Carbon Emissions of Chinese Urban Households Driven by Income: 1995-2014

Dechao LIU[1], Rui GUAN[2], Yating YANG[1], Jingyi HE[1], Pengge LI[1], Rong KANG[1] and Nan LI[1]*

[1] School of Economics and Management, Northwest University, Xi'an, China; leo_dechao@163.com; yatingyang2022@163.com; 18791375709@163.com; lipengge0309@163.com; kangrong@nwu.edu.cn; linan@nuw.edu.cn

[2] Carbon neutrality college (YULIN), Northwest University, Xi'an, China; rax0695090@163.com

* Corresponding author: linan@nuw.edu.cn

Abstract: Over the past three decades, the rapid development of the Chinese economy has driven consumption in urban households, leading to a significant increase in indirect carbon dioxide emissions. The issue of indirect household carbon emissions has increasingly become a focal point of academic research. This paper, based on micro-level survey data of urban households, employed the input-output method to calculate indirect carbon emissions from 1995 to 2014. By utilizing the structural path decomposition method, it identified key paths contributing to carbon emissions. The results indicate that from 1995 to 2014, per capita indirect carbon emissions for Chinese urban residents increased from 1.08 tons to 7.39 tons. The multiple of indirect carbon emissions for high-income household compared to low-income household rose from 2.30 times in 1997 to 4.51 times in 2012. Carbon emissions from low-income household were primarily attributed to essential goods such as clothing and food, while high-income household's emissions were largely associated with the consumption of transportation-related goods. This paper provides insights for policymakers in developing countries seeking to reduce household carbon emissions, as the differences in carbon emissions and their driving factors among income households serve as a basis for formulating differentiated policies.

Keywords: input-output analysis; household carbon emissions; household income; structural path decomposition

JEL Classification: D10; Q50; Q56

1. Introduction

Over the past thirty years, China has experienced rapid economic development, accompanied by a substantial increase in carbon emissions. In response to the rising global temperatures, China, as the world's largest carbon dioxide emitter, has set ambitious long-term climate goals, aiming to peak carbon emissions by 2030 and achieve carbon neutrality by 2060.

Carbon emissions resulting from Chinese residents' consumption have been rapidly increasing. Household consumption has been proven to account for a significant proportion of carbon emissions in multiple countries. For example, in Canada, household carbon emissions constituted 65.62% of the national total carbon emissions in 1990 and 59.75% in 2007, while in the UK, household carbon emissions were 76% of the national total in 1997 and 77.8% in 2011

(Maraseni et al., 2015). Chinese household carbon emissions have consistently remained above 40% of the national total (Liu et al., 2011). Therefore, research on household carbon emissions is of critical importance for China in addressing climate change issues.

In 1995, the urban population in China accounted for 29.04% of the total population, and by 2014, this proportion had increased to 55.75%. The proportion of China's urban population is rapidly rising. Highlighting the significance of researching carbon emissions from urban residents in achieving China's long-term climate goals.

Carbon emissions can be roughly categorized into two types: direct carbon emissions, which result from the direct use of energy sources, and indirect carbon emissions, which stem from the use of goods or services outside of energy consumption. A notable feature of urban resident carbon emissions compared to rural resident emissions is that indirect emissions far surpass direct emissions (Liu et al., 2011; Zhang et al., 2023). Indirect carbon emissions involve numerous consumption sectors, allowing for a detailed examination of carbon emissions' specific impact on residents' consumption behavior at a more micro-level. The emission characteristics of indirect carbon emissions also differ from those of direct emissions. Consumption behavior varies among different income households, leading to variations in household carbon emissions(Wang et al., 2021). Nevertheless, research on carbon emissions based on different income households is limited, despite its crucial significance for China in developing energy-saving and emissions-reducing strategies from the perspective of domestic residents' consumption.

Hence, this paper, based on a large sample of urban resident consumption survey data, employed input-output analysis to estimate urban residents' indirect carbon emissions. It evaluated carbon emission inequality among different income households in various regions and further explored the carbon emission characteristics of different income households from macro, meso, and micro perspectives.

2. Methodology

2.1. Input-Output Model

The Input-Output model, initially proposed by Wassily Leontief, is a model used to calculate the indirect output driven by interconnections among various sectors within an economic system. In recent years, the Input-Output model has also been frequently used for calculating carbon emissions (Cao et al., 2019).Input-output tables are categorized as either competitive or non-competitive, based on whether they include foreign imports. Since this paper primarily focuses on carbon emissions from urban household consumption within one country, imported products are not considered within the scope of this paper, as their production processes occur outside the national borders. Therefore, a non-competitive input-output table is used.

The basic structure of the Input-Output model is as follows:

$$X = (I - A^d)^{-1} Y^h = LY^h \tag{1}$$

In this context, X represents total output, I is the identity matrix, and A^d is the matrix of direct consumption coefficients excluding imported products. Y^hrepresents the consumption matrix of each household. L is known as the Leontief inverse matrix. When calculating carbon emissions, by introducing sector-specific direct carbon emission intensity, the model is expanded in the following form:

$$C = EX = E(I - A^d)^{-1}Y^h = ELY^h \tag{2}$$

C represents the carbon emission matrix from residents' consumption in each sector, and E represents the diagonal matrix of direct carbon emission intensity for each sector. It denotes the carbon dioxide directly emitted by sector's per unit of output.

2.2. Structural Decomposition Analysis (SDA)

This paper employs a structural decomposition analysis model to identify the impact of different factors on changes in carbon emissions. In this paper, the final demand, represented by consumption, is decomposed into the product of four factors: commodity structure matrix, consumption structure matrix, economic scale, and population scale. Therefore, the indirect carbon emissions from urban households can be expressed as:

$$C = ELY = ELDMFP \tag{3}$$

D represents the commodity structure matrix, indicating the quantity of products from sector used to satisfy the consumption of different income households. M is the consumption structure matrix, representing the structure of consumption for different income households. F and P are numerical values, representing the level of consumption and the scale of the population, respectively. SDA has multiple decomposition methods, and this paper adopts a two-level decomposition method to quantify the impact of changes in various factors on carbon emissions.

2.3. Structural Path Decomposition (SPD)

Structural path decomposition is a decomposition method based on input-output analysis, which can analyze economic changes over a period of time at the industry chain level and identify the most important influencing factors (Li et al., 2021).This paper further utilizes the SPD model to analyze the indirect carbon emissions among urban residents. The basic principle of the SPD model involves performing a Taylor decomposition on the Leontief inverse matrix L. Substituting the Leontief inverse matrix L, after the Taylor decomposition, into Equation (3) transforms the original equation as:

$$C = ELY = EDMFP + EADMFP + EA^2DMFP + \cdots \tag{4}$$

The first term represents the carbon emissions induced by the first-order industrial chain, which reflects consumers' direct demand for a product from a specific sector. The second term represents the carbon emissions induced by the second-order industrial chain, which involves passing through an intermediate sector before reaching consumers. This reflects the indirect demand generated by consumers' demand for a product from one sector on another sector.

Similarly, the third-order industrial chain refers to the industry chain that has passed through two intermediate sectors. This decomposition can continue indefinitely, representing the carbon emissions brought about by an (n+1)-order industrial chain. Based on previous research findings, this paper selects the first three-order industrial chains for analysis. The carbon emissions, after introducing the Taylor decomposition into the Leontief inverse matrix, can be expressed as:

$$\begin{aligned}\Delta C = {} & \Delta C^{E1} + \Delta C^{D1} + \Delta C^{M1} + \Delta C^{F1} + \Delta C^{P1} + \Delta C^{E2} + \Delta C^{A2} + \Delta C^{D2} + \Delta C^{M2} \\ & + \Delta C^{F2} + \Delta C^{P2} + \Delta C^{E3} + \Delta C^{A3} + \Delta C^{D3} + \Delta C^{M3} + \Delta C^{F3} \\ & + \Delta C^{P3} + \cdots \end{aligned} \tag{5}$$

The first to fifth terms represent the first-order effects of carbon dioxide emissions, the sixth to eleventh terms represent the second-order effects of carbon dioxide emissions, and the twelfth to eighteenth terms represent the third-order effects of carbon dioxide emissions. The superscript for each term indicates its inducing factor and the order of the industrial chain to which it belongs.

2.4. Data Processing

The direct carbon emissions intensity of each sector for each year is derived from the fuel consumption, the direct emission coefficients of the fuels used, and the output of each sector from 1995 to 2014. The types of fuels and their respective quantities consumed by each sector are referenced from the China Emission Accounts and Datasets (CEAD) subnational carbon emission inventory (CEADs, n.d.). The direct emission coefficients of the fuels are calculated based on the China Energy Statistical Yearbook and the Greenhouse Gas Inventory Guide. The output data for each sector is obtained from the input-output tables.

The input-output table data and trade data in this paper are sourced from the official input-output tables published by the Chinese government. In years when the government did not publish input-output tables, the data used in this paper were obtained by averaging weighted input-output data from nearby years.

The household consumption and income data used in this paper are sourced from the China Urban Household Survey (UHS). This paper uses a portion of the UHS dataset from 1995 to 2014. As the consumption categories in household consumption data do not align precisely with the sector classifications in the input-output table, this paper combines household consumption sectors and input-output sectors into 29 mutually matched sectors, following previous studies (Golley & Meng, 2012; Zhang et al., 2023) and Chinese industry classification standards. Urban population data are calculated based on census data provided by the National Bureau of Statistics of China.

The data used in this paper is from non-public micro-level survey data. The paper has made efforts to obtain data up to 2014. However, due to the complexity and intricacy of household data surveys, the data has not been updated beyond 2014.Although the household carbon emission results calculated in this paper are only up to 2014 due to the lack of updated data, there may be some discrepancies with the current household carbon emission trends. However, this paper tracks the long-term trends of Chinese household carbon emissions from a micro perspective. The paper uses non-public household survey data from UHS, which is difficult to obtain. Because of the detailed survey items, the calculated results in this paper are more accurate and can better reflect the characteristics of household carbon emissions compared to calculations directly based on macro data. Furthermore, compared to short-term changes, this paper focuses on studying the long-term trends from 1995 to 2014, spanning twenty years. Long-term studies can capture more trends that cannot be discovered in short-term studies, and long-term trends are also of greater concern to policymakers.

3. Results

3.1. Main Result

According to equation (2), the variation in per household carbon emissions in China from 1995 to 2014 was calculated. In 1995, the per household indirect carbon emissions for urban households in China were 1.08 tons, increasing to 7.39 tons in 2014, a growth of 6.83 times compared to the original value. The carbon emissions from Chinese household consumption have consistently been in a phase of steady increase.

Combining data on the number of urban households in China, this paper estimated the total indirect carbon emissions from urban households. The calculation results show that in 1995, China's total indirect carbon emissions from urban households amounted to 10,257.35 million tons, increasing to 190,966.72 million tons in 2014. Carbon emissions grew by 1,861.76% during these two decades, with an average annual growth rate of 19.21%.

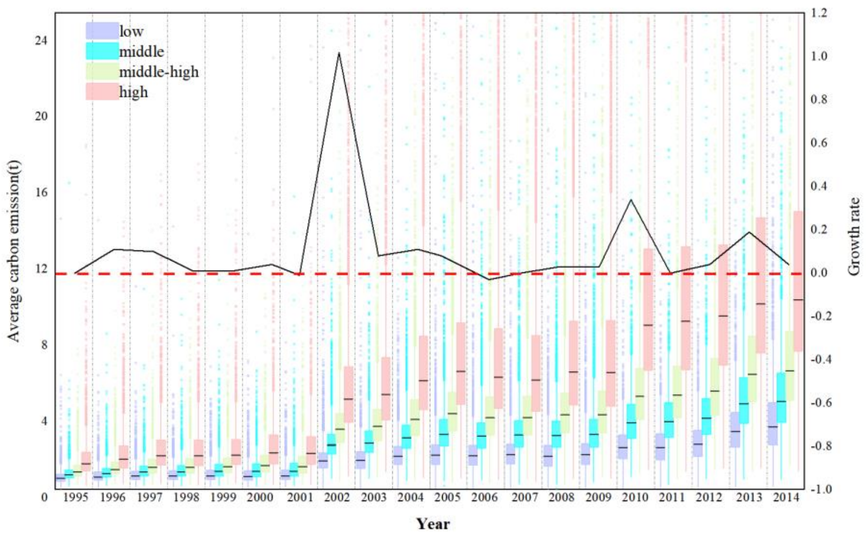

Figure 1. Average household carbon emissions by income and year. (The top 25% of the total population represents high-income, while the 25% to 50% range corresponds to middle-high-income households, and so on)

Analyzing different income households, we categorized the urban population into four income households based on their annual income and plotted the corresponding per capita carbon emission coefficients in a line chart, as shown in Figure (1). The carbon emissions for the highest-income household increased from 2.48 times that of the low-income household in 1995, 1.98 times for the middle-income household, and 1.61 times for the middle-high income household. By 2010, these ratios had risen to 4.82 times, 2.99 times, and 2.08 times, respectively. By 2014, there was a slight reduction, with ratios of 3.4 times for the low-income household, 2.49 times for the middle-income household, and 1.81 times for the middle-high income household. From 1995 to 2014, the proportion of total emissions in China attributable to high-income household increased from 39% to 45%, while the carbon emissions share of low-income household decreased from 16% to 13%. It is evident that there are significant disparities in carbon emissions among different income household, and this inequality has become more pronounced over time.

Based on the proportion of different income household in various regions in the sample and the corresponding per capita indirect carbon emissions, the total proportion of indirect carbon emissions from household in different income household in each region can be calculated. As shown in Figure (2), the average household carbon emissions in the southeast coastal region are consistently higher than those in the northwest inland region, and the East China and South China regions always have the highest per capita carbon emissions in China. The proportion of carbon emissions from high-income household is strongly positively correlated with the regional average carbon emissions. In the two regions with the highest per capita carbon emissions in China—East China and South China—high-income household carbon emissions account for over 70%, indicating that high-income household are the main driving force behind carbon emissions. This is partly because the average carbon emissions of high-income household in the southeast coastal region are higher than those in the inland region, and another reason is that high-income individuals are mainly concentrated in the southeast coastal region. An apparent exception seems to be the North China region, which exhibits high carbon emissions that do not align with its geographical characteristics. A reasonable explanation is that China's capital, Beijing, is included in the North China region, and the proportion of high-income household in Beijing is higher than in other provinces in the North China region.

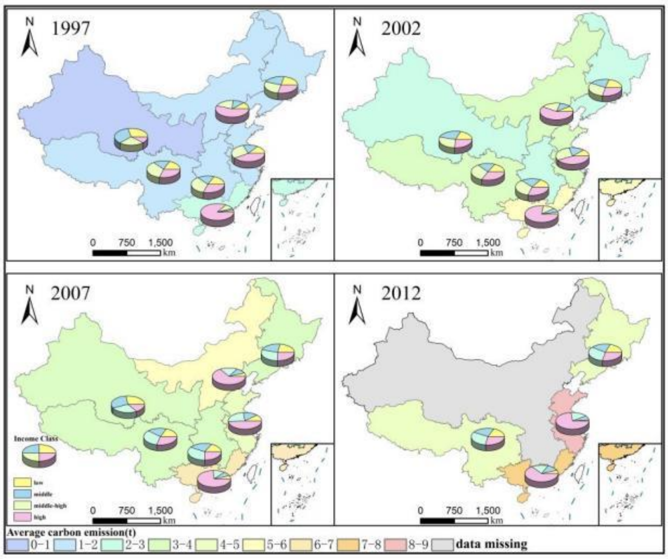

Figure 2. The distribution of total carbon emissions from households with different incomes in different regions and the average carbon emissions in different regions. The pie chart represents the total carbon emissions, and the colors in different regions represent different average carbon emissions (the data in North China, Central China and Northwest China are lacking in 2012)

3.2. Decomposition Analysis

To further decompose the impact of various factors on carbon emissions, this paper investigated the changes in carbon emissions from 1997 to 2012. This period was divided into three segments: 1997-2002, 2002-2007, and 2007-2012. Structural decomposition analysis and structural path decomposition were employed to break down the changes in household indirect carbon emissions during these three periods. The decomposition results were analyzed at both macro, meso and micro levels.

According to equations (3), the changes in carbon emissions can be decomposed. The decomposition results are shown in Figure 3. At the macro level, the effects of consumption scale, population scale, commodity structure, and consumption structure have all contributed to the increase in carbon emissions from urban residents in China to a certain extent.

Regardless of the time period, the consumption scale effect remains the largest driving force behind the increase in carbon emissions from urban residents in China. This trend is continuously expanding: the contribution of the consumption scale effect to urban resident carbon emissions in China increased from 102.48% in 1997-2002 to 117.69% in 2002-2007 and further to 128.58% in 2007-2012. The increase in carbon emissions due to the population scale effect is also significant, rising from 27.29% in 1997-2002 to 53.26% in 2002-2007 and then to 37.91% in 2007-2012. This reflects both a substantial increase in the consumption capacity of urban residents and a significant increase in their population.

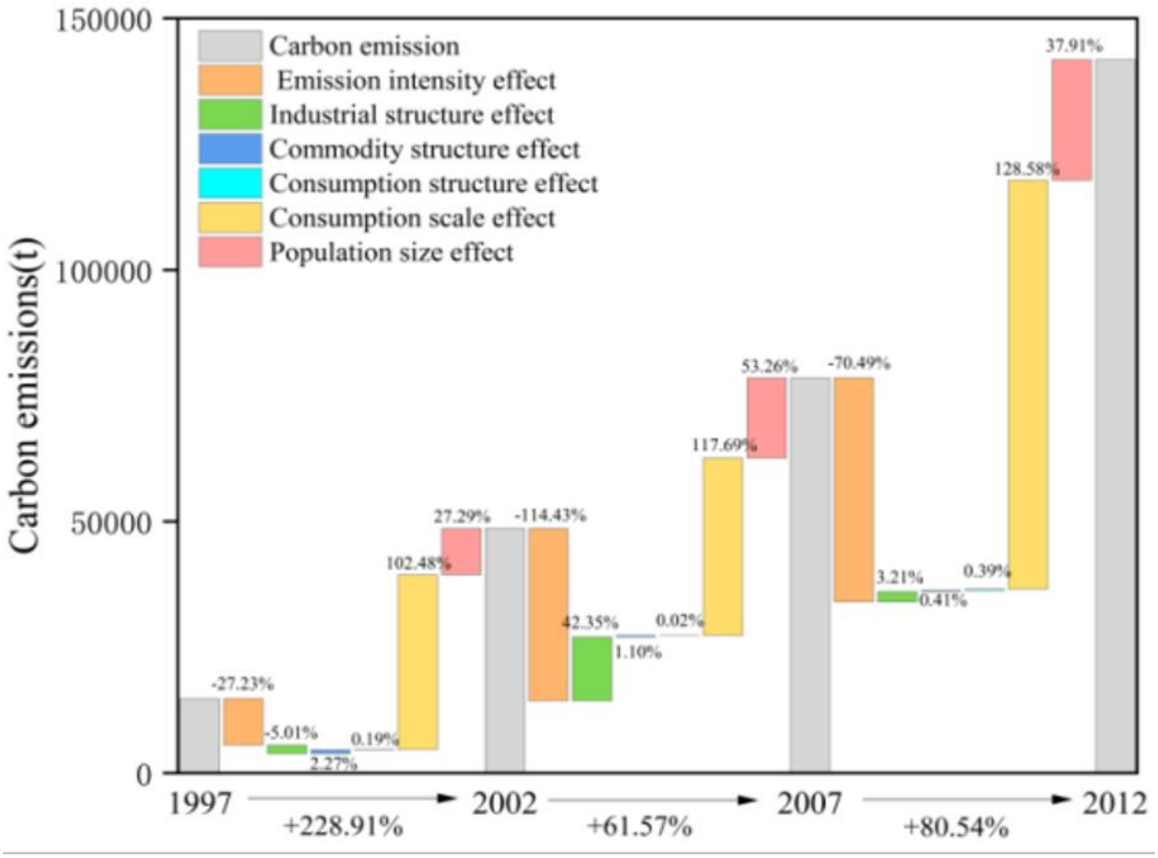

Figure 3. Changes and driving factors of indirect carbon emissions from urban household from 1997 to 2012. The structural decomposition analysis and structural path decomposition were used to analyze the changes of indirect household carbon emissions in three periods

The industrial structure effect initially showed a trend of reducing carbon emissions from urban residents in China, with a reduction contribution of 5.01% in 1997-2002. However, in the subsequent periods of 2002-2007 and 2007-2012, it exhibited a trend of increasing carbon emissions. In the 2002-2007 period, it even contributed 42.35% to the net increase in carbon emissions in China, reflecting the reality of China's overall shift in industrial structure towards the manufacturing of high-carbon-emission products after 2002.

The carbon emission intensity effect has been the primary driver of carbon reduction in China, showing a strong trend of reducing carbon emissions from urban residents during all three periods, with reduction contributions of 27.23%, 114.43%, and 70.49% respectively. Especially in the 2002-2007 period, the contribution of emission intensity to carbon reduction almost offset the increase in carbon emissions due to the expansion of consumption scale, demonstrating the continuous improvement of China's industrial technology and the greener nature of its technology.

According to formulas (4), the order of urban residents' consumption goods can be obtained. The calculation results show that the newly added carbon emissions come predominantly from the first, second, and third-order industrial chains, accounting for 79%, 61%, and 70% respectively. Therefore, it can be considered that the first three orders are the main components of urban residents' consumption. In our subsequent research, we mainly analyze the carbon emissions characteristics caused by the first three-order industrial chains. As the order of the industrial chain increases, the corresponding products result in less carbon emissions in urban residents' consumption. This indicates that consumer goods for urban residents are different from the complex products required for industrial manufacturing, and shorter-order simple products are the main objects of consumption for urban residents.

Based on the frequency of being among the top ten in carbon emissions or reductions in each period, this paper identifies key industry chains in the first, second, and third-order: these industry chains play a crucial role in both carbon emissions and reductions. Over three periods, the key sectors in the first order industry chain are food and tobacco processing manufacturing, chemical industry, and electricity, heat production, and supply. In the second order industry chain, the most important one is the chemical industry to chemical industry chain, followed by the agriculture, forestry, animal husbandry, and fishery to food and tobacco processing manufacturing chain. The chain from non-metallic mineral products industry to construction and from petroleum and natural gas extraction to petroleum processing and coking industry is in the third place. In the third order industry chain, the chemical industry to chemical industry to chemical industry holds the most crucial position, followed by agriculture, forestry, animal husbandry, and fishery to agriculture, forestry, animal husbandry, and fishery to food and tobacco processing manufacturing. Petroleum and natural gas extraction to petroleum and natural gas extraction to petroleum processing and coking industry ranks third. It can be observed that the chemical industry and food and tobacco processing manufacturing play important roles, and some sectors exhibit clear self-circulation phenomena, such as the chemical industry, agriculture, forestry, animal husbandry, and fishery, and petroleum and natural gas extraction.

To gain a deeper understanding of the specific industrial chain's carbon emissions and its driving factors, this paper conducted structural path decomposition of urban residents' indirect carbon emissions in three time periods: 1997-2002, 2002-2007, and 2007-2012, based on formula (5). It identified the thirty key paths contributing to the growth or reduction of carbon emissions for urban residents in China during these periods.

From an industrial chain perspective, the industry chain with the highest carbon emissions increase in China from 1997-2002 was the chain from chemical industry to high-income household, with a net emission of 1,105.93 million tons of carbon dioxide. In 2002-2007, it was the chain from transportation, warehousing, and postal services to high-income household, with a net emission of 685.68 million tons of carbon dioxide. In 2007-2012, it was the chain from petroleum processing and coking to high-income household, with a net emission of 2,489.54 million tons of carbon dioxide. From a carbon reduction perspective, the most significant chain from 1997-2002 was the chain from chemical industry to textile industry to chemical industry again to high-income household, with a net reduction of 1.98 million tons of carbon dioxide. In 2002-2007, it was the chain from electricity, heat production, and supply to high-income household, with a net reduction of 197.06 million tons of carbon dioxide. In 2007-2012, it was the chain from gas production and supply to high-income household, with a net reduction of 72.83 million tons of carbon dioxide. Urban residents' indirect carbon emissions generally have short orders.

There are key sectors in the key paths of urban residents' indirect carbon emissions. From 1997-2002, eight paths involved food and tobacco processing, accounting for 9.99% of the total increase in household indirect carbon emissions. In 2007-2012, six paths involving S6 remained, accounting for 8.56%, seven paths involving the chemical industry accounted for 9.7%, and seven paths involving petroleum processing and coking accounted for 9.45%. This reflects changes in the consumption goods structure of urban residents in China, where the key components of food and tobacco processing are various processed foods, and the key components of petroleum processing and coking are expenses related to fuel and transportation.

The consumption scale effect remains the most important factor contributing to the increase in carbon emissions, accounting for 73.53%, 72.74%, and 71.31% of the total change in carbon emissions for the thirty key paths during the periods 1997-2002, 2002-2007, and 2007-2012 respectively. The commodity structure effect and population scale effect are also important factors contributing to carbon emission increases. The ratio of the commodity structure effect to the total change in carbon emissions for the thirty key paths is 9.56%, 6.17%, and 12.21% for the three time periods, while the population scale effect is 6.93%, 18.79%, and 7.72%.

From 1997-2002, high-income household accounted for 16 out of the thirty key paths, contributing 54.07% to the total change in carbon emissions and 14.71% to the total increase. From 2007-2012, high-income household occupied 19 out of the thirty key paths, contributing 65.42% to the total change in carbon emissions and 24.96% to the total increase. The proportion of carbon emissions attributed to high-income household is not proportional to their population, and this ratio tends to expand over time.

The most significant driver of carbon reduction for urban residents in China is the emission intensity effect, accounting for 62.87%, 98.28%, and 88.08% of the total reduction for the thirty key paths during the periods 1997-2002, 2002-2007, and 2007-2012 respectively. The reduction from the commodity structure effect is relatively small, accounting for 29.84% of the total reduction for the thirty key paths in 1997-2002 and 11.9% in 2007-2012. Food and tobacco processing, chemical industry, electricity and heat production, and petroleum processing and coking play important roles in carbon reduction.

High-income household bear a much higher responsibility for carbon emission increases in China than low-income household. In 2007-2012, the industry chain with the highest emission increase for high-income household was the chain from petroleum processing and coking to high-income household, with a net increase of 2,489.54 million tons of carbon dioxide. The chain with the highest emission increase for low-income household was the chain from chemical industry to low-income household, with a net increase of 314.76 million tons of carbon dioxide. The former is 7.9 times the latter. The chain with the most reduction for high-income household was the chain from gas production and supply to high-income household, with a net reduction of 72.83 million tons of carbon dioxide. The chain with the most reduction for low-income household was the chain from coal mining and washing to low-income household, with a net reduction of 34.74 million tons of carbon dioxide. The former is only 2.09 times the latter.

4. Discussion

The research results of this paper confirm the existence of differences in carbon emissions among household with different income levels, and these differences have further widened over time. The majority of urban household carbon emissions are caused by affluent families: over 69% of urban household carbon emissions come from affluent families. From 1995 to 2014, the proportion of emissions from high-income families, representing 25% of the total population, increased from 39% to 45%, while the carbon emissions share of low-income household, also representing 25% of the total population, decreased from 16% to 13%. The research results also indicate that these differences are more pronounced in the southeastern coastal regions of China. These differences are evidently associated with regional disparities, as carbon emissions in households from the southeast coastal regions are significantly higher than those in the less developed northwest inland areas, with variations among different income households being greater in coastal regions than inland areas.

The paper also identifies key drivers influencing carbon emissions and reductions, confirming that the disparity in carbon emissions is associated with the consumption patterns of household with different incomes. The increase in consumption scale resulting from rising household income contributes to a significant surge in urban household carbon emissions, while the decrease in emission intensity due to technological advancements is the main driver of carbon emission reduction. Urban household carbon emissions primarily stem from the consumption of low-tier industrial chain goods, especially those in the first-tier industrial chain. Through structural path decomposition, based on different orders of the industrial chain, the paper identifies key industrial chains that are significant for carbon emissions, some of which exhibit obvious self-circulation phenomena. Food and tobacco processing industry, chemical industry, petroleum processing and coking industry, and electricity, heat production, and supply industry are key sectors for urban household carbon emissions. High-income families tend to consume goods related to transportation and fuel, which result in more carbon emissions compared to the goods purchased by low-income families such as food and textiles. High-income families play important roles in both carbon emissions and reductions, but the carbon emissions caused by high-income families are much higher than their reduced carbon emissions.

The research reveals characteristics of carbon emissions in Chinese households, including regional, income, and commodity distribution features, providing insights for the formulation of relevant carbon reduction policies in China. The increase in urban consumption scale and population growth is inevitable in the future. Therefore, in addition to developing green technologies to reduce carbon emissions, urban household carbon reduction will depend on changes in industrial structure, income structure, and consumption structure. Government-specified policies can influence these factors. Firstly, carbon reduction policies in China should distinguish between the southeast coastal region and the northwest inland region, taking into account the economic development level differences, especially in carbon reduction policies designated from the consumption end. Secondly, when formulating consumption-side carbon reduction policies, the government should be aware of the importance of carbon emission transmission between different sectors. High carbon emissions in consumer goods are likely caused by a high carbon-emitting sector in the consumer goods industry chain. Therefore, carbon reduction policies should focus on these crucial sectors, using key nodes in each industry chain to promote energy-saving and emission reduction in China's overall industrial structure. For example, in recent years, petroleum processing and coking industry have become the main sectors for household carbon emissions. Targeted policies should be developed to achieve coordinated carbon reduction in various sectors while ensuring stable economic development. Thirdly, residents' final demand remains the driving force for household carbon emissions. To control the increase in household carbon emissions and narrow the carbon emission gap between different income households, the government should formulate differentiated consumption-side policies based on the consumption patterns of households with different income levels. Urban household carbon emissions mostly come from high-income families, and consumption related to transportation has become the largest source of carbon emissions for high-income families. Advocating for environmentally friendly modes of transportation is a crucial direction for promoting urban household carbon reduction. Encouraging non-motorized transportation, public transportation, and shared transportation, imposing higher taxes on environmentally polluting fuels, and levying higher taxes on cars, especially luxury cars favored by high-income families, can effectively promote urban household carbon reduction. Additionally, implementing income redistribution systems from high-income families to low-income families and advocating for a green lifestyle are also crucial.

High-income households evidently contribute more to carbon emissions, but it must be acknowledged that the drivers of socioeconomic development and predominant consumers are often high-income families. If carbon reduction policies are selectively targeted at high-income households, it is bound to have an impact on economic development. Striking a balance between economic development and environmental protection will be a major challenge for policymakers.

Acknowledgements: This research is funded by the Youth Project of National Natural Science Foundation of China (No.72103163), the Later funded project of philosophy and social science research of the Ministry of Education (No.22JHQ066), General project of Shaanxi Provincial Social Science Foundation (No.2023D011), Shaanxi Provincial Department of Education Science Research Program Project - Youth Innovation Team Project (No. 23JP166), Education Department Special Research Program Project of Shaanxi Province (No. 23JK0227).

Conflict of interest: none.

References

Cao, Q., Kang, W., Xu, S., Sajid, M. J., & Cao, M. (2019). Estimation and decomposition analysis of carbon emissions from the entire production cycle for Chinese household consumption. *Journal of Environmental Management*, *247*, 525–537. https://doi.org/10.1016/j.jenvman.2019.06.044

CEADs. (n.d.). *Carbon Emission Accounts and Datasets for emerging economies*. Retrieved October 26, 2023, from https://www.ceads.net/

Golley, J., & Meng, X. (2012). Income inequality and carbon dioxide emissions: The case of Chinese urban households. *Energy Economics*, *34*(6), 1864–1872. https://doi.org/10.1016/j.eneco.2012.07.025

Jiang, T., Huang, S., & Yang, J. (2019). Structural carbon emissions from industry and energy systems in China: An input-output analysis. *Journal of Cleaner Production*, *240*, 118116. https://doi.org/10.1016/j.jclepro.2019.118116

Li, Q., Wu, S., Lei, Y., Li, S., & Li, L. (2021). Evolutionary path and driving forces of inter-industry transfer of CO2 emissions in China: Evidence from structural path and decomposition analysis. *Science of The Total Environment*, *765*, 142773. https://doi.org/10.1016/j.scitotenv.2020.142773

Liang, L., Chen, M., & Zhang, X. (2023). Measuring inequality of household carbon footprints between income groups and across consumption categories in China. *Journal of Cleaner Production*, *418*, 138075. https://doi.org/10.1016/j.jclepro.2023.138075

Lin, B., & Teng, Y. (2022). Structural path and decomposition analysis of sectoral carbon emission changes in China. *Energy*, *261*, 125331. https://doi.org/10.1016/j.energy.2022.125331

Liu, L.-C., Wu, G., Wang, J.-N., & Wei, Y.-M. (2011). China's carbon emissions from urban and rural households during 1992–2007. *Journal of Cleaner Production*, *19*(15), 1754–1762. https://doi.org/10.1016/j.jclepro.2011.06.011

Maraseni, T. N., Qu, J., & Zeng, J. (2015). A comparison of trends and magnitudes of household carbon emissions between China, Canada and UK. *Environmental Development*, *15*, 103–119. https://doi.org/10.1016/j.envdev.2015.04.001

Wang, J., Li, N., Huang, M., Zhao, Y., & Qiao, Y. (2021). The challenges of rising income on urban household carbon emission: do savings matter? *Journal of Cleaner Production*, *326*, 129295. https://doi.org/10.1016/j.jclepro.2021.129295

Yu, S., Zhang, Q., Hao, J. L., Ma, W., Sun, Y., Wang, X., & Song, Y. (2023). Development of an extended STIRPAT model to assess the driving factors of household carbon dioxide emissions in China. *Journal of Environmental Management*, *325*, 116502. https://doi.org/10.1016/j.jenvman.2022.116502

Yuan, R., Rodrigues, J. F. D., & Behrens, P. (2019). Driving forces of household carbon emissions in China: A spatial decomposition analysis. *Journal of Cleaner Production*, *233*, 932–945. https://doi.org/10.1016/j.jclepro.2019.06.110

Zhang, Y., Wang, F., & Zhang, B. (2023). The impacts of household structure transitions on household carbon emissions in China. *Ecological Economics*, 206, 107734. https://doi.org/10.1016/j.ecolecon.2022.107734