Allocation of China's Interprovincial Carbon Emission Allowance Considering Regional Carbon Transfer and Industry Heterogeneity

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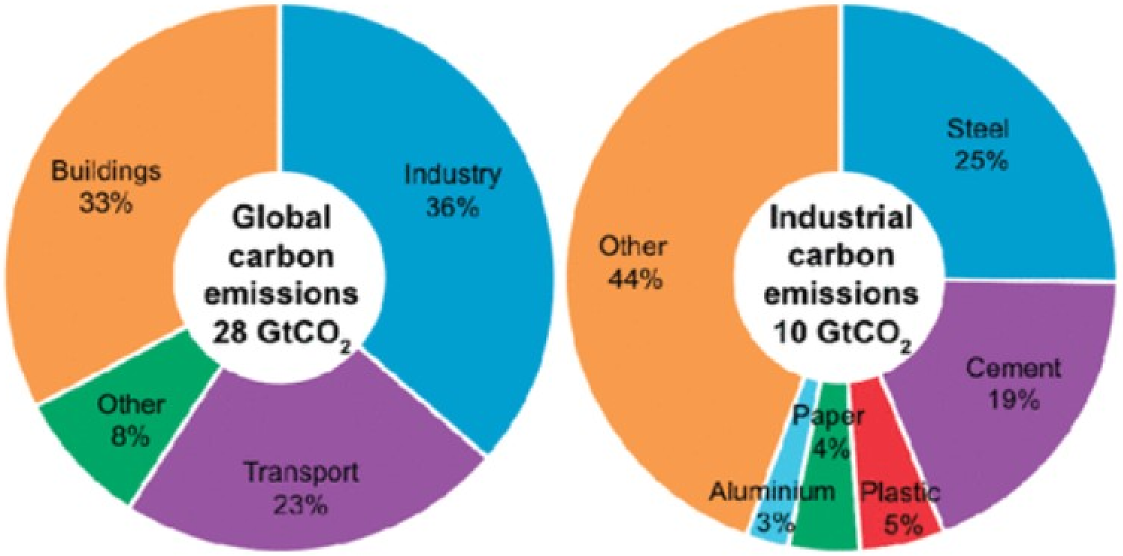
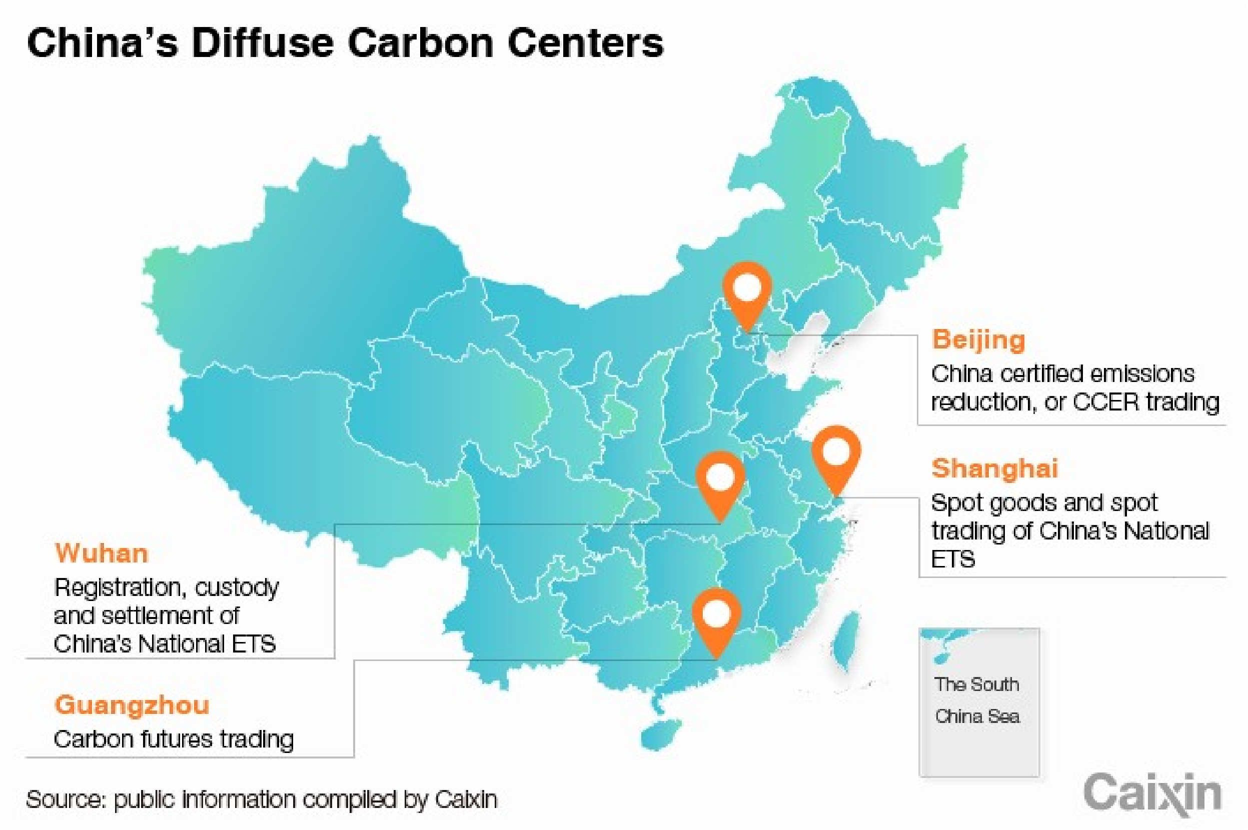
Background



Global anthropogenic CO_2 emissions related to energy and industrial processes for all sectors and for industry.



China's "double carbon" goals: reaching the carbon emissions peak by 2030 and achieving carbon neutrality by 2060.

Content

Review and Research Goal

Principle	Interpretation	Indicators	Operational rules
Egalitarianism	Everyone has an equal right to pollute and to be free from pollution	Population Total population over the years	CEA should be proportional to the historical population/total population
Efficiency	Focusing on maximizing the input-output efficiency of the whole society, regions with more output and less emissions should obtain more quotas	Carbon intensity Efficiency measurement	CEA should be inversely proportional to carbon intensity CEA should be proportional to efficiency measurement
Historical responsibility	Regions with large historical emissions will inevitably bear more burden of emission reduction	Historical Cumulative Emissions	CEA should be inversely proportional to historical cumulative emissions
Emission reduction capacity	The higher the level of economic development, the greater the ability to undertake emission reduction responsibilities	GDP per capita	CEA should be inversely proportional to per capita GDP
Grandfathering	All regions enjoy equal rights to pollute and not to pollute, and emission reduction must ensure the continuity of production	Base year emissions	The CEA ratio should be the same as the base year emissions ratio

Note: Collected and summarized by the author according to Adam (1992), Ringius et al. (1998), Zhou and Wang (2016), and Wu et al. (2020).

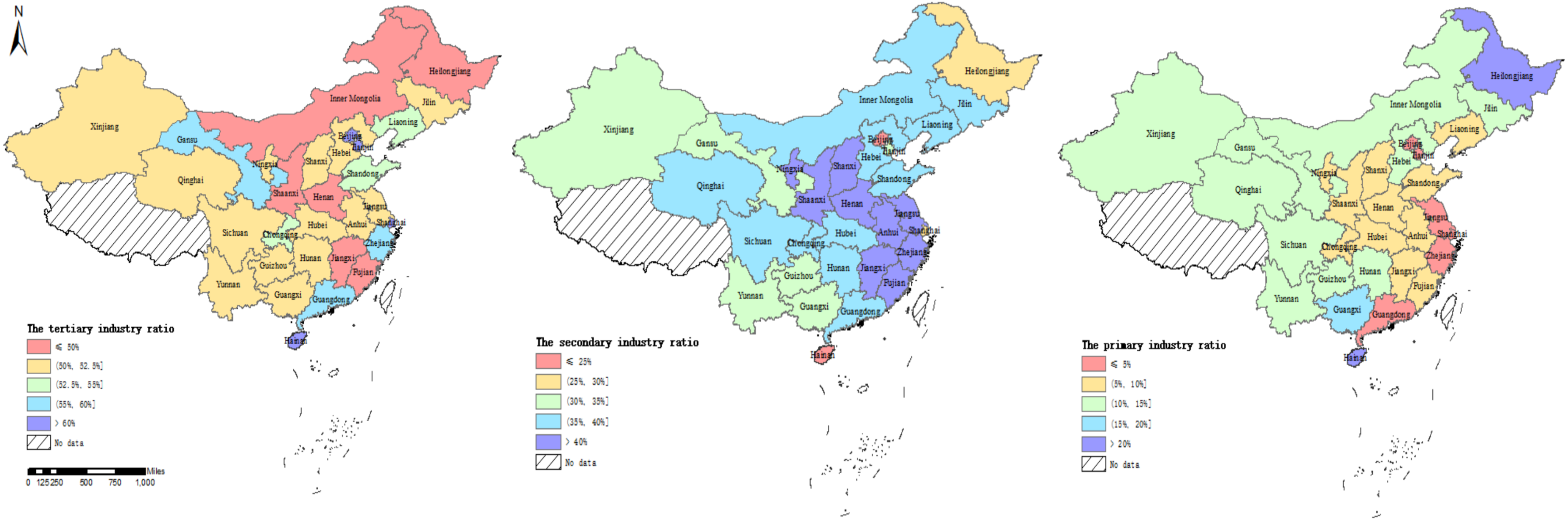
CEA allocation method	
Indicator method	Single Indicator Method Comprehensive indicator method
Optimization method	Assignment of CEA by linear or nonlinear models from an efficiency perspective
Game theory approach	Treat the allocation of CEA as a game process
Hybrid approach	Assignment of CEA based on a combination of methods and composite indicators

Review and Research Goal

Methods of constructing composite indicators

Entropy weight method	**Advantage**: • Objectively measure the importance of indicators according to the difference between regions. **Shortcomings**: • The "relationship" between each quota allocation indicator and carbon emissions is completely separated. • It implies that the weight of each indicator is the same in different regions, which may not match the reality.
Gray correlation model	• Can better solve the problem of "heterogeneity" of index weights. • The requirements for the amount of data are not high, and the calculation results are consistent with the qualitative analysis results. • Often used to quantify the degree of influence of various factors on carbon emissions.

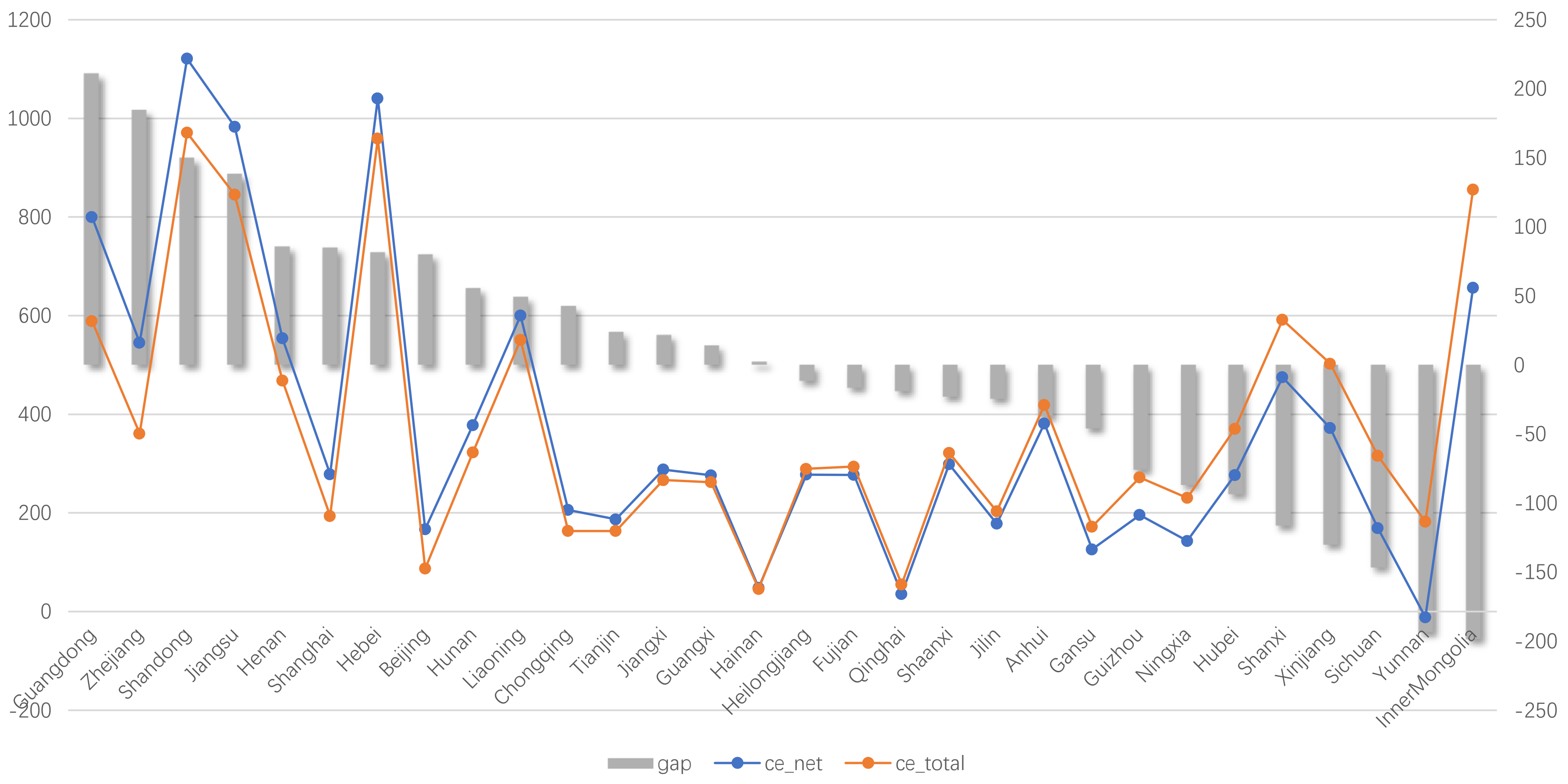
Review and Research Goal



The spatial distribution map of the output value of the primary, secondary and tertiary industries as a percentage of GDP (2020)

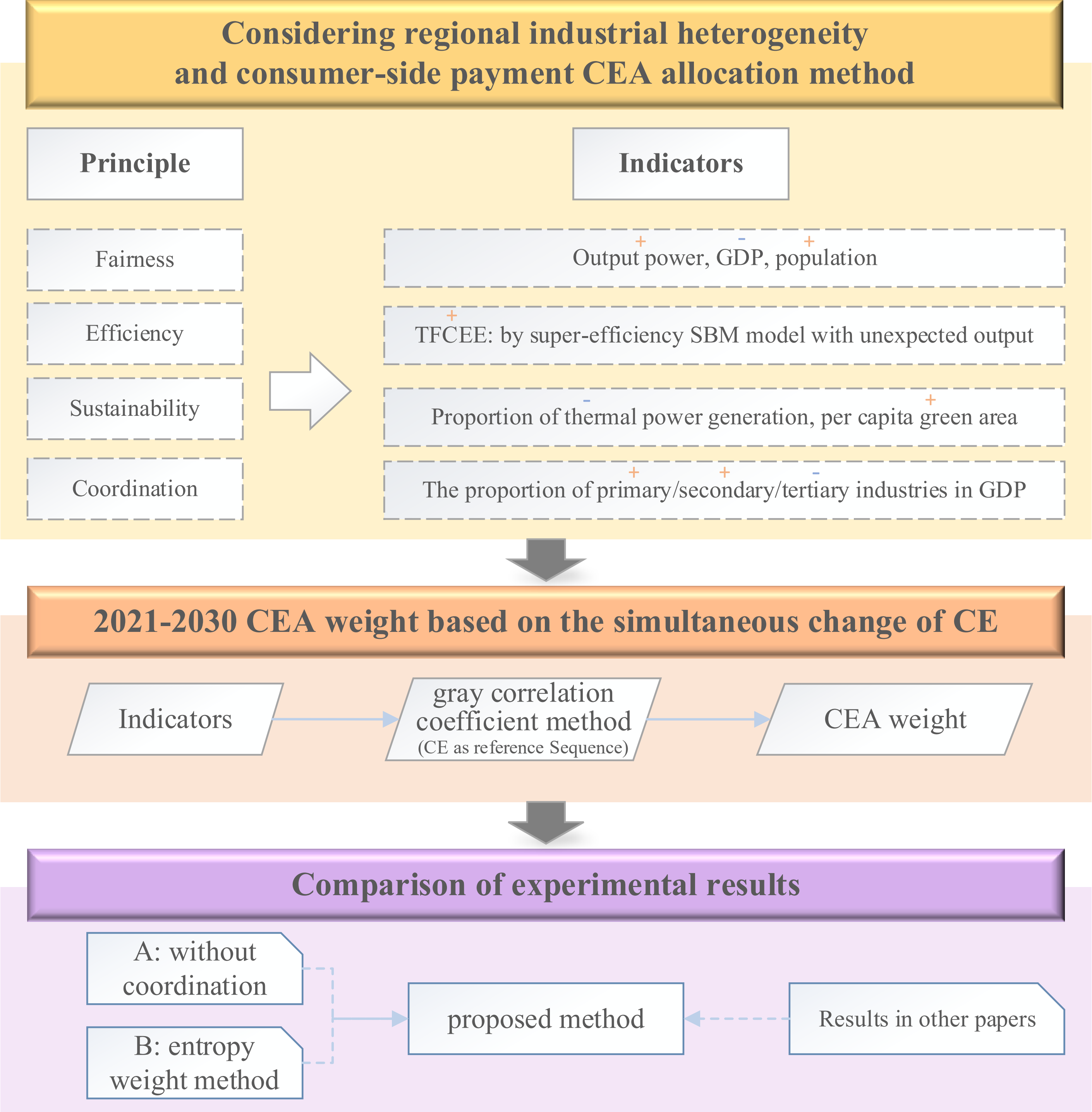
Data collected by the author from China Yearbook

Review and Research Goal



The picture shows an overview of CE in China's provinces in 2021. The orange line shows the total CE of the province. The blue line refers to the CE considering the power transmission, and the gray rectangle shows the difference between the two.

Research Framework



Data and Methodology

- **DEA model** for **Total Factor Carbon Emission Efficiency (TFCEE)**
- Super-SBM-Undesirable model
  - DMUs: Provinces
  - Input: Energy, Population, Fixed asset investment
  - Output: GDP(desirable), Carbon Emission(undesirable)
  - The higher the efficiency value, it indicates that the region can obtain higher desired output and lower undesired output with less input.

$$\theta_k = min \frac{1+\frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{ik}}{1-\frac{1}{q+p}\left(\sum_{r=1}^{q} s_r^+ / y_{rk} + \sum_{l=1}^{p} s_l^- / b_{lk}\right)}$$

$$\begin{aligned} s.t.\ & \sum_{j=1, j\neq k}^{n} x_{ij}\lambda_j - s_i^- \leq x_{ik} \\ & \sum_{j=1, j\neq k}^{n} y_{rj}\lambda_j + s_r^+ \geq y_{rk} \\ & \sum_{j=1, j\neq k}^{n} b_{lj}\lambda_j - s_l^{b-} \leq b_{lk} \\ & \lambda, s^-, s^+, s^{b-} \geq 0 \\ & i=1,2,\ldots,m; r=1,2,\ldots,q; l=1,2,\ldots,p; j=1,2,\ldots,n (j \neq k) \end{aligned}$$

Data and Methodology

- **Grey correlation model for CEA weight**
  - Grey correlation degree can reflect the "synchronous trend of change" of different indicators.
    - Reference sequence: CE
    - Comparison sequence: Other indicators
  - The degree of correlation reflects the degree of influence of the comparison sequence on the reference sequence, and the closer its value is to 1, the greater the influence of the comparison sequence on the reference sequence.

$$x_{ij}^{'}(k)=\frac{X_{ij}(k)-\min X_{ij}(k)}{\max X_{ij}(k)-\min X_{ij}(k)}$$

$$x_{ij}^{'}(k)=\frac{\max X_{ij}(k)-X_{ij}(k)}{\max X_{ij}(k)-\min X_{ij}(k)}$$

$$\zeta_{ij}(k)=\frac{\min_i \min_k \Delta_i(k)+\rho \max_i \max_k \Delta_i(k)}{\Delta_i(k)+\rho \max_i \max_k \Delta_i(k)}$$

$$\Delta_i(k)=\left|x_0(k)-x_i(k)\right|$$

$$\gamma_{ij}=\frac{1}{n}\sum_{k=1}^{n}\zeta_{ij}(k)$$

Data and Methodology

- **Data for 2021-2030**
  - The CE is calculated based on the consumption of fossil fuels in various industries of each province, and then the CE of each province are predicted based on an annual growth rate of 2% (by Q Liu, 2017).
  - We predicted the total carbon emissions in the future based on the downward trend of China's future CEI.
  - Predict the future GDP of the whole country according to the *Government Work Report* the China Macroeconomic Forum.
  - Predicted the future CEI of the country according to the target proposed in China's 14th FYP the 2020 climate summit.

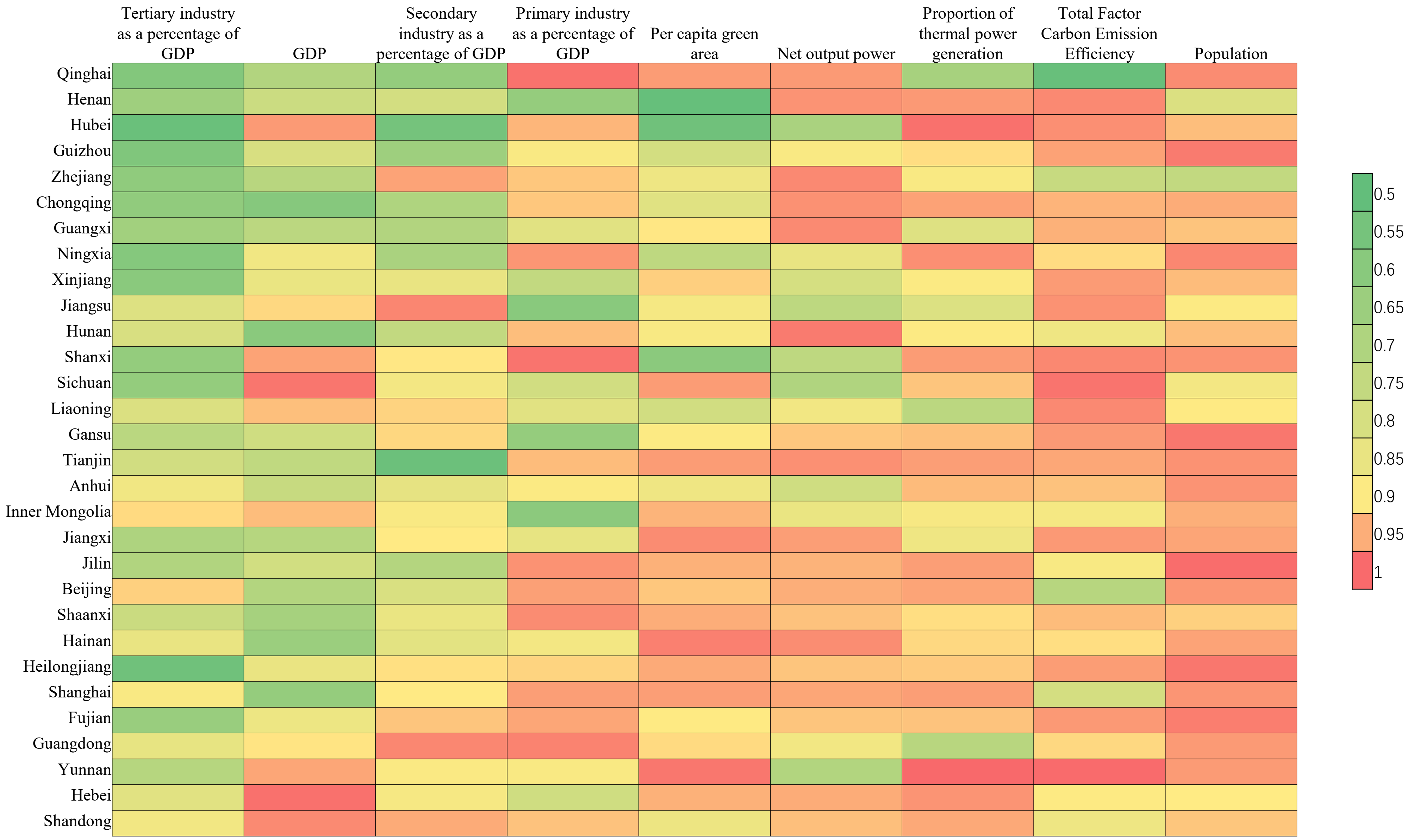
Results and Analysis

Total Factor Carbon Emission Efficiency

	Beijing	Tianjin	Hebei	Shanxi	Inner Mongolia	Liaoning	Jilin	Heilongjiang	Shanghai	Jiangsu	Zhejiang	Anhui	Fujian	Jiangxi	Shandong	Henan	Hubei	Hunan	Guangdong	Guangxi	Hainan	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Xinjiang
2021	1.00	0.48	0.25	1.13	0.36	0.44	0.51	0.41	1.00	1.02	0.74	0.45	0.59	0.46	0.55	0.57	0.61	0.54	1.00	0.37	1.00	0.54	0.49	0.38	0.38	0.36	0.48	1.09	0.66	0.29
2022	1.00	0.49	0.25	1.15	0.36	0.44	0.53	0.41	0.83	1.03	0.74	0.45	0.60	0.46	0.55	0.58	0.63	0.55	1.00	0.37	1.00	0.54	0.50	0.39	0.38	0.36	0.48	1.11	0.64	0.29
2023	1.00	0.49	0.25	1.17	0.37	0.44	0.55	0.42	0.81	1.04	0.74	0.46	0.60	0.45	0.54	0.58	0.64	0.55	1.00	0.36	1.00	0.55	0.50	0.39	0.38	0.35	0.49	1.13	0.63	0.29
2024	1.00	0.50	0.24	1.19	0.38	0.44	0.57	0.42	0.80	1.05	0.74	0.46	0.61	0.44	0.53	0.59	0.65	0.56	1.00	0.36	1.00	0.55	0.51	0.40	0.38	0.35	0.50	1.15	0.62	0.29
2025	1.00	0.50	0.24	1.22	0.39	0.44	0.59	0.42	0.79	1.07	0.74	0.47	0.62	0.44	0.52	0.59	0.66	0.57	1.00	0.35	1.00	0.56	0.51	0.41	0.39	0.34	0.51	1.17	0.60	0.29
2026	1.00	0.51	0.24	1.24	0.39	0.44	0.61	0.43	0.77	1.10	0.74	0.46	0.62	0.44	0.51	0.59	0.66	0.57	1.00	0.35	1.00	0.56	0.51	0.41	0.39	0.34	0.52	1.19	0.59	0.29
2027	1.00	0.52	0.24	1.27	0.40	0.44	0.64	0.43	0.77	1.12	1.00	0.47	0.63	0.43	0.50	0.60	0.68	0.58	1.00	0.35	1.00	0.56	0.52	0.42	0.39	0.33	0.53	1.21	0.58	0.30
2028	1.00	0.53	0.23	1.31	0.40	0.43	0.67	0.44	0.76	1.15	1.00	0.47	0.63	0.43	0.50	0.60	0.69	0.59	1.00	0.34	1.00	0.57	0.52	0.42	0.39	0.33	0.54	1.23	0.57	0.30
2029	1.00	0.52	0.23	1.35	0.40	0.43	0.68	0.44	0.75	1.17	1.00	0.47	0.64	0.42	0.49	0.61	0.69	0.60	1.00	0.34	1.00	0.57	0.53	0.43	0.40	0.32	0.54	1.25	0.55	0.30
2030	1.00	0.53	0.23	1.40	0.41	0.43	0.71	0.45	0.75	1.19	1.00	0.48	0.65	0.42	0.48	0.61	0.71	0.60	1.00	0.34	1.00	0.57	0.53	0.43	0.40	0.32	0.55	1.28	0.54	0.30

Results and Analysis

Grey correlation coefficients



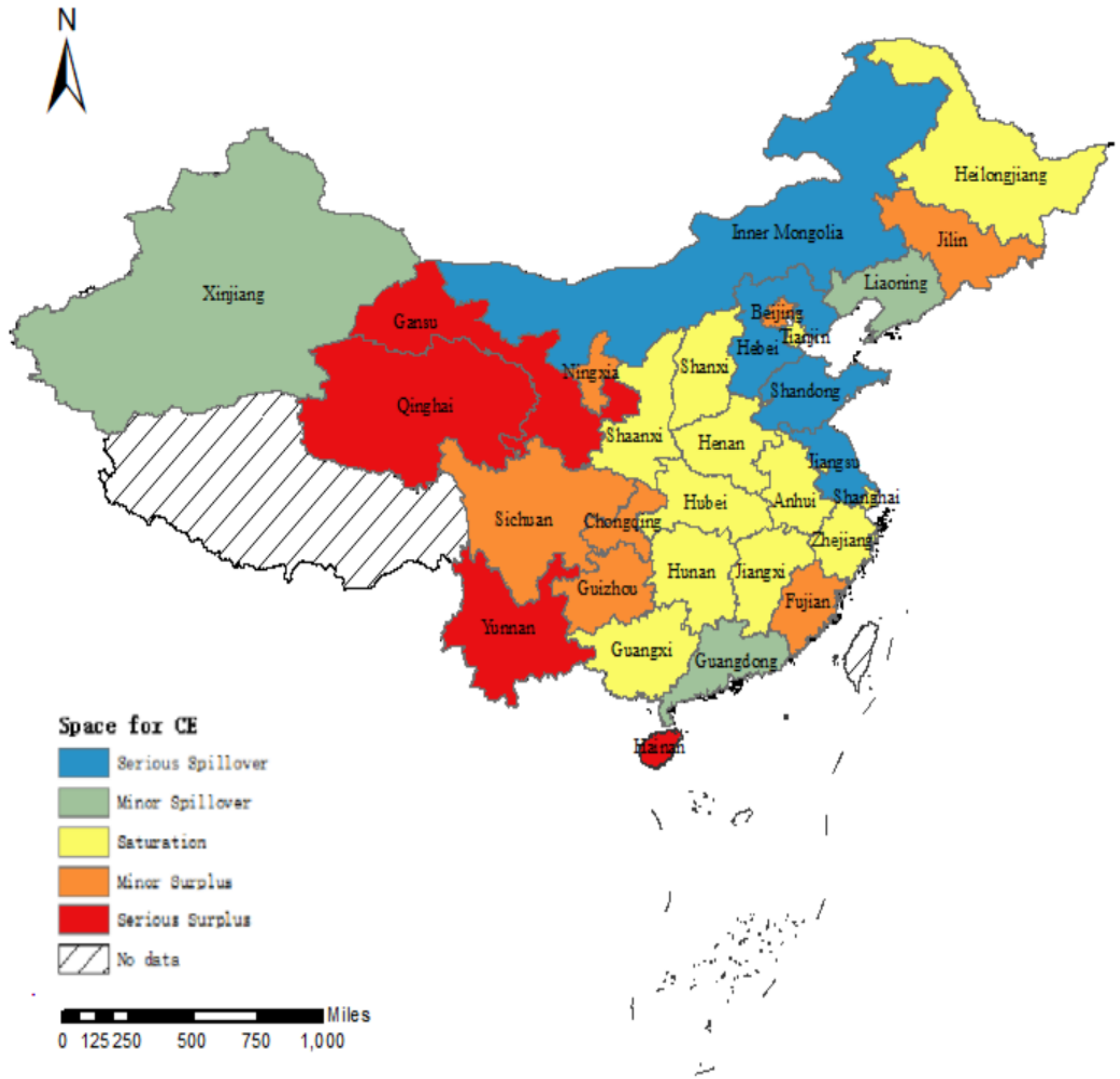
Results and Analysis

2021-2030 CEA allocation results (unit: Mt)

	Beijing	Tianjin	Hebei	Shanxi	Inner Mongolia	Liaoning	Jilin	Heilong-jiang	Shanghai	Jiangsu	Zhejiang	Anhui	Fujian	Jiangxi	Shandong
2021	207.77	239.01	365.77	449.04	467.70	363.84	362.09	385.61	199.13	378.95	309.04	381.77	430.15	390.74	372.05
2022	209.56	240.44	366.51	455.44	477.28	369.72	363.33	393.02	180.23	381.65	310.67	387.19	434.03	394.26	369.98
2023	212.42	242.43	366.47	462.33	485.57	375.11	363.63	399.49	175.02	384.63	312.11	391.43	437.25	397.21	366.76
2024	215.14	244.50	366.43	469.33	493.76	380.56	363.46	405.31	170.42	387.71	313.73	395.81	441.47	400.16	363.36
2025	217.77	246.93	366.25	476.31	501.71	386.12	362.94	410.68	165.61	392.43	315.65	400.37	445.33	403.72	360.18
2026	230.23	260.98	382.94	505.76	532.92	410.10	378.46	434.82	166.77	416.12	333.48	423.19	469.93	425.63	375.57
2027	243.32	274.78	398.77	534.04	563.39	433.46	392.94	458.11	169.19	438.07	374.05	445.55	493.18	446.68	390.03
2028	261.42	290.01	416.29	562.42	590.90	458.33	412.80	485.44	178.05	458.21	391.83	467.17	514.56	467.19	405.73
2029	281.73	306.26	434.09	591.14	617.71	483.32	431.53	512.37	190.33	478.34	409.96	488.33	535.68	487.82	421.91
2030	301.51	323.71	451.87	620.03	645.08	508.34	451.24	539.58	202.08	497.99	427.55	509.59	556.36	508.48	438.00
Average	238.09	266.91	391.54	512.58	537.60	416.89	388.24	442.44	179.68	421.41	349.81	429.04	475.79	432.19	386.36

	Henan	Hubei	Hunan	Guang-dong	Guangxi	Hainan	Chong-qing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Xinjiang
2021	346.92	384.48	367.00	414.33	368.21	367.57	344.85	479.19	392.44	480.21	356.94	402.52	409.47	417.43	373.84
2022	352.17	392.30	370.99	417.43	368.35	367.96	345.59	489.30	399.37	486.38	359.88	412.05	420.01	423.70	384.77
2023	356.26	399.00	373.50	420.78	368.03	367.96	346.58	498.92	406.11	492.72	360.46	421.78	430.60	429.89	394.62
2024	360.36	405.83	376.01	423.87	367.67	367.49	347.73	508.60	412.95	499.14	360.88	431.06	441.18	436.61	404.03
2025	364.38	411.97	378.38	427.07	367.02	367.01	349.35	518.22	419.53	505.71	360.81	440.46	451.76	443.29	413.11
2026	385.19	437.00	398.72	451.74	383.48	383.25	366.85	552.22	445.66	535.51	378.26	470.03	484.21	471.41	440.67
2027	405.46	461.19	418.32	475.13	399.57	398.96	384.24	585.39	470.48	564.29	394.33	499.06	515.46	497.78	466.93
2028	426.65	484.02	437.75	497.40	417.56	420.66	401.01	619.88	495.02	594.61	409.38	531.12	545.72	520.50	491.56
2029	448.10	506.24	456.18	519.65	435.07	443.47	417.73	653.79	518.28	625.07	424.50	562.01	575.44	542.00	516.20
2030	469.14	528.20	473.36	541.46	453.08	465.39	434.43	688.19	541.93	655.24	439.69	594.00	604.86	563.88	541.00
Average	391.46	441.02	405.02	458.89	392.80	394.97	373.84	559.37	450.18	543.89	384.51	476.41	487.87	474.65	442.67

Results and Analysis



Carbon emission space

Serious Spillover (CE space ≤ -300Mt),

Minor Spillover (CE space > -300Mt and ≤ -100Mt),

Saturation (CE space <100Mt and ≥ 100Mt),

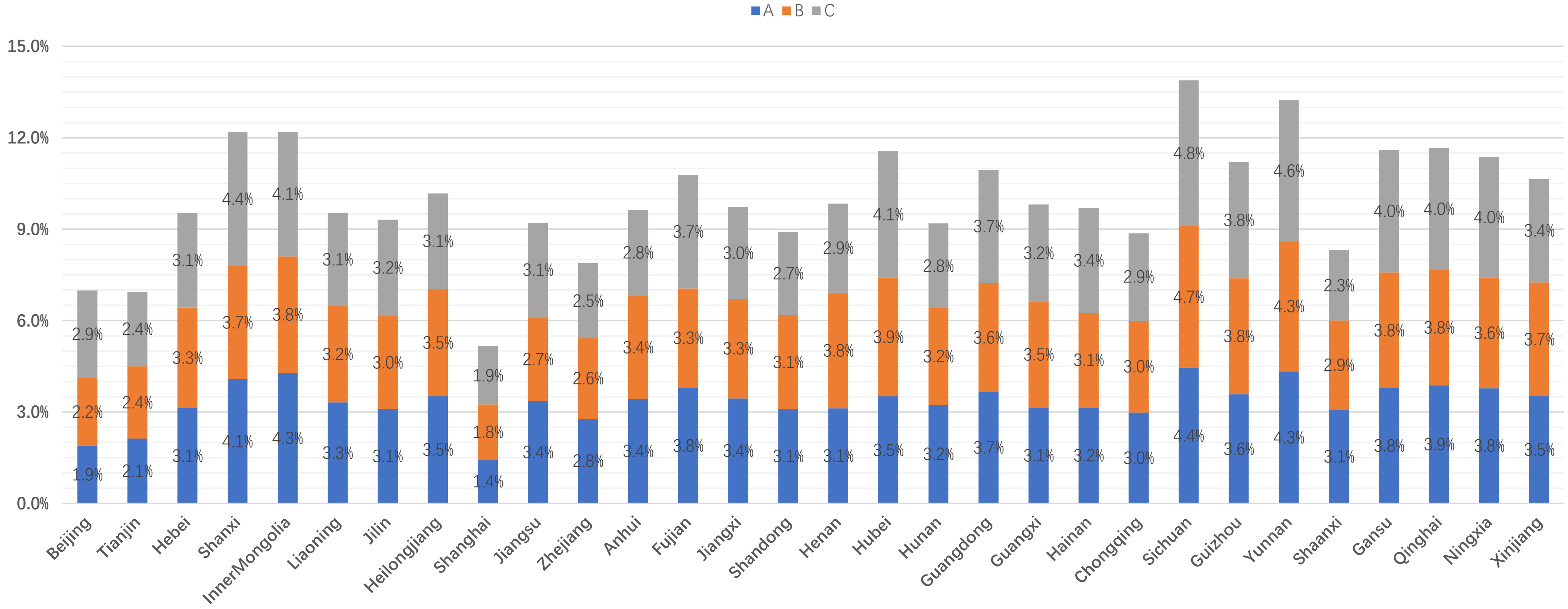
Minor Surplus (CE space <300Mt and ≥100Mt);

Serious Surplus (CE space ≥ 300Mt)

Results and Analysis

A: Grey correlation model + Industry collaboration
B: Entropy weight method + industrial collaboration
C: Grey correlation model

	A vs C	A vs B
Optimizing the amount of CEA	739.13Mt	105.96Mt



CEA allocation weight under three allocation methods

Conclusion

Main Fingdings:

- Firstly, the heterogeneity of regional industrial development is considered in the allocation indicators, and the industrial synergy indicators are included; secondly, the gray correlation analysis method is used to calculate the synchronous change degree of each indicator and carbon emissions in each region, so as to obtain the weight of each indicator in each region. Finally, the CEA and emission space of 30 provinces and regions of China from 2021 to 2030 were calculated. The results show that the population and TFCEE indicators have a strong correlation with the carbon emissions of various regions, therefore given a higher weight.
- The regions with the most CEA include Sichuan and Mongolia, and the regions with the least CEA include Shanghai and Beijing. The surplus analysis found that Yunnan, Qinghai and other regions have more carbon emission space surplus.
- The allocation of CEA in the central provinces is relatively reasonable; the four provinces, including Shandong and Inner Mongolia, are in a more serious overflow state, and will have to bear heavier pressure on emission reduction in the next 10 years.

Conclusion

- Limitation：
  - Firstly, the calculation of net carbon emissions based on electricity transfer does not take into account the different sources of electricity.
  - Lack of precise forecasting.
- Research Outlook:
  - It is necessary to further improve the allocation indicators and use a more suitable method for CEA allocation based on regional development differences.

Thanks for your attention!

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