission (NDRC), 2015. China's Intended Nationally Determined Contribution: Enhanced Actions on Climate Change. Available at: http://www.sdpc.gov.cn/xwzx/xwfb/201506/t20150630_710204.html.

Newell, R. (2015). The Role of Energy Technology Policy alongside Carbon Pricing. Parry, I.W. (ed.) Implementing a US Carbon Tax: Challenges and Debates. Routledge.

Nordhaus, W., 2011.Designing a friendly space for technological change to slow global warming. Energy Economics 33, 665-673.

Ouyang, X.L., Lin, B.Q., 2014. Levelized cost of electricity (LCOE) of renewable energies and required subsidies in China. Energy Policy 70, 64-73.

Schallenberg-Rodriguez, J., Haas, R., 2012.Fixed feed-in tariff versus premium: a review of the current Spanish system. Renewable and Sustainable Energy Reviews 16(1), 293-305.

Timilsina, G.R. and F. Landis (2014). Economics of Transiting to Renewable Energy in Morocco: A General Equilibrium Analysis, World Bank Policy Research Working Paper, WPS 6940, World Bank. Washington, DC.

Tsao, C.-C., Campbell, J.E., Chen, Y., 2011.When renewable portfolio standards meet cap-and-trade regulations in the electricity sector: Market interactions, profits implications, and policy redundancy. Energy Policy 39(7), 3966-3974.

Van den Bergh, K., Delarue, E., D'haeseleer, W, 2013. Impact of renewables deployment on the CO2 price and the CO2 emissions in the European electricity sector. Energy Policy 63, 1021-1031.

Weigt, H., Ellerman, A.D., Delarue, E., 2013. CO2 abatement from renewables in the German electricity sector: does a CO2 price help? Energy Economics 40, 149-158.

Wu J., Fan Y., Xia Y., 2016. The economic effects of initial quota allocations on carbon emissions trading in China. The Energy Journal 37(SI1), 129-151.

Zhang, S., Bauer, N., 2013.Utilization of the non-fossil fuel target and its implications in China. Climate Policy 13, 328-344.