sustainability

Interprovincial metal and GHG transfers embodied in electricity transmission across China: Trends and driving factors

Yawen Han[1], Wanli Xing[*2], Hongchang Hao[3], Xin Du[1], Chongyang Liu[4]

[1] School of Earth Sciences and Resources, China University of Geosciences, Beijing. 29 [1] School of Economics and Management, Zhejiang Sci-Tech University, No. 928, 2nd Street, Gaojiaoyuan District of Qiantang, Hangzhou, 310018, China

[2] Development research Center of China Geological Survey, No.45 Fuwai street, Xicheng District, Beijing, 100037, China.

[3] School of Earth Sciences and Resources, China University of Geosciences, Beijing. 29 Xueyuan Road,Haidian District, Beijing 100083, China

[4] Institute for energy development of China Southern Power Grid Company, No.11 Kexiang Road, Huangpu District, Guangzhou, 510700, China.

*Corresponding author: wanlicgs@163.com / xwanli@mail.cgs.gov.cn.

Supplementary information

Table S1-S12: See the attached Excel file.

Additional explanation:

1 How do the factors influence metal and GHG transfers?

To apply the QAP algorithm, we suppose that the difference in decarbonization effort can affect metal and GHG transfer. Provinces promote decarbonization of the power system by investing in low-carbon power, especially solar and wind power, phasing out outdated thermal power capacity, and encouraging technological innovation in low-carbon power. The provinces increase production capacity of low-carbon electricity by investment, which may promote the solar or wind electricity outflow, thereby expanding the metal transfer even curbing GHG transfer. Decommissioning polluting thermal units in provinces that are net importers of electricity may accelerate the electricity inflows, which in turn cause metal transfer or GHG transfer. Coal-deficient provinces have the potential to generate low-carbon electricity themselves through technological innovation, which may weaken the metal transfer or GHG transfer. Moreover, direct transmission path for electricity between provinces affects electricity transmission amount. Therefore, we also assume that metal and GHG transfer is facilitated through grid connection. Finally, as developed provinces consume more electricity and tend to purchase electricity from the provinces with power generation advantages, metal and GHG transfer may be the result of gaps in development levels and power generation characteristics.

In summary, the factors influencing the metal and GHG transfer embodied in electricity transmission in this study are: difference in decarbonization effort, grid connection, economic development gap and difference in power generation characteristics.

Additional results:

1: Changes in metal and GHG embodied in electricity consumption by province

With the growth of electricity consumption, changes in metal demand and GHG emissions show different characteristics in different provinces. The elasticity measures the relative speed between the growth in metal demand or GHG emissions and increase in electricity consumption. Figure S1 shows that metal demand elasticity of electricity consumption for each province is positive and greater than 1 while GHG emissions elasticity of electricity consumption varies by province. According to GHG emissions elasticity of electricity consumption, the provinces can be divided into 3 types: potential regions, transitional regions, and deteriorative regions.

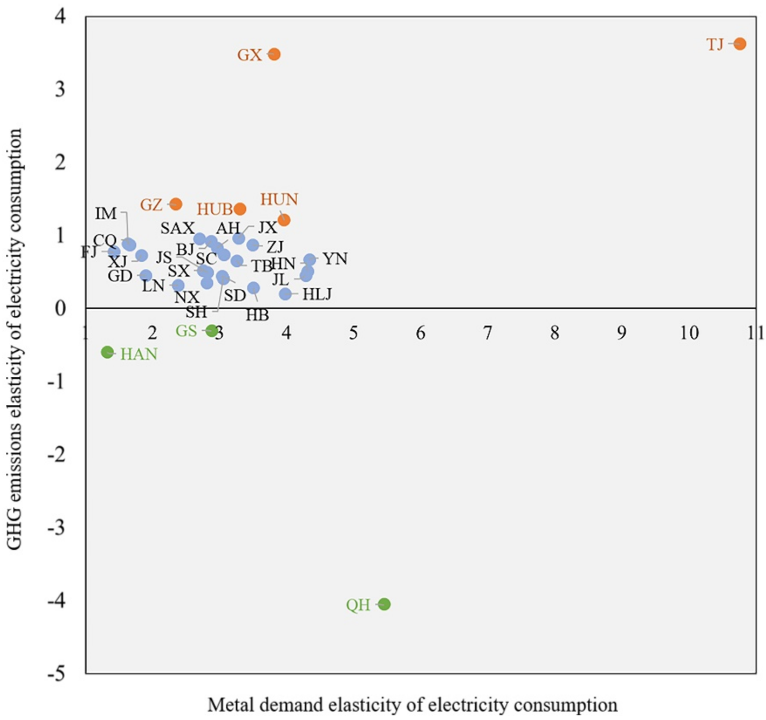

Figure S1 Metal demand elasticity of electricity consumption and GHG emissions elasticity of electricity consumption in each province

Note: Elasticity= $\frac{(e^c_{i\,2019} - e^c_{i\,2015})/e^c_{i\,2015}}{(C_{i_{2019}} - C_{i_{2015}})/C_{i_{2015}}}$;

The abbreviations of the provinces are shown in Table S1.

GHG emissions elasticity of potential region is negative while the metal demand elasticity is greater than one, for the provinces of Hainan, Qinghai, and Gansu. Specifically, for Qinghai province, a 1% increase in electricity consumption has led to 4% decrease in GHG emission, and 5% increase in metal demand. For transitional region, a 1% rise in electricity consumption will increase GHG emissions but by less than 1%, while metal demand responds more than proportionately, such as provinces represented by blue dots in Figure S1. The results indicate absolute or weak decoupling of electricity consumption increase and associated GHG emissions in most provinces. However, decoupling is always accompanied by rising reliance on metals, caused by the increase in the share of solar and wind power in the electricity consumption mix. To be specific, wind power and photovoltaic power generation produce almost no carbon emissions, which allow emissions to decline while electricity consumption growth continues, and copper, nickel, chromium, and zinc required to produce a unit of wind or photovoltaic power is times that of thermal power (Table S2). Under the trend of decarbonizing power system, more provinces will transform into potential regions. Huge increase in metal demand should receive notable attention so that the goal of net zero carbon emission can be achieved smoothly. Besides, the GHG emission and metal demand elasticities of deteriorative regions are always bigger than 1, which indicates electricity consumption growth in these regions (Guizhou, Guangxi, Hubei, Hunan, and Tianjin) brings more environmental burden than before.

2: Gap between environmental load intensities of electricity generation and consumption of provinces

If the total amount of cross-border power trading is large, the environmental load embodied in electricity transmission cannot be ignored. Therefore, the environmental load intensities of electricity generation and consumption should be distinguished. For example, the metal intensity of electricity consumption in Beijing is determined not only by the metal requirement in the generation, but also by the metal embodied in the increasing electricity import. Figure S2 shows the gap between environmental load intensities of electricity generation and consumption of provinces in 2019. For example, Cu, Ni, Cr, and Zn intensities of electricity consumption in Beijing were higher than that of electricity generation. This was because Beijing, where gas-fired generation accounted for 88% of its total power production, imported a large fraction of their electricity originally from provinces such as Shanxi, Hebei, and Shaanxi, which demonstrated higher metal intensity in electricity production. Higher metal intensity was due to the relatively high proportion of wind and photovoltaic power generation. However, the electricity generation in Shanxi, Hebei, and Shaanxi remained reliant on coal for about 80% of power generation, thus the GHG intensity of electricity in Beijing improved from 473 Kt/TWh to 610 Kt/TWh after considering electricity import. Overall, the electricity consumption of Beijing needed more metal and produced more GHG emissions than was apparent on the surface. The same phenomenon is seen in Tianjin and Liaoning, etc. Differently, Zhejiang mainly imported electricity from Gansu and Ningxia, where the proportion of wind and photovoltaic in electricity generation was sufficiently high. Though Zhejiang exhibited higher metal intensity of electricity consumption (52.96t/TWh) than that of electricity generation (51.08t/TWh) in 2019, the GHG emission per unit of electricity consumption was 7.7 Kt/TWh lower than GHG intensity of electricity production. Other typical examples include Shandong, Hunan, Shaanxi, etc. These provinces had achieved lower carbon electricity consumption through electricity trade, but their actual reliance on particular metals was high.

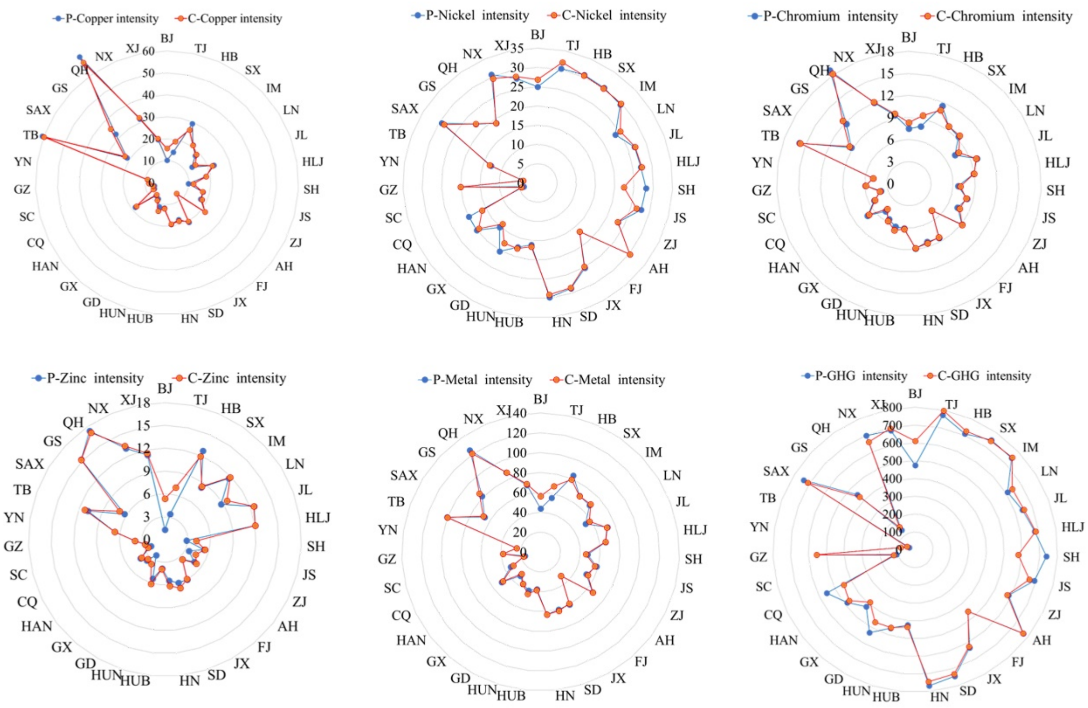

Figure S2 The gap between metal or GHG intensity of electricity production and consumption in 2019 (unit: t/TWh for metal intensity; Kt/TWh for GHG intensity)