

Regional Inequality of Carbon Emissions in China and Its Influencing Factors Based on Quantitative Modeling and Factorization Algorithm

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Abstract. Regional heterogeneity in population, economy, and energy consumption has created significant spatial imbalances in China's carbon emissions, complicating the allocation of provincial reduction targets. This paper employs the Theil Index to quantify regional carbon emission inequality across 31 provinces from 2012 to 2021, decomposing it into inter- and intra-regional components. An extended Kaya identity is used to assess contributions of four factors—energy structure, energy intensity, labor productivity, and employment rate. Results show inter-regional inequality is the dominant and growing source of overall inequality, while intra-regional inequality remains stable. Energy intensity and labor productivity are identified as the primary driving factors.

Keywords: Carbon emissions; Regional inequality; Theil Index; Extended Kaya identity; Influencing factors.

1. Introduction

Resource endowment and energy utilization efficiency have led to prominent regional differences in carbon emissions across China^[1], with highly uneven spatial distribution^{[2][3]}. This paper quantifies carbon emission inequality across China's seven geographic regions (2012–2021) using the Theil Index, decomposes it into inter- and intra-regional components, and applies an extended Kaya identity to examine contributions of energy structure, energy intensity, labor productivity, and employment rate. Region-specific carbon reduction recommendations are proposed.

2. Literature Review

Existing studies have explored carbon emission inequality using kernel density^[4], the Dagum Gini coefficient^[5], and Kaya-based decomposition^{[9]–[11]}. While international research has pioneered environmental inequality indicators^[6] and linked carbon with income inequality^[7], most domestic studies rely on coarse regional divisions and singular methods, lacking unified multi-factor quantitative analyses. This paper addresses these gaps by integrating the Theil Index with an extended Kaya identity for comprehensive decomposition.

3. Model Methods and data sources

3.1 Carbon Emission Calculation

Carbon dioxide emissions were calculated using the final consumption of coal, oil, and natural gas for each province from 2012 to 2021.

$$C_i = \sum_j E_{ij} \times LCV_j \times CEF_j \quad (1)$$

where i and j denote the province and energy type (coal, oil, gas), respectively; E_{ij} is the consumption of energy j in province i ; LCV_j and CEF_j are the low calorific value and carbon emission factor of energy j sourced from IPCC records, respectively.

3.2 Measurement and Decomposition of Regional Carbon Emission Inequality

The Theil Index (population-weighted) was adopted to quantify regional per capita carbon emission inequality. The formula is:

$$T = \sum_{i=1}^{31} \frac{P_i}{P} \ln \frac{P_i/P}{C_i/C} = \sum_{i=1}^{31} \frac{P_i}{P} \ln \frac{C/P}{C_i/P_i} = \sum_{i=1}^{31} w_i \ln \frac{c}{c_i} \quad (2)$$

where P_i and C_i are the population and carbon emissions of province i , while P and C are the respective national totals. w_i is province i 's population share; c_i and c are the provincial and national per capita emissions, respectively. Following Sherlocks^[12] the Theil index is decomposed into inter-regional and intra-regional components:

$$T = T_W + T_B = \sum_{j=1}^7 w_j T_j + \sum_{j=1}^7 w_j \ln \frac{c}{c_j} \quad (3)$$

$$T_j = \sum_i^N w_{ij} \ln \frac{c_j}{c_i} \quad (4)$$

where T_W and T_B represent the intra- and inter-regional Theil indices, respectively. T_j , w_j , and c_j denote the Theil index, population share, and per capita emissions of region j , while w_{ij} is province i 's population share within region j .

3.3 Decomposition of Influencing Factors of Regional Carbon Emission Inequality

Per capita carbon emissions were factorized into four driving factors: energy structure, energy intensity, labor productivity, and employment rate.

$$c_i = \frac{C_i}{P_i} = \frac{C_i}{E_i} \times \frac{E_i}{G_i} \times \frac{G_i}{L_i} \times \frac{L_i}{P_i} = CE_i \times EG_i \times GL_i \times LP_i \quad (5)$$

where E_i , G_i , L_i , and P_i are the total energy consumption, GDP, labor force, and population of province i , respectively. The four driving factors are defined as: energy structure ($CE_i = C_i/E_i$), energy intensity ($EG_i = E_i/G_i$), labor productivity ($GL_i = G_i/L_i$), and employment rate ($LP_i = L_i/P_i$). For simplicity, denoting these four factors as A, B, X , and Y , the equation becomes $c_i = A_i \times B_i \times X_i \times Y_i$. Per Shorrrcks et al.^{[8][12]}, the interaction terms were uniformly allocated to the corresponding influencing factors. The Theil index was completely decomposed into the following formula:

$$T = T^A + T^B + T^X + T^Y \quad (6)$$

Among them, T^A , T^B , T^X , T^Y are contributions of energy structure, energy intensity, labor productivity, and employment rate, respectively.

3.4 Data Sources

The primary energy consumption data originated from the "China Energy Statistical Yearbook." The population, employed population, and GDP data for each province were obtained from the "China Statistical Yearbook" and the "China Employment Statistical Yearbook". The gross domestic product (GDP) figures for each region were converted and adjusted to constant prices from 2012.

The study covers seven geographical regions: North, Northeast, East, Central, South, Southwest, and Northwest China^[13] (Xizang excluded due to insufficient data).

4. Analysis of Regional Inequality in Carbon Emissions in China

4.1 Current Situation of Carbon Emissions in China

From 2012 to 2021, total carbon emissions across all seven regions rose gradually, concentrated primarily in East and North China (Figure 1a). Per capita emissions were more evenly distributed, despite notable north-south disparities (Figure 1b).

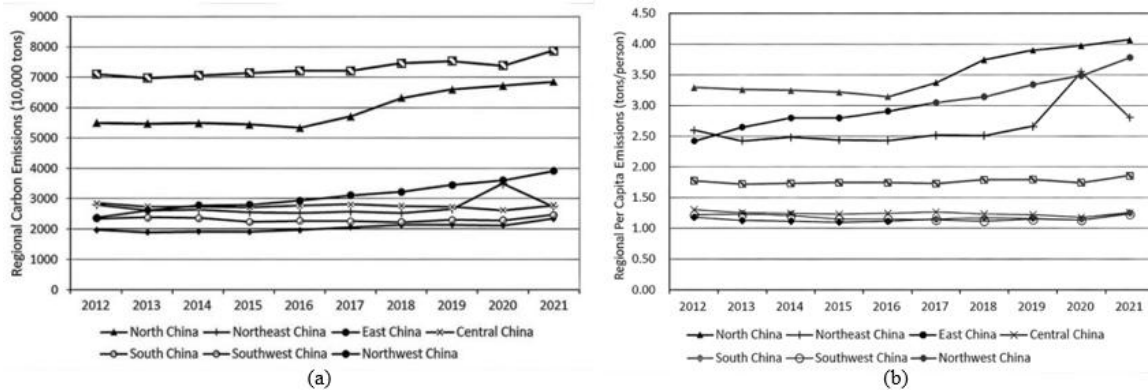


Fig.1 Total (a) and per capita (b) carbon emissions in China's seven major regions

4.2 Analysis of Regional Inequality in Carbon Emissions in China

4.2.1 The Current Situation and Evolving Trend of Regional Carbon Emission Inequality in China

Regional carbon emission inequality exhibited a fluctuating upward trend, driven primarily by inter-regional differences, while intra-regional inequality remained relatively stable (Figure 2a). Within regions (Figure 2b), the internal Theil index grew significantly in North (9.33%) and Northwest China (6.95%), exceeding the national average (3.33%). Conversely, East, South, and Central China showed downward trends (-8.07%, -7.94%, and -6.05%, respectively). Regarding intra-regional contributions (Figure 2c), North China became dominant, while Northwest China gradually overtook East China's declining share, reflecting divergent reduction progress.

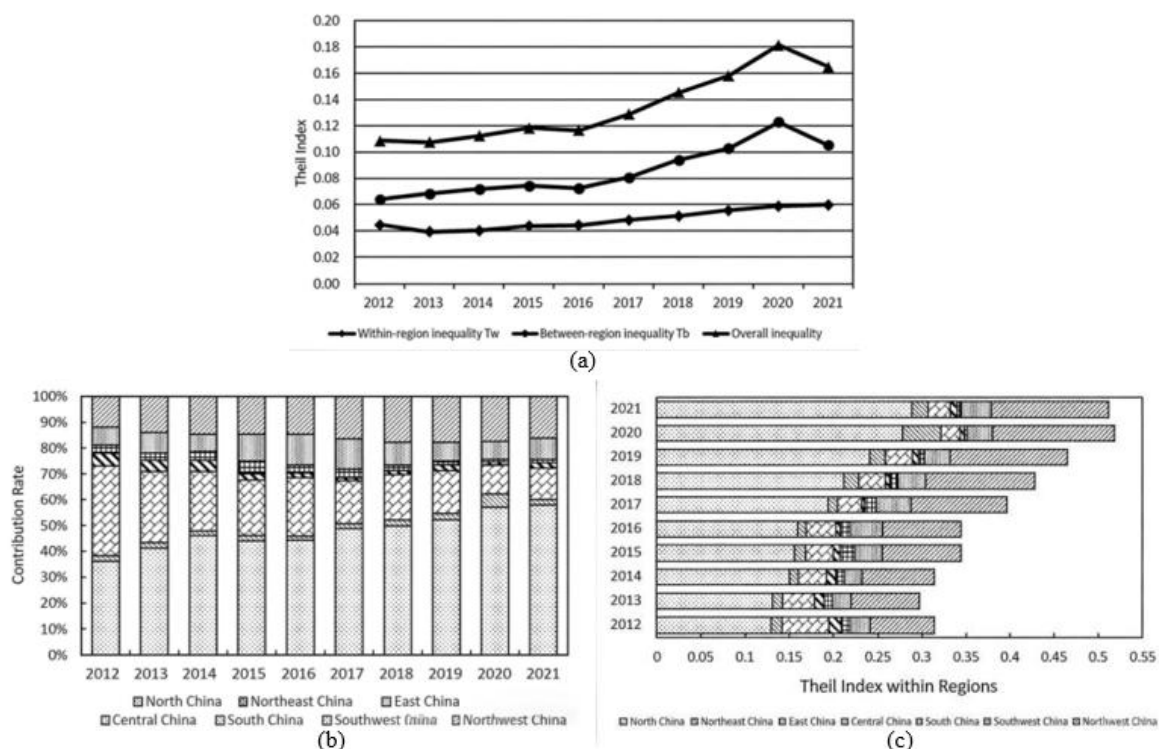


Fig.2 Regional Inequality and Decomposition

5. Analysis of Influencing Factors of Regional Inequality in Carbon Emissions in China

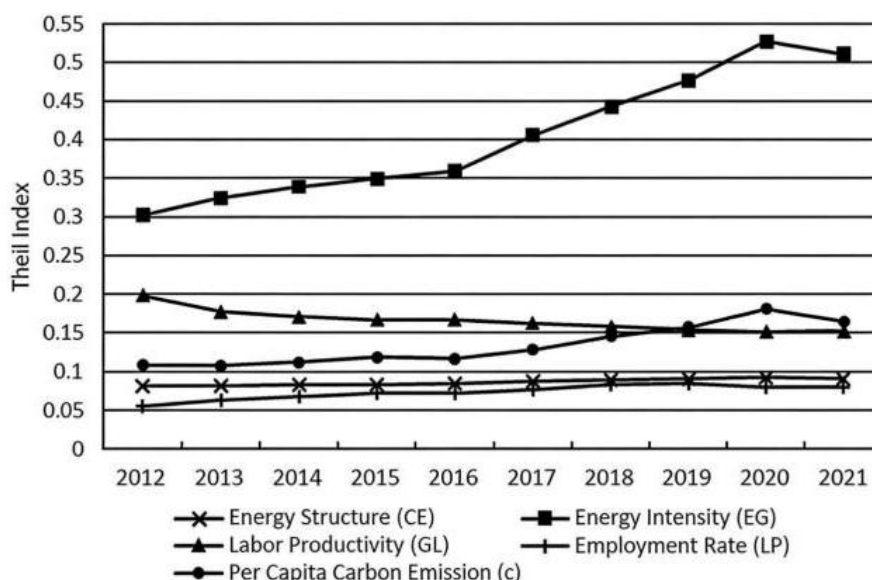


Fig.3 Regional inequality of China's carbon emissions and their influencing factors from 2012 to 2021

Based on the expanded Kaya identity decomposition (Fig.3), the Theil index of energy intensity significantly exceeded other indicators, followed by labor productivity, indicating pronounced regional distribution imbalances. Conversely, the indices for energy structure and employment rate remained stable at low averages (0.087 and 0.074, respectively), suggesting relatively balanced distributions across regions.

6. Conclusions and Suggestions

From 2012 to 2021, China's total and regional carbon emissions rose steadily, with significant inter-regional variations complicating the allocation of reduction targets. Overall carbon emission inequality exhibited an upward trend, driven predominantly by inter-regional differences, while intra-regional inequality remained comparatively stable. Furthermore, energy intensity and labor productivity were identified as the primary drivers of overall and inter-regional inequality, with energy intensity also dominating intra-regional inequality. In contrast, the energy structure's contribution to overall inequality was low and declining.

Based on these findings, policymakers should first establish a precise regional and provincial carbon emission evaluation system to monitor spatial variations effectively. Second, prioritizing energy intensity reduction is crucial, which can be achieved by facilitating inter-regional technology transfer and industrial cooperation. Finally, cross-regional cooperation must be enhanced to reduce labor productivity disparities, encouraging developed regions to support technology transfer and talent development in less developed areas.

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