Initial allocation of emissions trading among sub-regions in China

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Abstract

In the context of the 2060 carbon-neutral pledge, the Chinese emission trading scheme (ETS) is gaining importance in its role as a national market-based climate policy instrument. The design of a national ETS market necessitates an approach whereby initial allowances can be allocated, considering equity in regional growth, notably electricity transmission and emission relocation among regions. This study investigated five adjustment approaches for initial allowance allocation, including the adjustment between emissions generated from energy use (*energy consumption-based*) and emissions induced by the consumption of final goods and services (*final consumption-based*), as well as adjustments based on three economic indicators, namely per capita gross domestic product, ability to pay, and cost-effectiveness.

Based on the Input-Output table for 30 regions in 2012 and emission data from 2015, for the same total amount of CO_2 mitigation, the *energy consumption-based* and *final consumption-based* allocation approaches resulted in significantly different regional allocations. These disparities provided important information to aid future adjustment of the initial allowance allocation of sub-regions in China. An appropriate emission allocation should consider different allocation principles to expedite the shift towards energy-saving technologies and lifestyles in energy-intensive regions (e.g., Jiangsu, Beijing, and Guangdong), as well as to support CO_2 emission reductions in electricity supply regions (Shanxi and Inner Mongolia).

Abbreviation

CEADs	Carbon Emission Accounts and Datasets
ETS	Emission Trading Scheme
GRP	Gross Regional Product
ICAP	International Carbon Action Partnership
UNICEF	United Nations International Children's Emergency Fund
MAC	Marginal Abatement Cost

1. Introduction

In 2021, China's national CO2 Emission Trading Scheme (ETS) started operating after three years of preparation period. The ETS currently regulates more than 2,000 companies from the power sector, which emit 26,000 t-CO_2 per year. It is estimated to cover more than 4 billion t-CO_2, accounting for over 40% of national carbon emissions. (ICAP, 2021). Simultaneously, regional markets, originally constituting regional pilot markets, are operating parallel to each other in Beijing, Chongqing, Fujian, Guangdong, Hubei, Shanghai, Shenzhen, and Tianjin, as depicted in Figure 1. Currently, the national ETS is intensity-based with an ex-post cap adjustment based on actual levels of production. During the period in which both regional and national ETSs were in operation concurrently, the original ETS pilot regions in China faced both demand-driven and policy-induced carbon leakages. To avoid such leakages, it was essential to adjust the initial allocation of allowances according to regional emission flows. In this study, we provided some recommendations to adjust the allocation of carbon emission allowances by adopting multiple effort-sharing approaches.

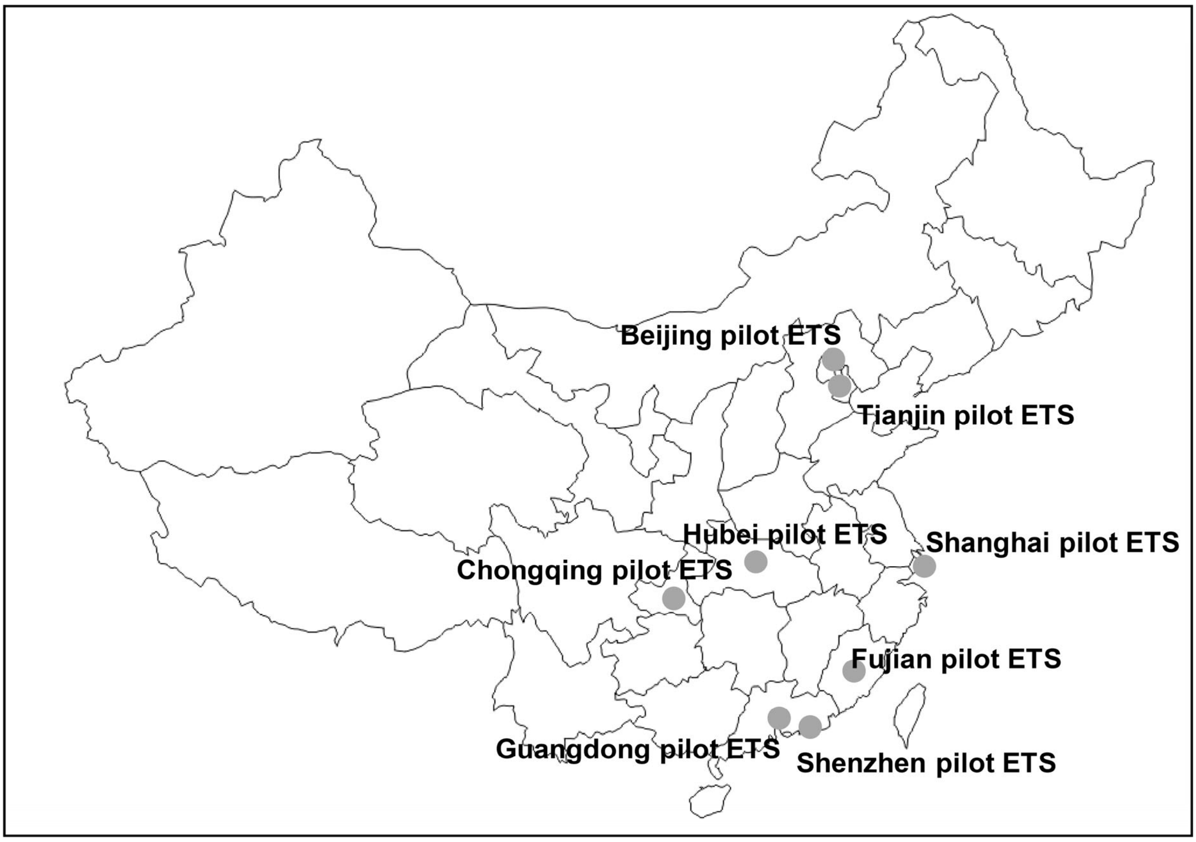

Figure 1 ETS map of China

Source: Authors

Numerous effort-sharing approaches based on various principles have been proposed. These principles include four basic tenets: responsibility, capability, equality, and cost-effectiveness. In this study, five effort-sharing approaches based on various principles were examined to provide a reference framework for the allocation of initial carbon emission allowances among different sub-regions in China.

2. Model and data sources

2.1 Model

Höhne et al. (2014) proposed the four distinct equity principles listed below.

(1) Responsibility

This principle considers the historical contribution of the region or country to global emissions or global warming.

(2) Capability

This principle is frequently referred to as the "right to development." Developing countries or regions could make less ambitious reduction efforts to secure their basic energy demands.

(3) Human rights

This principle recognizes our shared humanity and the equality of all human beings as constituting an equal claim to global collective goods (i.e., equal individual rights to atmospheric space).

(4) Cost-effectiveness

This principle considers the mitigation potential. In general, if there is considerable scope for reduction, marginal abatement costs (MACs) are low.

In this study, we considered and contrasted two perspectives on the theory of responsibility. The first aspect was the consumption of fossil fuels. Regions that consume fossil fuels are accountable for their direct contribution to CO_2 emissions. However, because fossil fuels are utilized to manufacture various end products, the regions in which the final products are consumed indirectly contribute to these CO_2 emissions. The former responsibility is referred to as "production responsibility," and the latter as "consumption responsibility." This study examined five distinct types of equity principles. Table 1 summarizes the relationships between the equity principles and their justifications.

Table 1 Five emission allocation approaches

Approach	Effort-sharing principle	Justification
Energy consumption-based	Production Responsibility	Allocations of emission allowances based on the emissions generated from final energy consumption.
Final consumption-based	Consumption Responsibility	Allocations of emission allowances based on the emissions resulting from the final consumption of goods and services.
Per capita convergence	Human rights	Allocations of emission allowances based on population proportions.
Ability to pay	Capability	Allocations of emission allowances depending on the capacity to bear the obligations.
Cost-optimal	Cost-effectiveness	Allocations of emission allowances based on the least expensive options from marginal abatement cost (MAC) curves.

Source: Authors, van den Berg et al. (2019), and Höhne et al. (2014)

For data availability and simplicity of discussion, we assumed that the initial allocations of the 30 provinces in China were the actual CO_2 emissions in 2021. In addition, we calculated the necessary adjustment amount for the initial allocations for each approach.

The CO_2 emissions generated from energy use $\mathbf{e}_{\mathrm{pr}}$, is formulated as equation (1):

$$\mathbf{e}_{\mathrm{pr}} = \mathbf{c}\hat{\mathbf{x}}, \quad (1)$$

where $\mathbf{c}$ represents the direct emission intensity and $\mathbf{x}$ represents total output.

The CO_2 emissions induced by the consumption of final goods and services $\mathbf{e}_{\mathrm{cm}}$ is formulated as equation (2):

$$\mathbf{e_{cm}} = \widehat{\mathbf{w_2}}[\mathbf{c}(\mathbf{I}-\mathbf{A})^{-\mathbf{1}}\hat{\mathbf{f}}], \quad (2)$$

where $(\mathbf{I}-\mathbf{A})^{-\mathbf{1}}$ represents the Leontief inverse matrix, $\hat{\mathbf{f}}$ denotes the diagonalized matrix of total final demand, and $\widehat{\mathbf{w_2}}$ represents the adjustment diagonalized matrix under the final consumption-based principle (weighted average of the inverse number such that the region with high consumption-based CO_2 emissions would be allocated with fewer emission allowances).

Several reference approaches that consider other effort-sharing principles have also been proposed. The allocation of emission allowances following the equality principle $\mathbf{e}_{\mathrm{pp}}$, is based on the population proportions of all regions. It is expressed as follows:

$$\mathbf{e_{pp}} = \mathbf{p}(\boldsymbol{\iota}'\mathbf{e_{pr}}), \quad (3)$$

where $\mathbf{p}$ represents the population share of each region.

The allocation of emission allowances following the capacity principle, $\mathbf{e}_{\mathrm{ap}}$, is based on the ability of each region to pay and bear the financial obligations associated with CO_2 emissions. It is formulated as follows:

$$\mathbf{e_{ap}} = \mathbf{v}(\boldsymbol{\iota}'\mathbf{e_{pr}}), \quad (4)$$

where $\mathbf{v}$ represents the Gross Regional Product (GRP) of each region.

The allocation of emission allowances following the cost-effectiveness principle, $\mathbf{e}_{\mathrm{co}}$, is based on the MACs of each region. It is formulated as follows:

$$\mathbf{e_{co}} = \widehat{\mathbf{w}_5}[\mathbf{m}(\boldsymbol{\iota}'\mathbf{e_{pr}})], \quad (5)$$

where $\mathbf{m}$ represents the relative MAC in each region and $\widehat{\mathbf{w}_5}$ represents the adjustment diagonalized matrix according to the cost-optimal principle (weighted average of the inverse number). The regions with the lowest marginal abatement costs have the most potential for further emission reduction and should therefore be allocated fewer emission allowances.

2.2 Data sources

All data sources are listed in Table 2.

(1) Input-output table

Production ($\hat{\mathbf{x}}$), final demand ($\hat{\mathbf{f}}$), input coefficient ($\mathbf{A}$), and value-added ($\mathbf{v}$) data were obtained from an input-output table. We used the “2012 China 30-region input-output table” issued by Carbon Emission Accounts and Datasets for Emerging Economies[1] (Mi et al. (2018)).

(2) Direct emission intensity ($\mathbf{c}$)

We used the “2012 China 30-region emission inventories by sectoral approach” data issued by Carbon Emission Accounts and Datasets for Emerging Economies, except for Tibet (Shan et al. (2018)). For Tibet, we used the data from Shan et al. (2017).

(3) Population ($\mathbf{p}$)

We utilized provincial data from the 2013 China Statistical Yearbook.

(4) The relative marginal abatement cost ($\mathbf{m}$)

We used the MAC curve of CO_2 for each region as estimated by Zhou et al. (2013)

[1] https://www.ceads.net/

Table 2 Data sources

Variable	Description	Sources
$\hat{\mathbf{x}}$; $\hat{\mathbf{f}}$; $\mathbf{A}$; $\mathbf{v}$	Total production vector; Final demand vector; Intermediate input matrix; Value added vector	2012 China 30-region input-output table, CEADs, Mi et al. (2018)
$\mathbf{c}$	Direct emission intensity vector	CEADs, Shan et al. (2017), Shan et al. (2018)
$\mathbf{p}$	Population of each province	China Statistical Yearbook 2013
$\mathbf{m}$	Marginal abatement cost coefficient of each province	Zhou et al. (2013)

Source: Authors

3. Results

3.1 Emission allowance allocations according to the five approaches

Table 3 lists the results of regional cap calculations. The total emissions of the Chinese electricity supply sector in 2020 were 4233.5 Mt-CO2. The gray cells in the table represent the top eight provinces for each approach. The following regions would have a high regional cap in the projected ETS under all or most of the five principles: Hebei, Jiangsu, Shandong, Henan, and Guangdong.

As shown in column (1), Shanxi and Inner Mongolia generate significant amounts of emissions because of the large consumption of final energy in these regions. However, if other principles were taken into consideration, their contribution to CO2 would largely decrease. Both regions had considerably lower MAC values than those of other regions, such as Shandong and Guizhou. Moreover, they received higher subsidies than other regions for phasing out coal and introducing renewable energies. As shown in column (2), if adhering to the final consumption-based principle, the regions that were allocated with greater initial allowances would have been the regions that emitted more CO2 than other regions (Shanxi, Inner Mongolia, Anhui, Guizhou).

Table 3 Emission allowance allocation by five approaches (Unit: Mt-CO_2)

Region	(1) Energy consumption-based	(2) Final consumption-based	(3) Per capita convergence	(4) Ability to pay	(5) Cost-optimal
Beijing	26.4	28.0	65.1	63.2	16.0
Tianjin	65.2	91.2	44.5	91.7	25.4
Hebei	234.1	135.5	229.4	53.2	257.0
Shanxi	226.2	325.6	113.7	118.1	300.0
Inner Mongolia	417.9	348.5	78.4	79.7	190.3
Liaoning	177.6	113.6	138.2	53.4	148.3
Jilin	103.7	119.9	86.6	116.7	40.8
Heilongjiang	110.5	151.5	120.7	102.5	129.0
Shanghai	64.3	67.1	74.9	48.0	36.4
Jiangsu	372.3	98.2	249.3	21.4	330.9
Zhejiang	221.8	106.8	172.4	36.3	93.2
Anhui	175.5	206.3	188.5	83.8	126.8
Fujian	118.0	135.0	118.0	61.8	69.5
Jiangxi	67.7	97.5	141.8	110.7	40.3
Shandong	358.8	114.4	304.9	26.4	650.2
Henan	251.9	158.8	296.1	48.7	205.7
Hubei	131.4	105.7	181.9	61.1	118.0
Hunan	91.3	119.0	209.0	66.0	96.0
Guangdong	253.8	94.2	333.5	18.7	137.3
Guangxi	76.6	134.0	147.4	105.2	22.6
Hainan	15.1	96.8	27.9	414.5	5.5
Chongqing	37.2	46.2	92.7	129.7	99.3
Sichuan	60.4	105.4	254.2	60.0	49.6
Guizhou	99.4	260.7	109.7	213.8	695.9
Yunnan	69.2	154.2	146.7	138.6	164.3
Shaanxi	94.3	100.0	118.1	94.7	55.7
Gansu	81.3	186.2	81.2	241.5	59.6
Qinghai	10.7	119.2	18.0	758.3	3.3
Ningxia	94.6	249.7	20.4	623.3	33.1
Xinjiang	126.3	164.5	70.3	192.4	33.6
Total	4233.5	4233.5	4233.5	4233.5	4233.5

Source: Authors

From column (5), it can be observed that Shanghai, Zhejiang, and Guangdong have substantial emission reduction potential (low MAC) and the ability to finance such reductions (higher value-added per capita).

3.2 Adjustment of emission allowance allocations in all regions

The regional caps were assumed to be set using the default (1) energy consumption-based approach and actual emission calculations for all regions to be conducted using the (2) final consumption-based, (3) per capita convergence, (4) ability to pay, and (5) cost-optimal approaches. The inter-regional CO_2 trade allowances were calculated as the difference between the values in column (1) and those in columns (2)–(5). The results are presented in Table 4. Column (1) of Table 4 shows the default capping values of the regions and is identical to column (1) of Table 3.

Table 4 Emission allowance changes compared to the Energy consumption-based approach (Unit: Mt CO_2)

Region	*(1) Energy consumption - based*	*(2) Final consumption -based*	*(3) Per capita convergence*	*(4) Ability to pay*	*(5) Cost-optimal*
Beijing	26.4	1.6	38.7	36.8	-10.4
Tianjin	65.2	26.0	-20.7	26.5	-39.8
Hebei	234.1	-98.6	-4.7	-180.9	22.9
Shanxi	226.2	99.4	-112.5	-108.1	73.8
Inner Mongolia	417.9	-69.4	-339.5	-338.2	-227.6
Liaoning	177.6	-64.0	-39.4	-124.2	-29.3
Jilin	103.7	16.2	-17.1	13.0	-62.9
Heilongjiang	110.5	41.0	10.2	-8.0	18.5
Shanghai	64.3	2.8	10.6	-16.3	-27.9
Jiangsu	372.3	-274.1	-123.0	-350.9	-41.4
Zhejiang	221.8	-115.0	-49.4	-185.5	-128.6
Anhui	175.5	30.8	13.0	-91.7	-48.7
Fujian	118.0	17.0	0.0	-56.2	-48.5
Jiangxi	67.7	29.8	74.1	43.0	-27.4
Shandong	358.8	-244.4	-53.9	-332.4	291.4
Henan	251.9	-93.1	44.2	-203.2	-46.2
Hubei	131.4	-25.7	50.5	-70.3	-13.4
Hunan	91.3	27.7	117.7	-25.3	4.7
Guangdong	253.8	-159.6	79.7	-235.1	-116.5
Guangxi	76.6	57.4	70.8	28.6	-54.0
Hainan	15.1	81.7	12.8	399.4	-9.6
Chongqing	37.2	9.0	55.5	92.5	62.1
Sichuan	60.4	45.0	193.8	-0.4	-10.8
Guizhou	99.4	161.3	10.3	114.4	596.5
Yunnan	69.2	85.0	77.5	69.4	95.1
Shaanxi	94.3	5.7	23.8	0.4	-38.6
Gansu	81.3	104.9	-0.1	160.2	-21.7
Qinghai	10.7	108.5	7.3	747.6	-7.4
Ningxia	94.6	155.1	-74.2	528.7	-61.5
Xinjiang	126.3	38.2	-56.0	66.1	-92.7
Total	4233.5	0.0	0.0	0.0	0.0

Notes: e.g., a negative value -274.1 of Jiangsu under *Final Consumption-based* means, if the emission accounting is conducted based on a *Final consumption-based* approach, Jiangsu would need to purchase another 274.1 Mt emission allowances.
Source: Authors

The regions that would be able to sell most of their initial emission allowances (light grey cells) were Qinghai, Ningxia, and Gansu. The regions that would need to purchase a larger proportion of emission allowances (dark gray cells) were Inner Mongolia, Jiangsu, and Guangdong. Inner Mongolia would not receive sufficient initial allowances owing to its low population density. Furthermore, it would receive fewer benefits under principles that promote human rights and sustainable development. In contrast to Jiangsu, Inner Mongolia would not benefit under the principle that focuses on the ability to pay because of a relatively high GRP. In addition, it would not benefit from the principle that considers cost efficiency because of the considerable potential for emission reduction at lower costs, such as in the Zhejiang region. However, it would purchase fewer emission allowances under the final consumption-based principle.

4. Discussion

Despite the fact that the Chinese national ETS currently only applies to the electricity generation sector, it is anticipated to be gradually expanded to include a total of eight sectors: petrochemical, chemical, building materials, steel, nonferrous metals, paper, and domestic aviation. The adoption of mitigation strategies in these industries among sub-regions and within these eight sectors may differ significantly. For example, the potential to utilize and access renewable energies differ among sub-regions and sectors; the same is true for green hydrogen. Such disparities may act as a barrier to efficient and equitable decarbonization transitions. Regional characteristics should be considered when determining the initial allocations of emission trading in China. In particular, access to renewable energy and the potential of bonus allowances for the utilization of green hydrogen would be the next stage of investigation following this study.

5. Conclusion

This study used the *energy consumption-based* (i.e., emissions generated from energy use) and *final consumption-based* (i.e., emissions induced by the consumption of final goods and services) approaches, in conjunction with three reference approaches (*per capita convergence*, *ability to pay*, and *cost-optimal approaches*) to provide a reference framework for further adjustment of initial allowance allocations.

An appropriate emission allocation within an ETS can expedite the transition towards electricity-saving technologies and lifestyles in energy-intensive regions. Jiangsu, Beijing, and Guangdong would be required to purchase larger proportions of emission allowances if emission allowances were calculated using a *final consumption-based* approach; these additional mitigation costs could inversely change the behavior of electricity consumers, ultimately resulting in a wider range of emission reductions.

Furthermore, appropriate emission allocations could support the improvement of emission intensity in regions that generate a large amount of electricity. Shanxi and Inner Mongolia would receive a greater number of emission allowances if the calculation of emission allowances were based on the *final consumption-based* approach; this revenue could be used to phase out coal and introduce renewable energy sources.

Regarding the *cost-optimal* reference approach, the regions with low MACs could initially share emission reduction efforts. However, the marginal abatement cost of a region would vary dynamically with time and cumulative emission reductions. These dynamic changes and the constraints on the potential for emission reduction in each region were not addressed in this study.

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