Green Finance

Green Finance, 5 (3):431–451.
DOI: 10.3934/GF.2023017
Received: 23 July 2023
Revised: 11 September 2023
Accepted: 19 September 2023
Published: 25 September 2023

http://www.aimspress.com/journal/GF

Research article

Designing the nationwide emission trading scheme in China

Shuyang Chen*

State Key Joint Laboratory of Environmental Simulation and Pollution Control (SKLESPC), School of Environment, Tsinghua University, Beijing 100084, China

* **Correspondence:** Email: SC5917@ic.ac.uk.

Supplementary

Table S1. The Divided Sectors in the Chinese Economy.

Sector	Abbreviation	Sector	Abbreviation
Agriculture	agric	Electricity Transmission and Distribution	TD
Mining and Washing of Coal	coalm	Supercritical Coal Generation	Supercrit
Extraction of Petroleum	petrm	Ultra-Supercritical Coal Generation	USC
Extraction of Natural Gas	gasn	Sub-c Coal Generation	Subc
Metal, Ore, Non-metal, and Other Mining	othm	Natural Gas Generation	NG
Foods, Beverage & Tobacco	food	Nuclear Power Generation	Nuclear
Textile Products	texti	Hydro Power Generation	Hydro
Furniture	furni	Wind Power Generation	Wind
Petroleum Processing	petrp	Solar Power Generation	Solar
Coking Processing	coking	Gas Production and Distribution	gasm
Chemical Industry	chemical	Water Production and Distribution	water
Mineral Products	mineral	Construction	const
Metal Products	metal	Transport, Storage and Post	trans
Machinery and Equipment	machi	Service	service
Heat Production and Distribution	fipow		

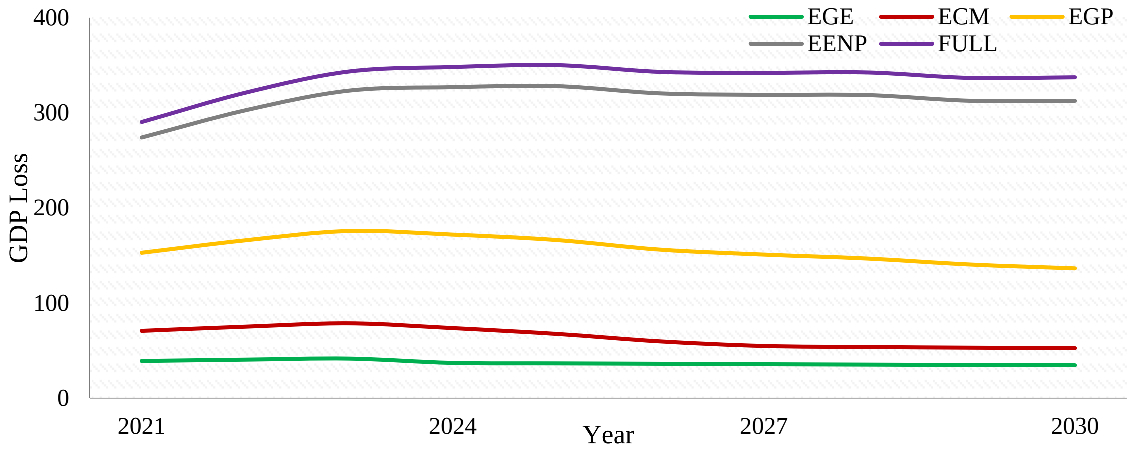

Figure S1. Sectoral Coverage Effect on GDP Loss (Unit: 10^9 CNY).

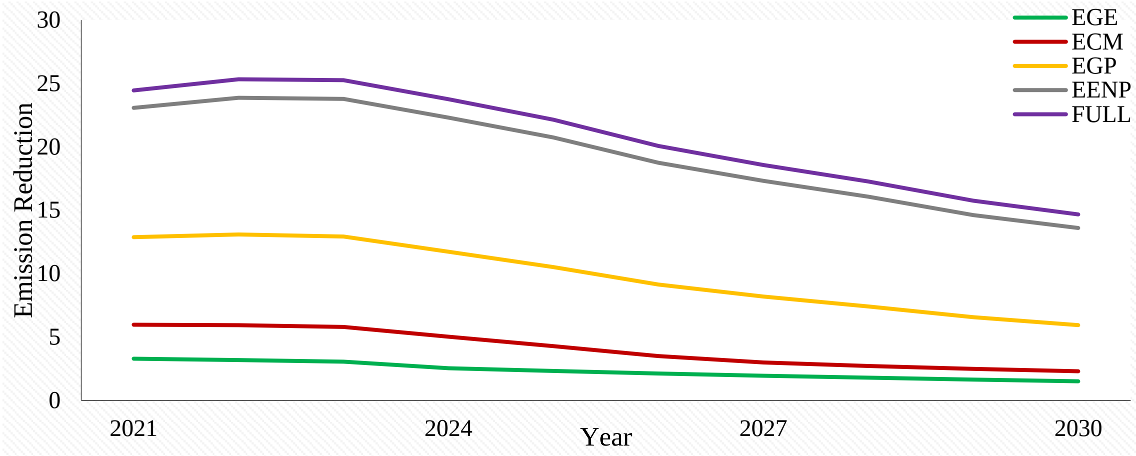

Figure S2. Sectoral Coverage Effect on Emission Abatement (Unit: 10^6 ton).

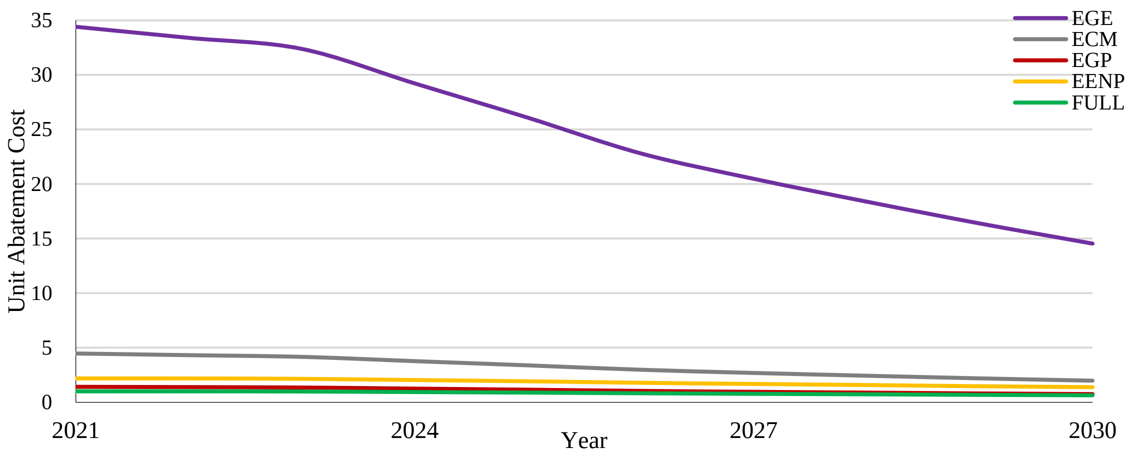

Figure S3. Sectoral Coverage Effect on UAC (Unit: $CNY/kg\ CO_2$).

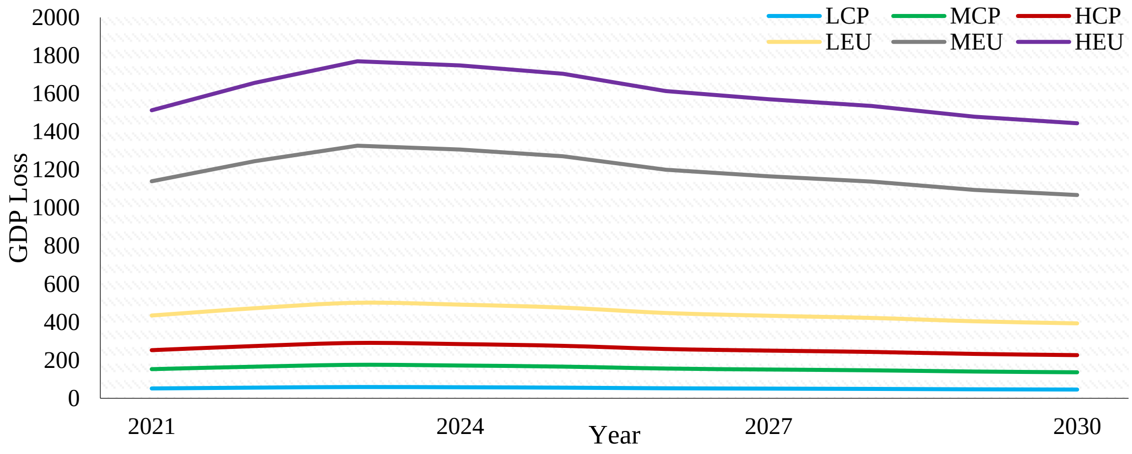

Figure S4. Carbon Price Effect on GDP Loss (Unit: 10^9 CNY).

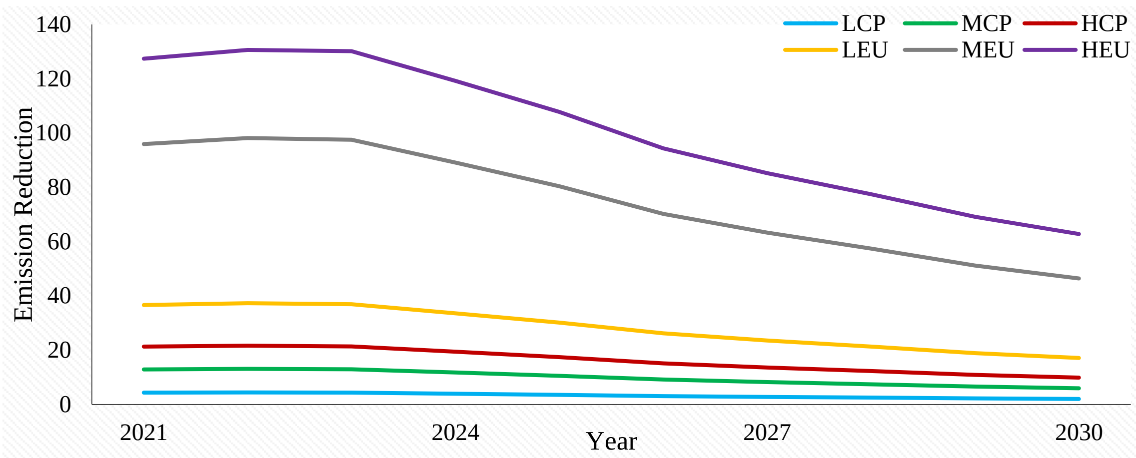

Figure S5. Carbon Price Effect on Emission Abatement (Unit: 10^6 ton).

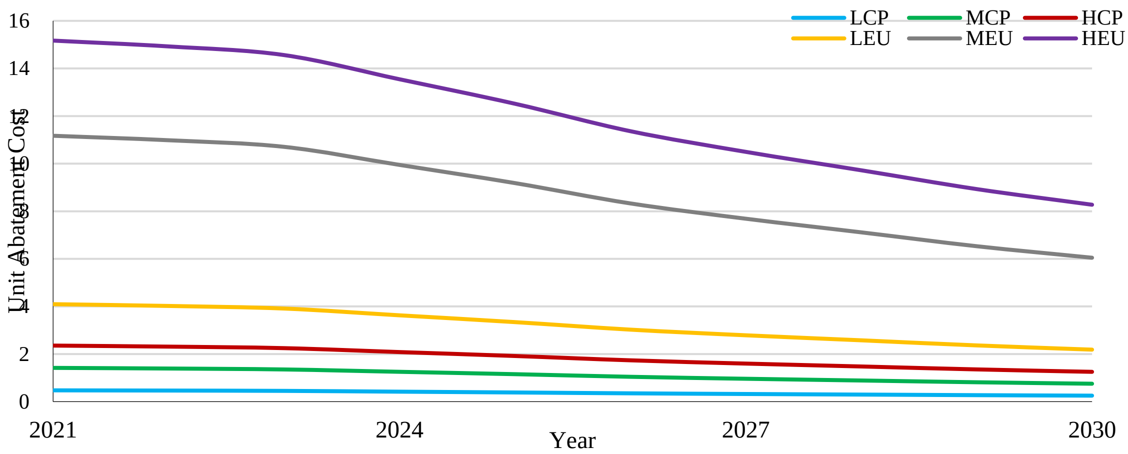

Figure S6. Carbon Price Effect on UAC (Unit: $CNY/kg\ CO_2$).

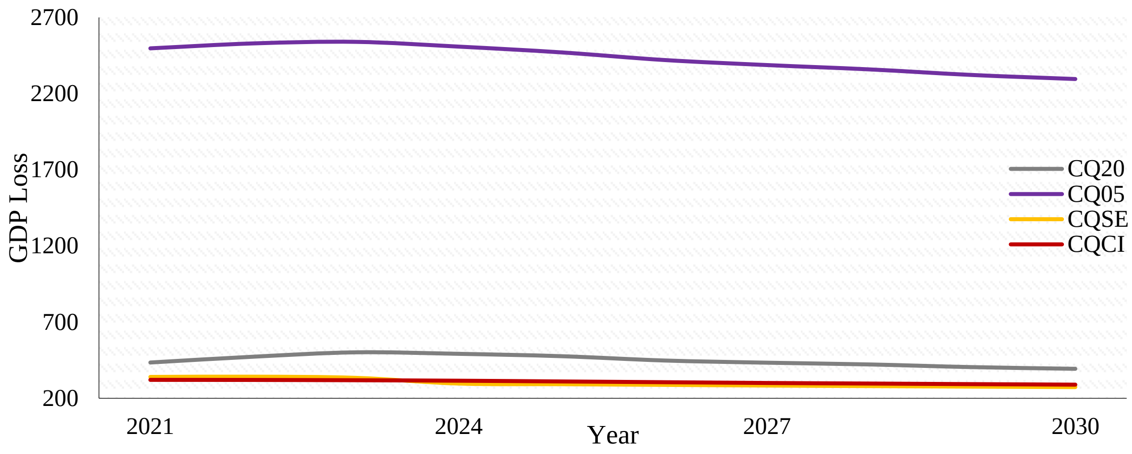

Figure S7. QAS Effect on GDP Loss (Unit: 10^9 CNY).

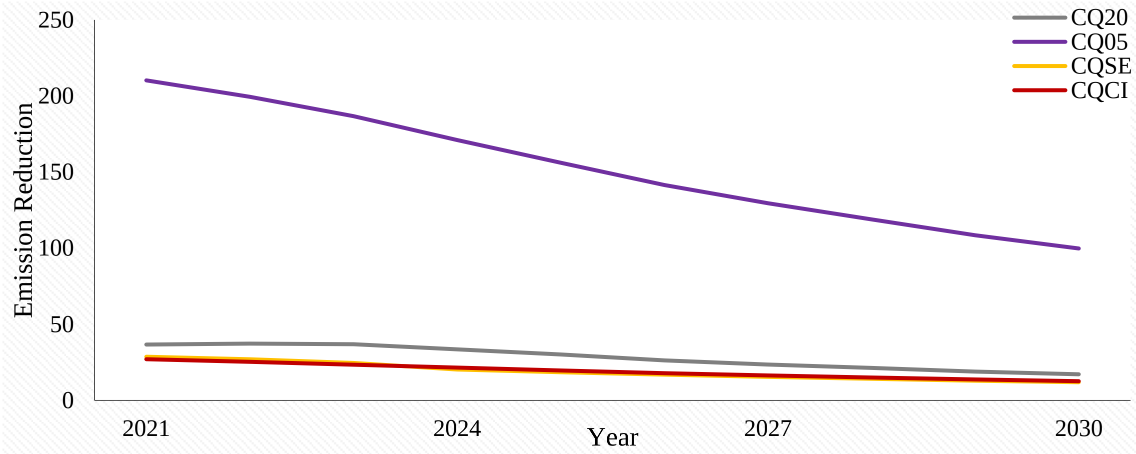

Figure S8. QAS Effect on Emission Abatement (Unit: 10^6 ton).

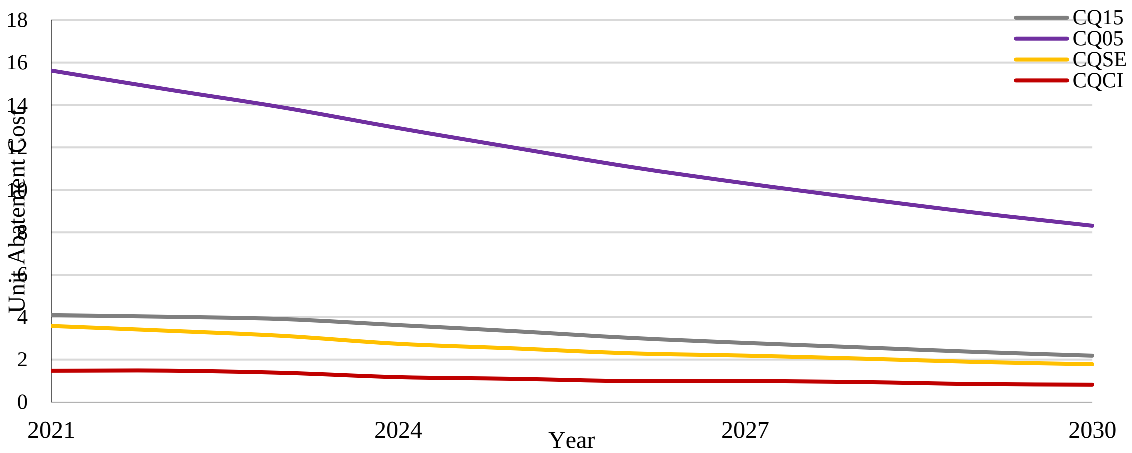

Figure S9. QAS Effect on UAC (Unit: $CNY/kg\ CO_2$).

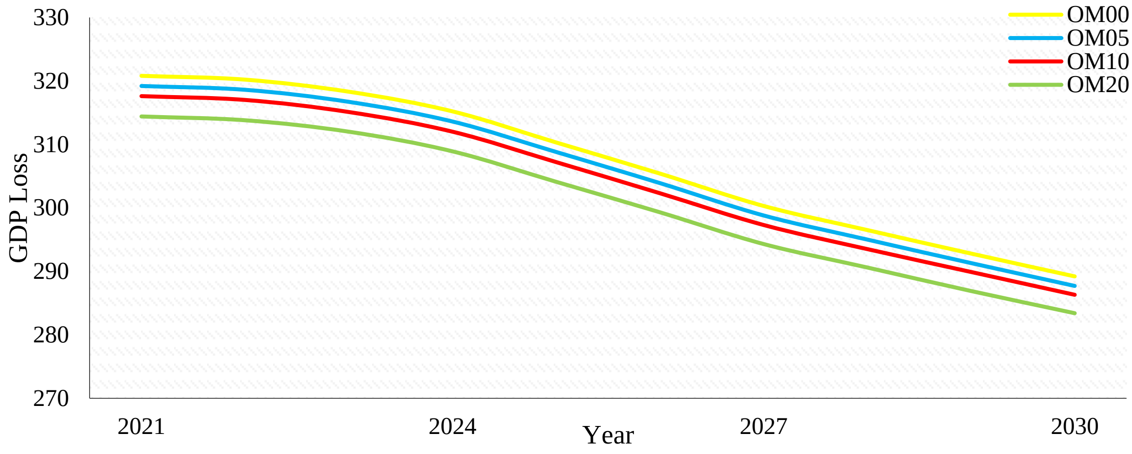

Figure S10. QDF Effect on GDP Loss (Unit: 10^9 CNY).

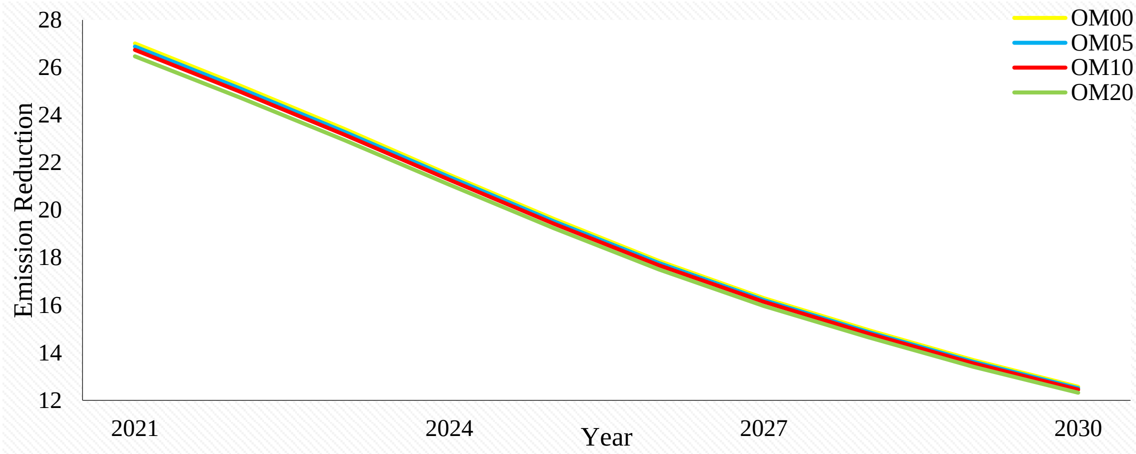

Figure S11. QDF Effect on Emission Abatement (Unit: 10^6 ton).

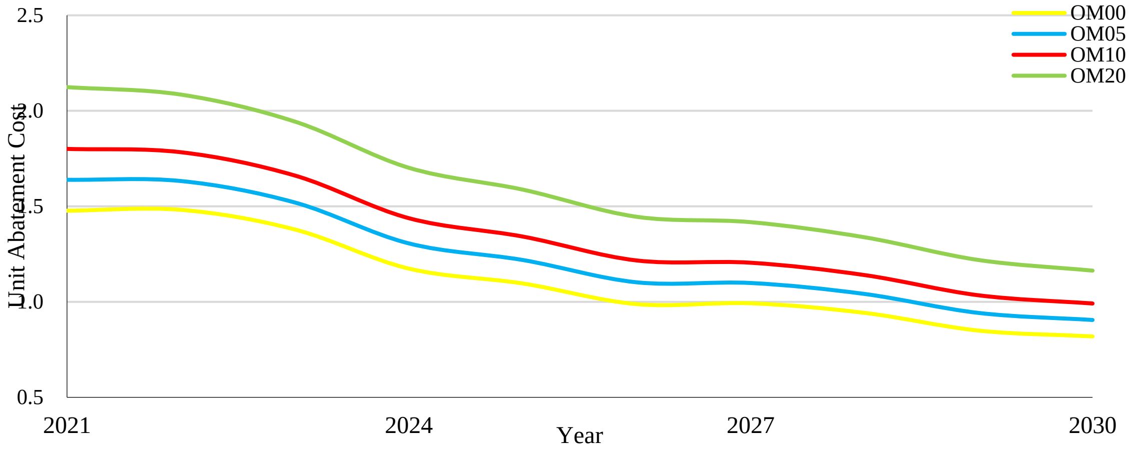

Figure S12. QDF Effect on UAC (Unit: $CNY/kg\ CO_2$).

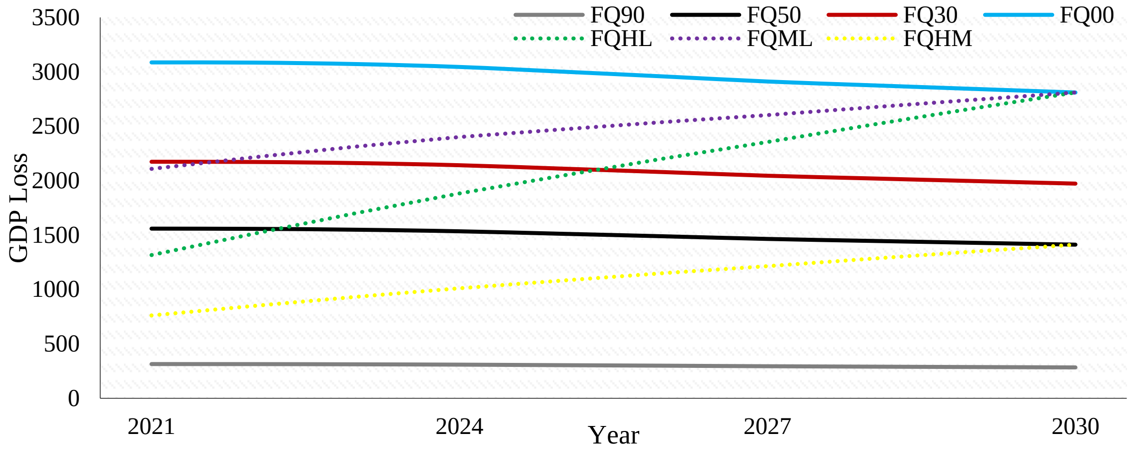

Figure S13. FQR Effect on GDP Loss (Unit: 10^9 CNY).

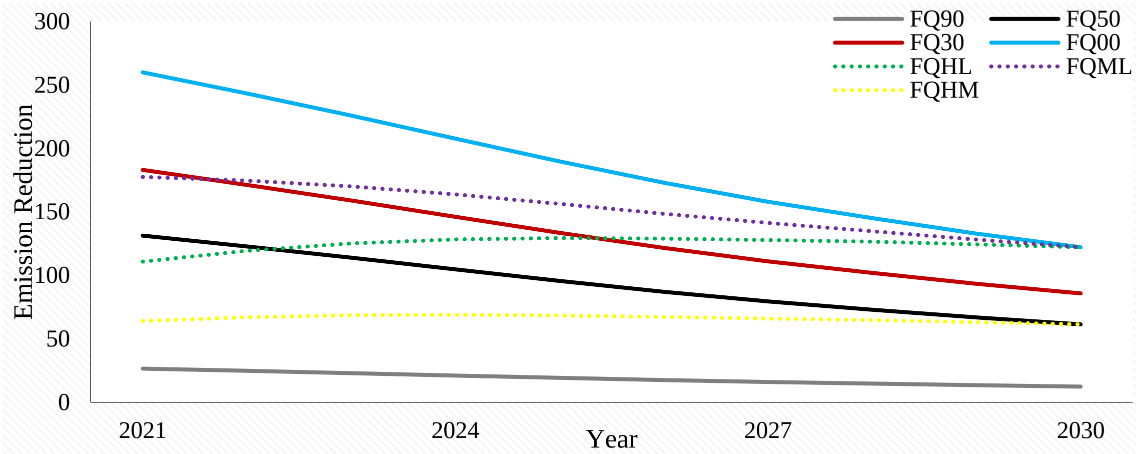

Figure S14. FQR Effect on Emission Abatement (Unit: 10^6 ton).

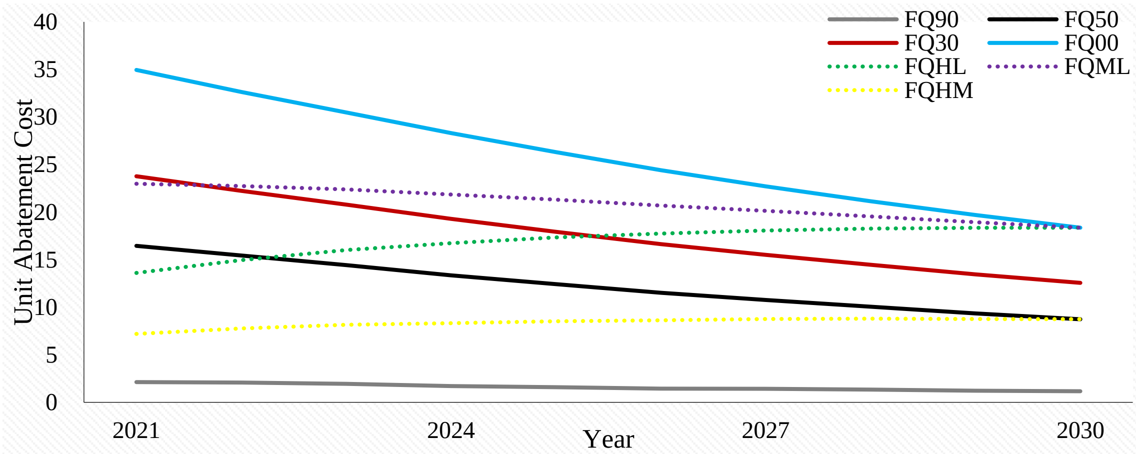

Figure S15. FQR Effect on UAC (Unit: $CNY/kg\ CO_2$).

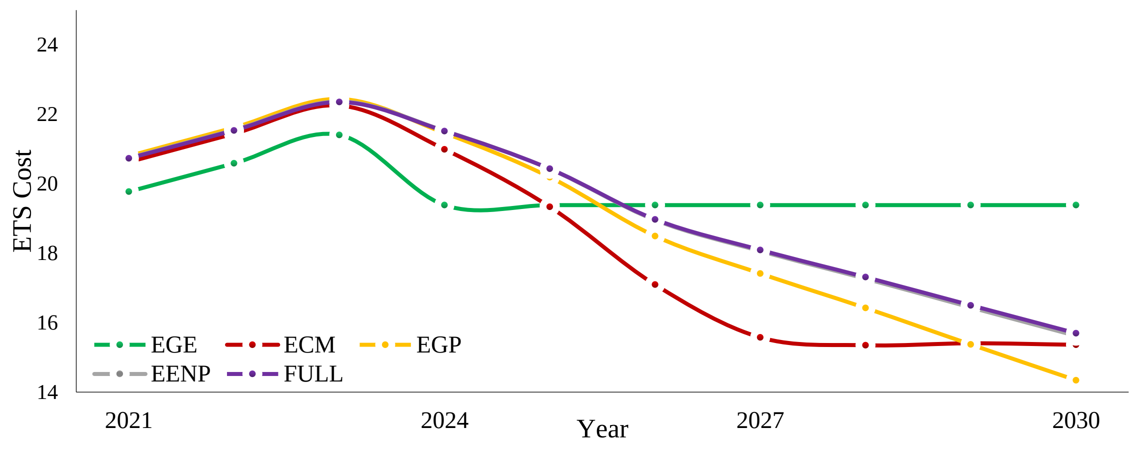

Figure S16. Sectoral Coverage Effect on ETS Cost in the NEG Sector (Unit: 10^9 CNY).

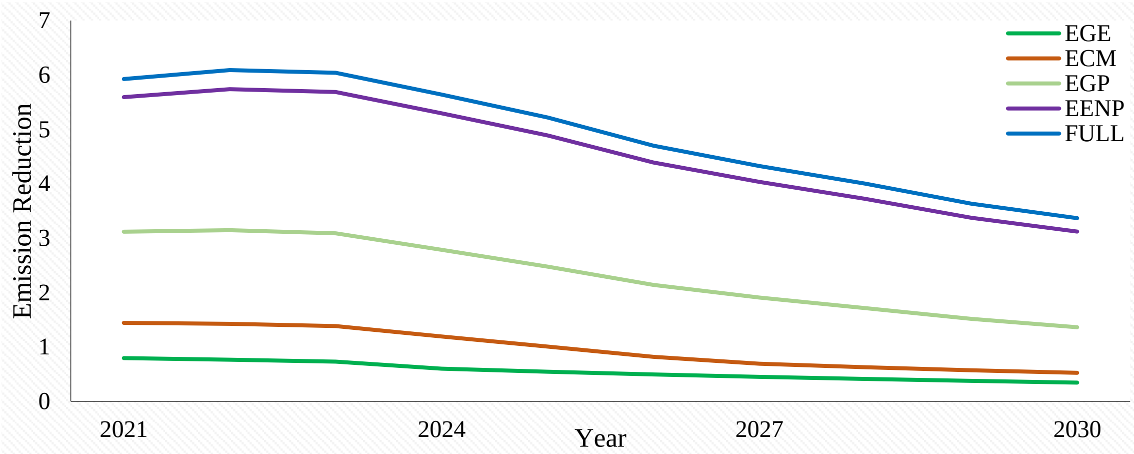

Figure S17. Sectoral Coverage Effect on Emission Abatement in the NEG Sector (Unit: 10^6 ton).

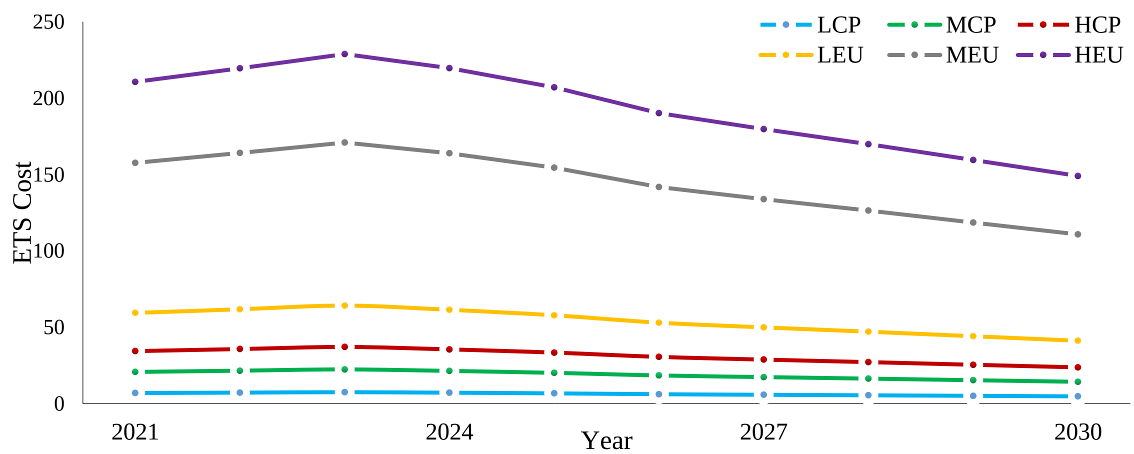

Figure S18. Carbon Price Effect on ETS Cost in the NEG Sector (Unit: 10^9 CNY).

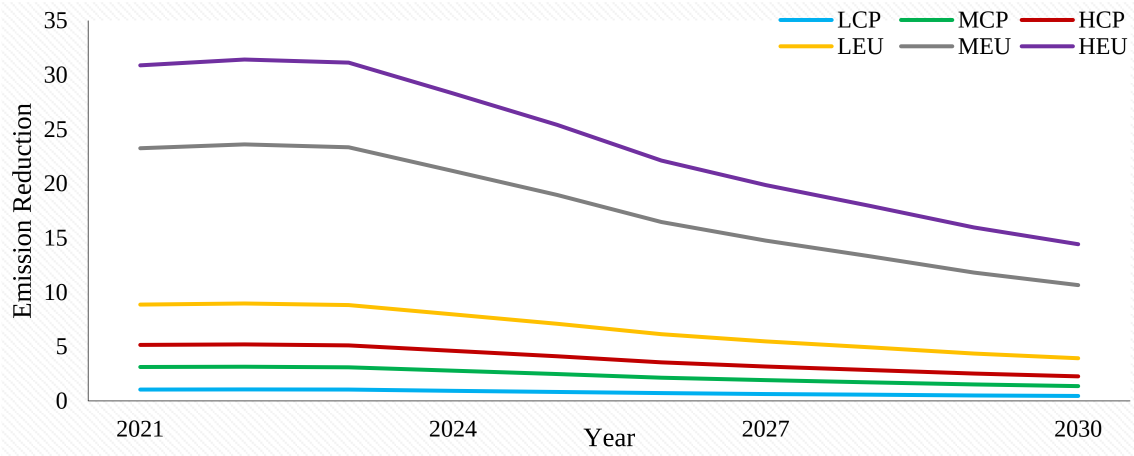

Figure S19. Carbon Price Effect on Emission Abatement in the NEG Sector (Unit: 10^6 ton).

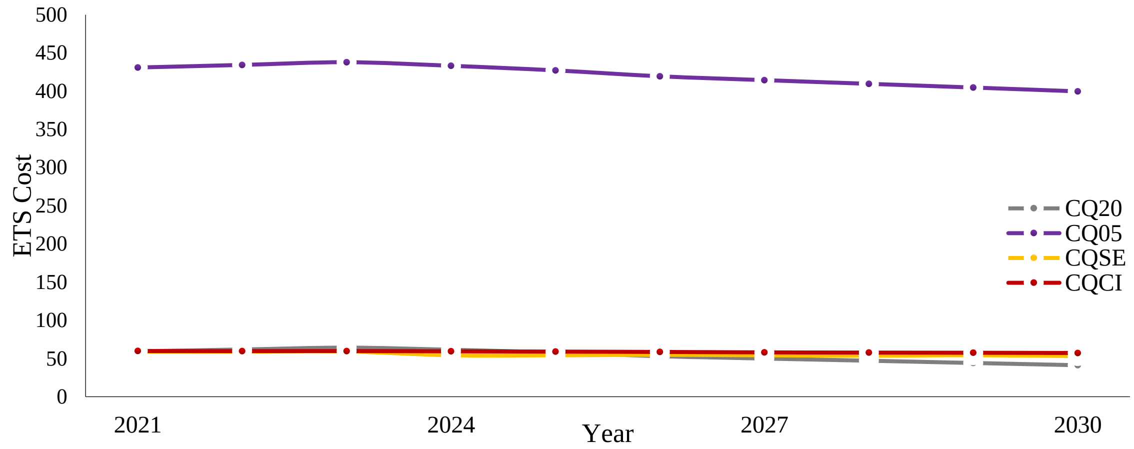

Figure S20. QAS Effect on ETS Cost in the NEG Sector (Unit: 10^9 CNY).

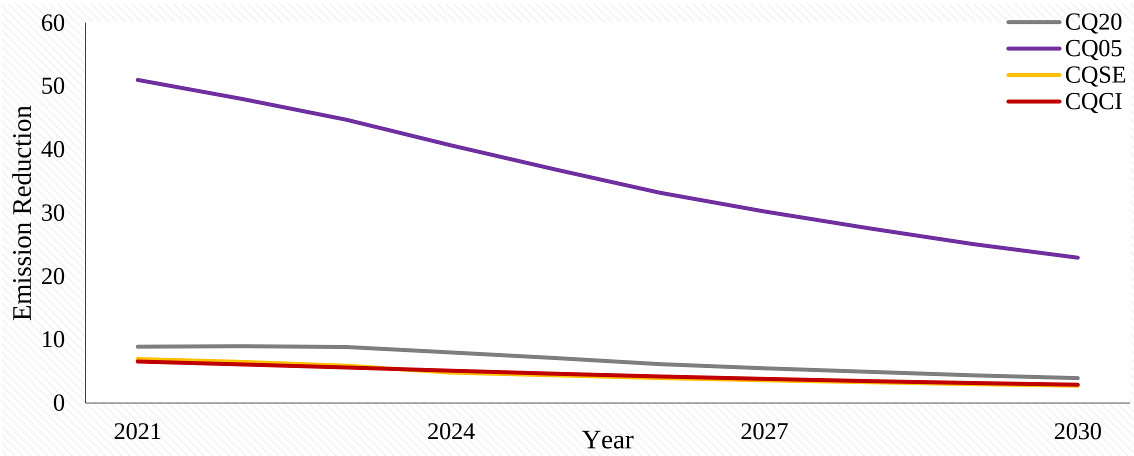

Figure S21. QAS Effect on Emission Abatement in the NEG Sector (Unit: 10^6 ton).

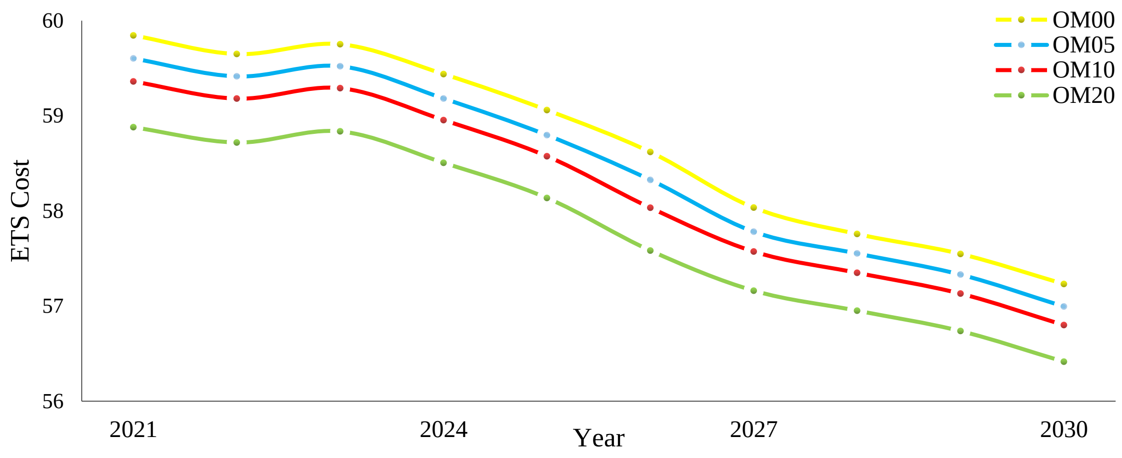

Figure S22. QDF Effect on ETS Cost in the NEG Sector (Unit: 10^9 CNY).

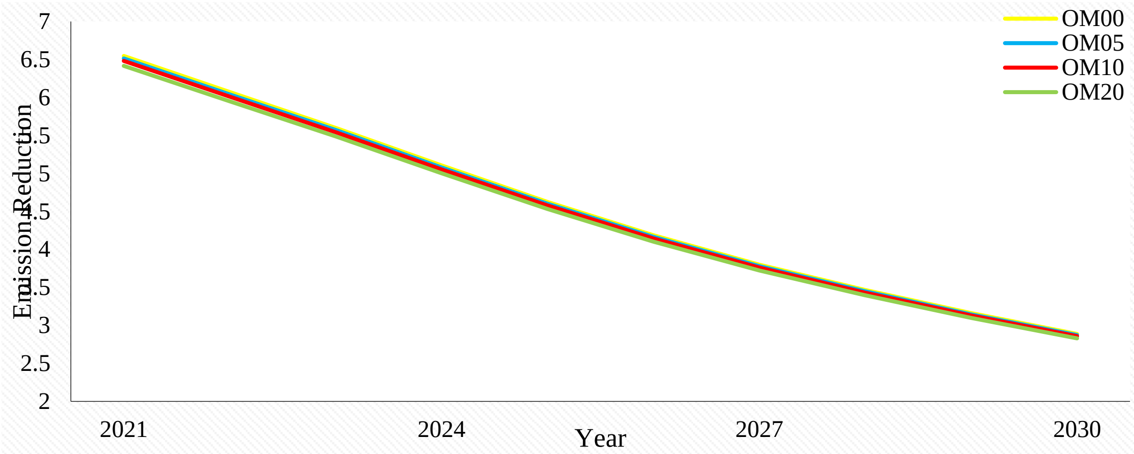

Figure S23. QDF Effect on Emission Abatement in the NEG Sector (Unit: 10^6 ton).

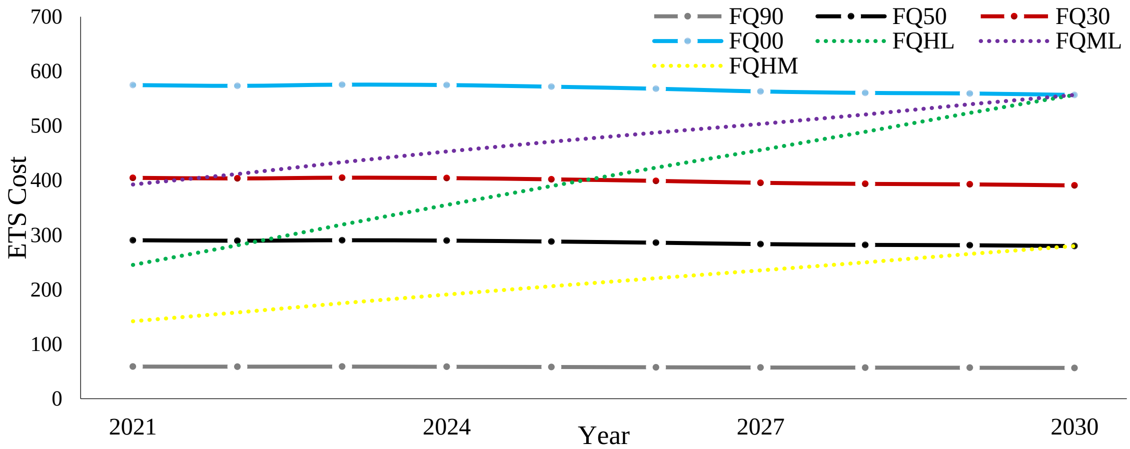

Figure S24. FQR Effect on ETS Cost in the NEG Sector (Unit: 10^9 CNY).

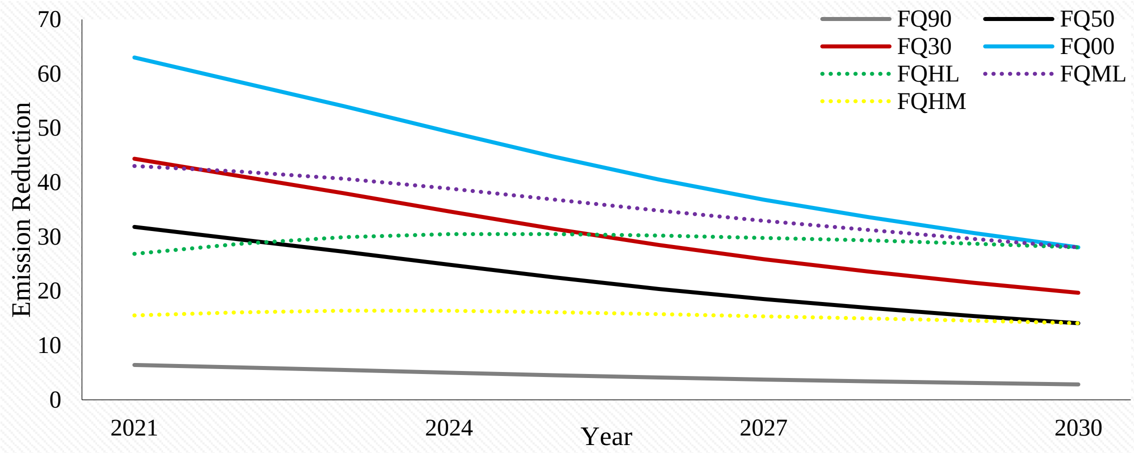

Figure S25. FQR Effect on Emission Abatement in the NEG Sector (Unit: 10^6 ton).

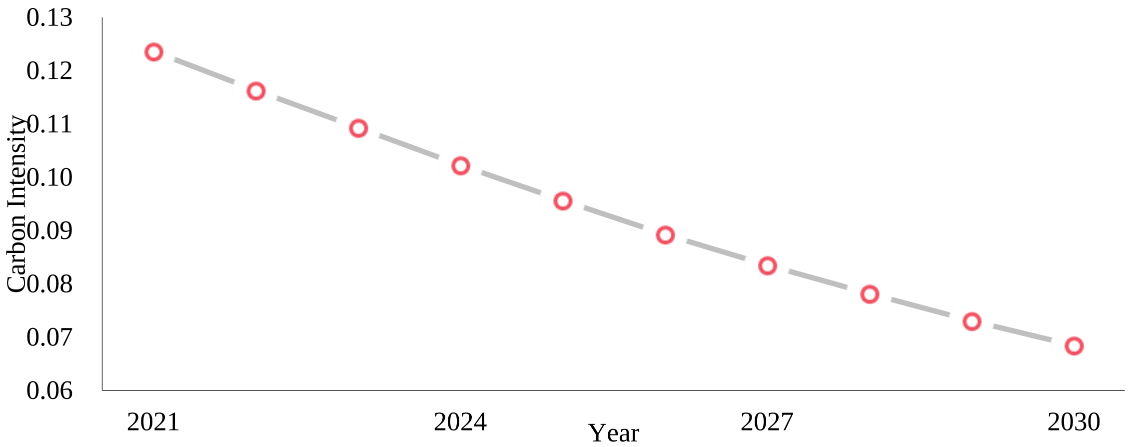

Figure S26. The Carbon Intensity under the Designed ETS (Unit: $kg\ CO_2/CNY$).

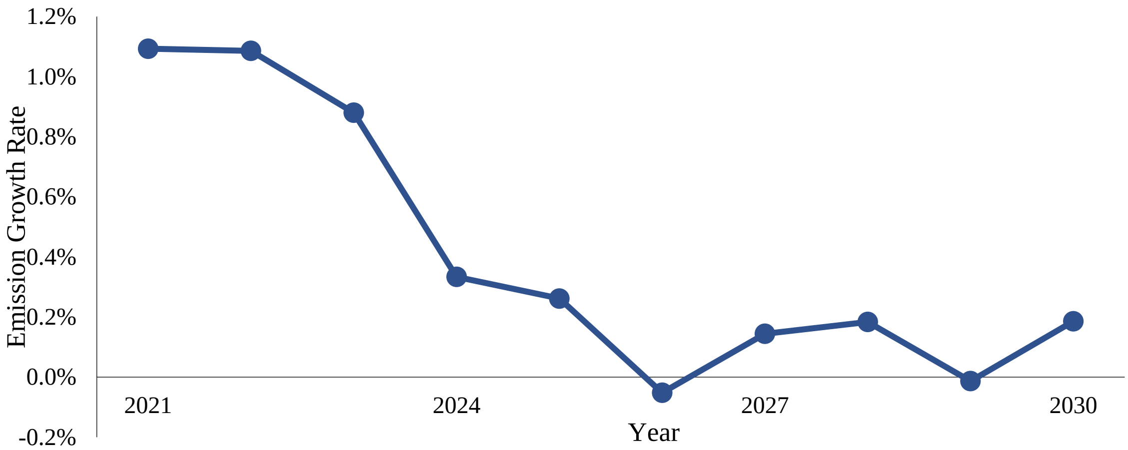

Figure S27. The Emission Growth Rate under the Designed ETS.

Equations to Quantify Unbalanced ETS Market

The over-emissions, implied in Fig. 1b, are defined in Eq. (S1). $CEdif_t$ refers to the total emission gap between the actual emissions and carbon quotas. A positive total emission gap ($CEdif_t > 0$) implies that not all the sectoral over-emissions can be covered by the ETS market, but all the sectoral surplus quotas can be sold in the market.

$$CEdif_t = \sum_i CE_{it} - \sum_i CQ_{it} \tag{S1}$$

When $CEdif_t > 0$, the ETS cost of sector with surplus quotas is defined in Eq. (S2). The subscript se refers to a sector with surplus quotas. CE_{it} is sectoral carbon emissions. P_t^{ets} is normal carbon (ETS) price. $Cost_{it}$ stands for sectoral ETS cost, and it can be negative when sectoral emissions are lower than free quotas. Negative cost means that sectors could earn net income from selling surplus quotas. The embedded assumption of Eq. (S2) is that auction price of carbon quotas is equal to ETS carbon price. This assumption is due to the EU ETS experience that auctions are canceled if the highest bid is significantly below the carbon price (ICAP 2022).

$$Cost_{se,t} = P_t^{ets} \times \left(CE_{se,t} - FCQ_{se,t}\right) \tag{S2}$$

When $CEdif_t > 0$, the cost of over-emission sector is defined in Eq. (S3) and (S4). The subscript oe refers to a sector with over-emissions. OCE_t is the aggregated over-emissions. P_t^* is penalty price of over-emissions, and it is set to be twice normal price (Lin & Jia 2018). In Eq. (S4), we have assumed that the over-emissions are distributed proportionally to the emissions for the sectors with over-emissions.

$$OCE_t = \sum_{oe}(CE_{oe,t} - CQ_{oe,t}) \tag{S3}$$

$$Cost_{oe,t} = P_t^{ets}\left(CQ_{oe} - FCQ_{oe,t}\right) + \left(CE_{oe,t} - CQ_{oe,t}\right) \times [P_t^{ets}(1 - \frac{CEdif_t}{OCE_t}) + P_t^* \frac{CEdif_t}{OCE_t}] \tag{S4}$$

When $CEdif_t > 0$, ETS revenues are defined in Eq. (S5). Rev_t is governmental revenues from auctioning quotas and penalties for over-emissions. In this paper, we have assumed that ETS revenues are kept in the governmental budget, as we are not interested in ETS revenue recycling in this paper.

$$Rev_t = P_t^{ets} \times (\sum_i CQ_{it} - \sum_i FCQ_{it}) + P_t^* \times CEdif_t \tag{S5}$$

In some cases, if governments generously supply higher quotas than actual emissions, no ETS penalties are applied. This is because quota supply is higher than quota demand, and thus sectors with over-emissions could buy additional quotas from the market to cover their over-emissions. In this case, the emission gap is lower than or equal to zero, denoted by $CEdif_t \leq 0$. Because of the over-supply of quotas, not all the surplus quotas can be sold in the market.

When $CEdif_t \leq 0$, the ETS cost of sector with surplus quotas is shown in Eq. (S6) and (S7), where $SPCE_t$ refers to the aggregated surplus quotas. There are two extreme cases in Eq. (S7): when the aggregated quotas are equal to the aggregated emissions or $CEdif_t = 0$, all the surplus quotas can be traded to cover the over-emissions, and thus Eq. (S7) is equal to Eq. (S2). When there are only sectors with surplus quotas in the ETS market or $SPCE_t = |CEdif_t|$, no quota trading occurs, and thus ETS cost is the monetary value of auctioned quotas.

$$SPCE_t = \sum_{se}(CQ_{se,t} - CE_{se,t}) \tag{S6}$$

$$Cost_{se,t} = P_t^{ets} \times \left(CQ_{se,t} - FCQ_{se,t}\right) - P_t^{ets} \times \left(CQ_{se,t} - CE_{se,t}\right) \times \frac{SPCE_t - |CEdif_t|}{SPCE_t} \tag{S7}$$

As supply of surplus quotas is larger than demand, all the sectoral over-emissions can be covered by surplus quotas, and the cost of over-emission sector is defined in Eq. (S8). Because there are no quota-uncovered excess emissions, ETS penalties are not applied; therefore, ETS revenues are only from auctioning carbon quotas, shown in Eq. (S9).

$$Cost_{oe,t} = P_t^{ets} \times \left(CE_{oe,t} - FCQ_{oe,t}\right) \tag{S8}$$

$$Rev_t = P_t^{ets} \times (\sum_i CQ_{it} - \sum_i FCQ_{it}) \tag{S9}$$

A numeric example is provided to explain Eq. (S1) to (S9) or Fig. 1b. Assuming there are four firms (Firm A to D) in the economy, the four firms had the emissions (40, 30, 20, 10) in the previous year; therefore, the total emissions of the economy was 140. Each firm is assumed to have equal power to buy quotas from the market. The government wants to achieve emission mitigation by the ETS where quota allocation is based on the firms' emissions in the previous year; carbon price is 1; penalty price for emission noncompliance is 3; free quota ratio is 0.9; there is no transaction cost for quota trading.

In the current year, the firms' emissions were expected to be 45, 27, 18, 11, and the total emissions are 101. Hence, the total emissions in the current year are larger than that in the previous year, and carbon quotas are in shortage. Firm B and C have emissions lower than quotas, and thus all their surplus ($30 - 27 + 20 - 18 = 5$) quotas can be sold at the given carbon price in the market. For Firm B and C, the abatement cost is calculated as $27 - 0.9 \times 30 = 0$ and $18 - 0.9 \times 20 = 0$, respectively.

The quota supply is 5 in the market, but Firm A and D have demands for extra ($45 - 40 + 11 - 10 = 6$) quotas; therefore, not all the emissions of Firm A and D can be covered by the quotas. The total over-emissions of these two firms are 6, and the quota-uncovered over-emissions of these two firms are $6 - 5 = 1$. Hence, $5/6$ of the over-emissions in Firm A and D can be covered by carbon quotas through the ETS market, whilst the other over-emissions are subject to the penalty. For Firm A and D, the abatement cost is calculated as $40 \times (1 - 0.9) + 5/6 \times (45 - 40) + 3 \times 1/6 \times (45 - 40) \approx 10.67$ and $10 \times (1 - 0.9) + 5/6 \times (11 - 10) + 3 \times 1/6 \times (11 - 10) \approx 2.33$, respectively. The total abatement cost or ETS revenue is calculated as $10.67 + 0 + 0 + 2.33 = 13$.

Now, we suppose that the government generously allocates 42 carbon quotas to Firm A, and the quota allocation for Firm B to D is unchanged. In this case, the total allocated quotas ($42 + 30 + 20 + 10 = 102$) are larger than the total emissions ($45 + 27 + 18 + 11 = 101$). All the sectoral over-emissions ($45 - 42 + 11 - 10 = 4$) can be covered by carbon quotas through the ETS market, but not all the sectoral surplus quotas ($30 - 27 + 20 - 18 = 5$) can be sold in the market. Hence, only $4/5$ of the surplus quotas can be traded in the market, whilst the other surplus quotas remain unsold.

For Firm B and C, the abatement cost is calculated as $30 \times (1 - 0.9) - 4/5 \times (30 - 27) = 0.6$ and $20 \times (1 - 0.9) - 4/5 \times (20 - 18) = 0.4$, respectively. For Firm A and D, the abatement cost is calculated as $45 - 42 \times 0.9 = 7.2$ and $11 - 10 \times 0.9 = 2$, respectively. The total abatement cost or ETS revenue is calculated as $7.2 + 0.6 + 0.4 + 2 = 10.2$.

AIMS Press