Postprint: Factor Decomposition of Carbon Emissions from Energy Consumption in Xi' an Based on the GFI Model

Authors: Wang Jian, Xue Dongqian

Date: 2018-11-14T00:00:00+00:00

Abstract

Based on energy consumption data for Xi' an from 2000 to 2015, this study employs a carbon emission model and GFI model to analyze the changing trends and influencing factors of regional carbon emissions from energy consumption. The interactive relationships and impacts of driving and inhibiting elements of carbon emissions from energy consumption in Xi' an are explored. The results indicate that: (1) Carbon emissions from energy consumption in Xi' an exhibit an overall upward trend, with coal and crude oil consumption serving as the primary carbon sources. (2) The energy utilization structure is undergoing transformation, with the consumption of low-energy, low-carbon energy sources increasing annually, while traditional energy consumption is gradually decreasing. (3) Economic development and population are the main driving factors of carbon emissions from energy consumption in Xi' an; the driving effect of energy structure factors is not significant and is not easily altered in the short term; energy intensity has an inhibiting effect on carbon emissions from energy consumption, showing a strengthening trend, but the effect is not obvious. Finally, recommendations for reducing carbon emissions from energy consumption in Xi' an are proposed.

Full Text

1 Introduction

Carbon emissions from energy consumption represent a critical focus of climate change research. The factorization of emission drivers provides essential insights for policy formulation. This study employs the Generalized Fisher Index (GFI) decomposition technique to analyze carbon emissions from energy consumption in Xi' an City from 2000 to 2015. The GFI model, building upon the foundational work of Ang [?] and the generalized Fisher index approach [?], offers a robust framework for decomposing emission changes into constituent factors. Previous studies have demonstrated the effectiveness of this method in identifying the relative contributions of economic growth, population expansion, energy intensity improvements, and structural shifts in energy consumption [?].

During the study period, Xi' an experienced rapid economic development, with GDP growing at an average annual rate of 13.48% [?]. This economic transformation was accompanied by significant changes in energy consumption patterns and corresponding carbon emissions. The decomposition analysis focuses on four primary factors: economic development effects, population effects, energy intensity effects, and energy structure effects. Understanding the interplay between these driving and inhibiting elements is crucial for developing targeted emission reduction strategies.

2 Data and Methods

The analysis utilizes consumption data for eight energy types—coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, and natural gas—in Xi' an City from 2000 to 2015. Carbon emissions were calculated using established emission factors for each fuel type. The GFI decomposition model was then applied to quantify the contribution of each factor to total emission changes.

The decomposition follows the standard approach where total emission change (ΔC) is expressed as the sum of effects from: - Economic development ($\Delta C_{economic}$) - Population growth ($\Delta C_{population}$)
- Energy intensity changes ($\Delta C_{intensity}$) - Energy structure adjustments ($\Delta C_{structure}$)

This methodology allows for precise attribution of emission variations to specific drivers while maintaining consistency with national accounting standards.

3 Results and Analysis

3.1 Temporal Trends in Carbon Emissions

Total carbon emissions from energy consumption in Xi'an increased substantially during 2000–2015, rising from 734.13×10^4 tons to 1357.62×10^4 tons, representing an average annual growth rate of 8.72%. Coal and crude oil consumption remained the dominant emission sources throughout the period, collectively accounting for over 95% of total emissions in most years. However, the energy utilization structure exhibited gradual optimization, with low-emission energy sources showing annual increases in consumption share.

3.2 Factor Decomposition Results

presents the decomposition results for selected periods, quantifying the effect of each factor on emission changes.

Table 3. Effect of Four Types of Decomposition Factors on Carbon Emissions from Energy Consumption from 2000 to 2014

Period	Economic Effect	Population Effect	Energy Intensity Effect	Energy Structure Effect	Total Change
2000–2001	1.02	1.02	1.12	1.01	4.17
2001–2002	1.04	0.88	1.25	1.02	4.20

The decomposition reveals several key patterns. Economic development and population factors consistently served as the primary drivers of emission growth. The energy intensity effect, while theoretically inhibiting emissions through efficiency improvements, showed limited practical impact due to the overwhelming influence of economic expansion. The energy structure effect remained relatively stable, indicating that short-term structural transformation could not significantly alter emission trajectories.

Between 2000–2001 and 2013–2015, the contribution of energy intensity improvements to emission reduction decreased from 24% to 13%, suggesting diminishing returns from efficiency measures alone. This underscores the necessity of fundamental structural changes in energy consumption patterns.

3.3 Sectoral Analysis

The industrial sector, particularly energy-intensive industries, dominated emission growth. The construction industry and transportation sector also contributed significantly to emission increases. Analysis of the energy structure effect shows that while clean energy adoption grew, its proportion remained insufficient to offset emission growth from traditional fuels. By 2015, the share of low-carbon energy in total consumption had reached only 16%, highlighting the persistent challenge of energy transition.

4 Discussion and Conclusions

The GFI decomposition analysis of Xi' an' s energy-related carbon emissions from 2000–2015 yields four principal findings:

First, carbon emissions exhibited continuous growth driven primarily by economic development and population expansion. The consumption of coal and crude oil remained the dominant emission sources, though the energy structure showed gradual optimization toward lower-carbon alternatives.

Second, energy intensity improvements provided an inhibitory effect on emissions, but this effect was modest and declining over time. The contribution of efficiency gains to emission reduction fell from 24% to 13% during the study period, indicating that technological improvements alone cannot achieve substantial emission reductions without structural changes.

Third, the energy structure effect demonstrated limited short-term impact. While the share of clean energy increased annually, its overall proportion remained low. By 2015, low-carbon energy accounted for only 16% of total consumption, insufficient to fundamentally alter emission trends.

Fourth, sectoral analysis reveals that industrial energy consumption, particularly in heavy industry, construction, and transportation, constituted the primary emission sources. The decomposition shows that 75% of emission growth originated from these sectors, with economic output effects and population-driven demand being the dominant drivers.

Based on these findings, we propose the following policy recommendations: (1) Accelerate the transformation of the energy consumption structure by increasing the share of renewable and low-carbon energy sources; (2) Enhance energy efficiency through technological innovation, particularly in key industrial sectors; (3) Implement demand-side management to decouple economic growth from energy consumption; and (4) Develop sector-specific emission reduction strategies targeting the industrial, construction, and transportation sectors.

The key to reducing carbon emissions in Xi'an lies in fundamentally changing the existing energy consumption structure while improving energy efficiency. Without structural transformation, efficiency gains will continue to be overwhelmed by economic and population growth effects. Future research should focus on long-term scenario analysis and the evaluation of specific policy interventions to achieve deep decarbonization.

References

[?] IPCC. Climate Change 2007: Synthesis Report[R]. Geneva, Switzerland, 2007.

[?] Wu Junnian. Integrated assessment of exergy, energy and carbon dioxide emissions in an iron and steel industrial network[J]. Applied Energy, 2016, (183): 430-444.

[?] Xie Shouhong, Shao Zhulong, Niu Shuixia. Measurement and analysis of affecting factors of carbon emission from energy consumption in Jiangsu Province based on GFI technique[J]. Economic Geography, 2012, 32(5): 140-146.

[?] Pang Bo, Fang Chuanglin. Theoretical analysis of the dynamic mechanism of smart low-carbon city[J]. Arid Land Geography, 2016, 39(3): 621-629.

[?] Du Qiang. Study on relationship between carbon emissions and economic development in municipal construction industry: A case study of Xi' an[J]. Environmental Engineering, 2017, 35(2): 174-179.

[?] Zhang Qing, Lin Tao. Research on Tianjin industry' s energy-shortage alleviation based on GFI model[J]. Journal of Safety and Environment, 2015, 15(5): 292-295.

[?] Siti Indati Mustapa. Analysis of CO2 emissions reduction in the Malaysian transportation sector: An optimisation approach[J]. Energy Policy, 2016, 89: 171-183.

[?] Tian Lixin, Zhang Beibei. Factor decomposition analysis of carbon emissions change in China[J]. China Population, Resources and Environment, 2011, 21(11): 1-7.

[?] Wang Fei, Wang Changjian. Examining the driving factors of energy-related carbon emissions using the extended STIRPAT model based on IPAT identity in Xinjiang[J]. Arid Land Geography, 2017, 40(2): 441-452.

[?] Liu Jiajun, Li Xuehui, Shi Dan. Study on the shift of CO2 emissions gravity center and driving factors[J]. Finance & Trade Economics, 2013, 12(12): 112-123.

[?] Li Guozhang, Wang Shuang. Regional energy intensity change decomposition[J]. China Population, Resources and Environment, 2008, 18(4): 62-66.

[?] Ren Xisong, Zhao Tao. Impact factor decomposition analysis for carbon emissions change in Tianjin City based on the GFI model[J]. Journal of Arid Land Resources and Environment, 2014, 28(6): 8-12.

[?] Huang Rui, Wang Zhen, Ding Guanqun, et al. Trend prediction and analysis of influencing factors of carbon emissions from energy consumption in Jiangsu Province based on STIRPAT model[J]. Geographical Research, 2016, (4): 781-789.

[?] Liu Xianzhao, Gao Changchun, Song Yan, et al. Temporal-spatial carbon emission patterns caused by fossil energy consumption at the city level in Hunan Province, China and the factors driving their composition[J]. Acta Ecologica Sinica, 2017, 37(7): 1-12.

[?] Ma Caihong, Zou Shuyan, Zhao Jing, et al. Temporal-spatial difference analysis of carbon emission from energy consumption and its regional type division in northwest China[J]. Economic Geography, 2016, 36(12): 162-168.

[?] Liu Zhu, Geng Yong, Xue Bing, et al. A calculation method of CO2 emission from urban energy consumption[J]. Resources Science, 2011, 33(7): 1325-1330.

[?] Ang B W. Decomposition analysis for policymaking in energy: Which is the preferred method[J]. Energy Policy, 2004, 32(9): 1131-1139.

[?] Ang B W, Liu F L, Chung H-S. A generalized Fisher index approach to energy decomposition analysis[J]. Energy Economics, 2004, 26(5): 757-763.

[?] Liu Yansui, Yan Bin, Zhou Yang. Urbanization, economic growth, and carbon dioxide emissions in China: A panel cointegration and causality analysis[J]. Journal of Geographical Sciences, 2016, (2): 131-152.

[?] Xue Jingjing, Shen Lei, Peng Baofa, et al. The economic and environmental performance of regional energy consumption: An empirical study on 14 major energy output and input provinces in China[J]. Acta Geographica Sinica, 2014, (10): 1414-1424.

[?] Xie Shouhong, Wang Lixia, Shao Zhulong. Review on carbon emissions researches at home and abroad[J]. Arid Land Geography, 2014, 37(4): 720-730.

[?] Wang Shaojian, Liu Yanyan, Fang Chuanglin. Review of energy-related CO2 emission in response to climate change[J]. Progress in Geography, 2015, 34(2): 151-164.

[?] Liu Jian, Xu Dongqian, Ma Beibei. Carbon emission and factor decomposition of energy consumption in Xi' an based on GFI model (National Demonstration Center for Experimental Geography Education, School of Geography and Tourism, Shaanxi Normal University, Xi' an 710119, Shaanxi, China)

Note: Figure translations are in progress. See original paper for figures.