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# Inequality of carbon emissions between urban and rural residents in China and emission reduction strategies: evidence from Shandong Province

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China is actively heeding the call and striving for a low-carbon and environmentally friendly development route as part of the general trend toward a global low-carbon economy. The rapid economic development of our nation has brought to light the issue of carbon emissions resulting from the consumption habits of residents. This paper delves into the topic by conducting a thorough analysis of the carbon emission of residents' consumption using the input-output method. Based on the survey findings, the disparity in carbon emission between urban and rural communities in Shandong Province is evident not only in terms of total emissions but also in different categories and regions. Urban residents generate a total carbon emission of approximately 70.2921 million tons, which is three times higher than that of rural residents at 23.7846 million tons. The carbon emission of both urban and rural residents is primarily attributed to their embodied carbon emission. In examining the composition of the implied carbon emission of residents' consumption in Shandong Province, urban residents' carbon emission is concentrated in three areas, namely, food, culture, education, entertainment, transportation, and communication, accounting for 21.45%, 20.88%, and 15.10%, respectively. Conversely, rural residents' carbon emission is concentrated in four areas, including clothing, food, culture, education, entertainment, transportation, and communication, accounting for 29.01%, 17.45%, 15.43%, and 13.36%, respectively. Finally, according to the characteristics of the consumption carbon emission of urban and rural residents in Shandong Province, we give corresponding emission reduction strategies.

KEYWORDS

**consumption carbon emission, Shandong Province, input-output method, household consumption, urban and rural residents in China**

# 1 Introduction

As China becomes the world's second largest economy, the rise of consumerism and the pursuit of higher living standards have resulted in increased national energy consumption, which has had a significant impact on the environment. China has become one of the largest emitters of $CO_2$ and greenhouse gases globally (Feng Ling and Zhao, 2010; Dietz et al., 2009), with Chinese residents accounting for half of the total emissions (Xin et al., 2021). In response, the Chinese government proposed timeline for carbon neutrality and carbon peaking (dual carbon) on September 22, 2020. Rural areas in China play an important role in achieving the country's "dual carbon" goals. By 2035, China is expected to achieve agricultural and rural modernization, and by 2050, it will fully realize rural revitalization. It is noteworthy that household energy consumption in some developed countries remains higher than industrial energy consumption, making it an essential area for growth (Huijuan and Yong, 2012).

The term "carbon emission" pertains to the total $CO_2$ (or $CO_2$ equivalent emissions) that are released directly or indirectly during the entire lifecycle of a product or service or within a specific geographic region during the interaction process (Huijuan and Yong, 2012). This paper examines the carbon emission related to the greenhouse gases that are produced by residents in Shandong Province during their household consumption (Yusheng et al., 2016). When considering the individual units of households in the country, the total amount of $CO_2$ emissions is substantial. The carbon emission of residents' living consumption is composed of two parts: direct and implied carbon emissions. The direct carbon emission mainly comprises household activities such as travel, cooking, and heating. The implied carbon emission, however, consists mainly of the daily necessities of residents, including clothing, food, housing, and transportation. It is important to note that a significant amount of non-energy goods and services are consumed by residents in these activities, which inevitably results in energy consumption and carbon emissions (Kerkhof et al., 2009; Jansen, 2006). In daily life, the household's implied carbon emission emissions are generally greater than their direct carbon emission emissions (Shui and Dowlatabadi, 2005).

Currently, scholars have made significant progress in researching the carbon emission of residents' consumption. Firstly, scholars have multiple options when selecting survey subjects. In a study conducted on college students in Hebei Province, it was observed that the highest proportion of carbon emissions is from food and consumption, whereas living has the smallest proportion (Jiao et al., 2023). Another survey conducted on college students in Shandong Province revealed that issues such as high water and electricity consumption and excessive consumption of takeaway packaging are prevalent in universities, and students' "carbon neutrality" ideology cannot be overlooked (Ying et al., 2022). A study on the carbon emission of the tourism industry in Jiujiang City determined that transportation has the most significant carbon emission, followed by catering and accommodation, and finally tourism activities (Qunming and Ziqi, 2022). According to Kenny and Gray, who studied the carbon footprint of Irish households, trash disposal only makes up 2.1% of the carbon footprint. The highest amount of the carbon footprint, at 42.2%, is caused by direct energy usage, which is followed by transportation (at 35.1%) (Kenny and Gray, 2009). According to research performed by Bin, the majority of energy use and carbon emissions (80%) in the US are caused by household consumption and related economic activity (Shui and Dowlatabadi, 2005). According to Ramaswami et al., there has been a clear increase in locals' carbon emissions during the past few years (Ramaswami and Chavez, 2013). Secondly, scholars primarily focus on three methods for calculating the carbon emission, namely input-output analysis, life cycle assessment, and hybrid life cycle assessment. Using the life cycle assessment method, it was discovered that the larger the family size and income level of farmers in the Gannan Plateau, the more distant their location from the county town, and thus, the higher the carbon emission of the farmers. Furthermore, the higher the level of education, the higher the Engel coefficient of the household, and the higher the degree of non-agriculturalization, the lower the carbon emission of farmers (Fang et al., 2015). A study of the household carbon emission of British residents from 1990 to 2004 using QM-RIO (Quasi-Multi-Regional Input-Output) revealed that embodied carbon represented the largest proportion, while private cars and aviation accounted for the smallest (Druckman, 2010). In the study of the carbon emission of American households using the MRIO model, 13 categories of consumption were analyzed individually, including but not limited to diet, leisure and entertainment, and transportation. Results indicate that carbon emissions are positively correlated with income level and the advanced nature of consumption categories (Weber and Matthews, 2008). Meanwhile, when using the IPCC [The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change (IPCC OFFICIAL[EB/OL])] method to conduct research on carbon emissions in urban households in Kunming, energy carbon emissions were found to account for the highest percentage of the carbon emission structure (Qi et al., 2010). In contrast to Chinese domestic scholars, the foreign scholars have conducted more extensive research on the carbon emission of residents' consumption, examining national and local levels, emission characteristics, and influencing factors. The method of resident consumption carbon emission is relatively mature, primarily based on the input-output method (Input-Output Analysis) (Huijuan and Yong, 2012).

Based on the research of relevant domestic and foreign literature, this paper conducts a detailed study on the carbon emission characteristics of urban and rural residents by using the input-output method and taking Shandong Province as the research sample. Based on this research, we hope:

① It could clarify the carbon emission of residents in Shandong Province.

② It could provide values for the construction of energy conservation and emission reduction in other provinces.

③ It could provide reasonable policy recommendations for emission reduction for the government.

④ In addition, this paper presents the following innovations:

⑤ It distinguishes between direct carbon footprint and implied carbon footprint.

⑥ It compares the carbon footprints of urban and rural residents in Shandong Province, analyzing the differences.

Theoretical frame diagram of this article is shown in Figure 1.

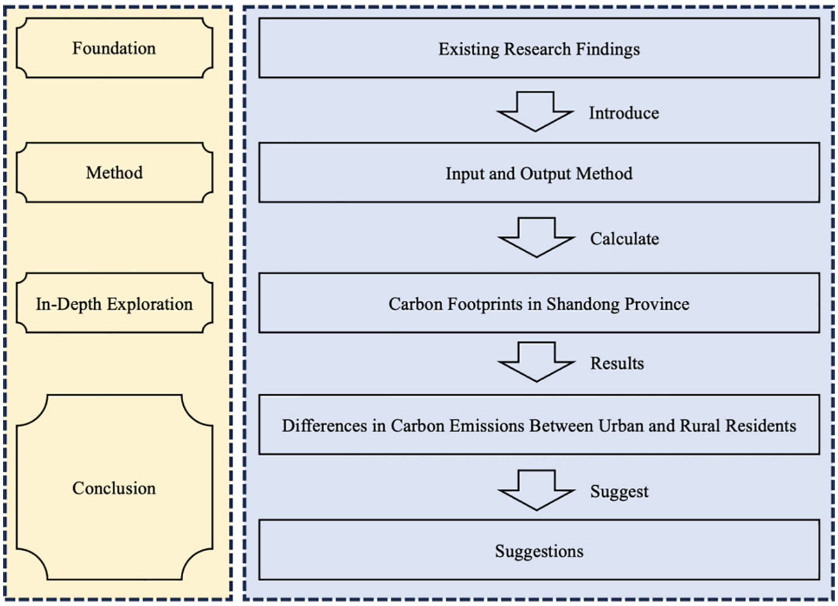


FIGURE 1
Theoretical frame diagram.

# 2 Methods and data

## 2.1 Data resource

This research paper employs the input-output method to calculate the implied carbon emission of residents' consumption in Shandong Province. As the input-output table serves as the basis for this method, it is imperative to utilize the most up-to-date version. According to the publication schedule, the input-output table is released annually when the unit digit falls on 2 and 7. The latest input-output table, "China Regional Input-Output Table-2017," was released by the National Bureau of Statistics. With respect to data sources, input-output-related data is derived from "Input-output Table of Shandong Province (2017)". Similarly, the data on direct energy consumption of residents stems from "Energy balance sheet of Shandong Province (2017)", while data on direct energy consumption by industry and consumption expenditure of residents of Shandong Province is obtained from "Statistical Yearbook of Shandong Province (Shandong Statistical Yearbook-2017[EB/OL])". Finally, the 2017 energy balance sheet of Shandong Province is sourced from "China Energy Statistical Yearbook (2018)".

## 2.2 Direct carbon emission

Residents of Shandong Province primarily consume Raw Coal, Gasoline, Liquefied Gas, Natural Gas, Heat, and Electricity, which together constitute six components of their daily energy usage (such as, heating, using machinery and equipment, cooking, and lighting). Of these, the carbon emissions attributable to electricity consumption are particularly complex due to the interdependence of electricity generation and the direct combustion of fossil fuels. Despite this complexity, electricity has been widely regarded as a major energy source (Larsen and Hertwich, 2009). While heat and electricity can be categorized as embodied emissions from a production and consumption standpoint, this paper examines them as direct sources of household carbon emission (Shui and Dowlatabadi, 2005; Wei et al., 2007; Spreng, 2002).

The direct carbon emission of Shandong Province's residents is typically calculated using the following formula (Equation 1) (Huijuan and Yong, 2012):

$$CF^d = \sum_{i=1}^{n} Mi \times EF_i \tag{1}$$

In the above formula, $CF^d$ indicates the direct carbon emission of residents in Shandong Province ($t$); $M_i$ indicates the consumption of the $i$ fuel ($t$); $EF_i$ is the $i$ fuel $CO_2$ emission factor ($tCO_2/t$ fuel). This study employs the $CO_2$ emission factor obtained by combining the IPCC method, the "Guidelines for the Accounting Method and Reporting of Greenhouse Emission Standards for Greenhouses in China (Trial)" issued by the National Development and Reform Commission, and existing scholarly research results (Huijuan and Yong, 2012; Quanyi and Taiping, 2023), while also referring to the calorific value and oxidation rate of China's current petroleum. The resulting $CO_2$ emission factors for direct energy consumption by Shandong Province's residents are presented in Table 1.

## 2.3 Implied carbon emission

The study employs the input-output methodology to estimate the inferred carbon emission resulting from the residents'

TABLE 1 $CO_2$ emission factors for direct residential energy consumption.

| | Raw Coal | Gasoline | Liquefied Gas | Natural Gas | Heat | Electricity |
|---|---|---|---|---|---|---|
| | (*t/t*) | (*t/t*) | (*t/t*) | (*t/million* $m^3$) | (*t/GJ*) | (*t/MWh*) |
| Emission Factor | 1.8160 | 3.0330 | 3.1300 | 24.3100 | 0.1100 | 0.9419 |

①The heat emission factor adheres to the standard set forth in the "Guidelines for Accounting and Reporting Greenhouse Gas Emissions of Coal Production Enterprises in China (Trial)" released by the National Development and Reform Commission of the People's Republic of China in 2014 (Notice of the General Office of the National Development and Reform Commission on Printing and Distributing the Second Batch of Greenhouse Gas Emission Accounting Methods and Reporting Guidelines for Enterprises in 4 Industries (Trial Implementation)[EB/OL]).
②The electricity emission factor aligns with the marginal emission factor of the North China Power Grid as outlined in the "2019 Emission Reduction Project China Regional Power Grid Baseline Emission Factor" (Baseline Emission Factors of CHINA's Regional Power Grids for Emission Reduction Projects in 2019[EB/OL]).

consumption patterns in Shandong Province. The computation involves the use of the following formula (Huijuan and Yong, 2012):

$$CF^e = \widehat{F} \times E_j = \widehat{F} \times D_j \times (I - A)^{-1} \qquad (2)$$

In Equation 2, the implied carbon emission ($t$) of residents' consumption in Shandong Province is represented by $CF^e$; $F$ represents other items (capital formation, exports, etc.) included in the final consumption or final use of residents in Shandong Province. $\hat{F}$ is the diagonal matrix of $F$; $E_j$ and $D_j$ represent the implied and direct carbon emission intensity of sector j's energy consumption ($t$/miilion RMB, respectively). This value is the ratio of $CO_2$ emissions from energy consumption in the industry to the total output value of the industry. A represents the direct consumption coefficient matrix in the input-output table; $I$ is the identity matrix with the same order as $A$.

To enhance the standardization of the thesis argument and improve the comparability of the results, a one-to-one correspondence is established between the section of the input-output table and the industry's energy consumption sector. Thus, the industrial sector in this study is divided into 41 sectors, and the implied $CO_2$ emission intensity of specific sectors is presented in Table 2 (Huijuan and Yong, 2012). It is important to note that due to the unavailability of data on energy consumption from various sources in different industries, the total energy consumption of each industry (in standard coal) is employed for the computation, and the standard coal $CO_2$ emission factor is 2.277 $CO_2/tce$ (Hongmin, 2009).

## 2.4 Implied carbon emissions under different consumption categories

By utilizing the classification method outlined in the National Statistical Yearbook, the consumption habits of individuals can be categorized into eight distinct groups, including Food, Clothing, Supplies and Services, Medical Care, Transport and Communications, Recreation Education and Cultural, Residence, and Others. In accordance with Equation 2, it is possible to calculate the corresponding carbon emission emissions for each of these consumption categories. The implied carbon emissions of different industries are shown in Table 3 (Quanyi and Taiping, 2023).

The present study has conducted an estimation of the energy consumption in Shandong Province with regard to residential raw coal, gasoline, natural gas, liquefied gas, and other energy sources. Consequently, the calculation of the implied carbon emission has been adjusted by removing the household fuel expenditures from the residential consumption expenditures, and by excluding the transportation fuel consumption from the transportation and communication expenditures.

# 3 Results and analysis

## 3.1 Direct carbon emission

The direct carbon emission of residents' consumption in Shandong Province is shown in Figure 2. The energy and consumption patterns of the residents in this area primarily rely on raw coal, gasoline, liquefied gas, natural gas, heat, and electricity. The carbon emission resulting from the direct consumption of urban residents living in Shandong Province is approximately 2995 million tons, whereas the direct carbon emission of rural residents is measured at 833 million tons. The analysis of the data suggests that the carbon emission of urban residents is primarily caused by heat and gasoline, accounting for 41.32% and 39.79% of the total carbon emission, respectively. In contrast, the carbon emission of rural residents in Shandong Province is mainly attributed to raw coal and gasoline, which together account for 32.66% and 42.49% of the total carbon emission, respectively.

The primary objective of the analysis lies in the fact that unlike their rural counterparts, urban inhabitants are unable to utilize raw coal for winter heating purposes. Instead, municipal heating systems serve as the primary source of warmth. The major proportion of this heating is provided directly by thermal power plants. Moreover, the standard of living of urban residents is higher than that of rural residents. With a per capita disposable income of 36,789 RMB (Residential Income and Consumption Expenditure in 2022[EB/OL]), urban dwellers tend to purchase more private automobiles than their rural counterparts, leading to increased gasoline consumption. In contrast, in Shandong Province, rural residents continue to rely on individual coal-burning for winter heating, especially in those areas that have not undergone modernization. As a result, the consumption of raw coal in rural areas remains substantial. Additionally, with the advent of large-scale agricultural production and mechanized operations, farmers rely heavily on agricultural machinery for crop cultivation and harvesting, fueled mainly by gasoline. Therefore, gasoline consumption in Shandong Province's rural population accounts for a significant proportion.

TABLE 2 Implied $CO_2$ emission intensity of specific sectors.

| Sector | Implied $CO_2$ Emission Intensity (*t/ Million RMB*) | Sector | Implied $CO_2$ Emission Intensity (*t/ Million RMB*) |
|---|---|---|---|
| 1. Agriculture, Forestry, Animal Husbandry and Fishery | 2.4050 | 22. Waste | 3.1662 |
| 2. Mining and Washing of Coal | 2.1052 | 23. Production and Supply of Electric Power and Heat Power | 2.1696 |
| 3. Extraction of Petroleum and Natural gas | 1.3207 | 24. Production and Supply of Gas | 0.7619 |
| 4. Mining Metal Ores | 3.7215 | 25. Production and Supply of Water | 2.9957 |
| 5. Mining and Processing of Nonmetal Ore and Other Ores | 9.7227 | 26. Construction Enterprises | 4.0454 |
| 6. Manufacture of Foods and Processing of Tobacco | 2.3030 | 27. Transport, Storage and Postal Services | 3.5686 |
| 7. Manufacture of Textile | 1.9408 | 28. Information Transmission, Software and Information Technology Services | 1.1227 |
| 8. Manufacture of Textile Wearing Apparel, leather, Fur, Feather & Its Products | 1.5522 | 29. Wholesale and Retail | 1.1265 |
| 9. Processing of Timbers and Manufacture of Furniture | 2.9276 | 30. Hotels and Catering Services | 1.9586 |
| 10. Manufacture of Paper, Culture, Education, Arts and crafts, Sport and Entertainment Goods | 2.3247 | 31. Banking | 0.6303 |
| 11. Processing of Petroleum, Coking and Nuclear Fuel | 6.6602 | 32. Real Estate | 1.1725 |
| 12. Chemical Industry | 2.5552 | 33. Leasing and Business Services | 1.5783 |
| 13. Manufacture of Non-Metallic Mineral Products | 6.6249 | 34. Research and Experimental Development | 2.1888 |
| 14. Processing of Metal Smelting and Rolling | 7.1454 | 35. Comprehensive Technical Service | 1.7030 |
| 15. Manufacture of Metal Products | 4.9425 | 36. Management of Water Conservancy, Environment and Public Facilities | 2.3779 |
| 16. Manufacture of General and Special Purpose Machinery | 2.7419 | 37. Households' Service, Repair and Other Services | 2.3273 |
| 17. Manufacture of Transportation Equipment | 2.2711 | 38. Education | 1.8339 |
| 18. Manufacture of Electrical Machinery & Equipment | 2.7258 | 39. Health, Social Security and Social Welfare | 1.8865 |
| 19. Manufacture of Communications Computer, and Other Electronic Equipment | 1.8229 | 40. Culture, Sports and Entertainment | 1.4727 |
| 20. Manufacture of Measuring Instrument and Cultural Office Supplies Machinery | 1.7882 | 41. Public Management and Social Organization | 1.4434 |
| 21. Manufacture of Handicrafts and Other Products | 4.7314 | | |

*(Continued)*

TABLE 2 Continued

## 3.2 Implied carbon emission

Table 4 and Figure 3 display the composition of the implied carbon emission of the consumption patterns of inhabitants in Shandong Province in 2017. The aggregate carbon emission of the living consumption of Shandong Province's residents in that year amounted to 5580.05 million tons. Of this total, the implied carbon emission of urban denizens in the aforementioned province was 4034.43 million tons, while the implied carbon emission of their rural counterparts was merely 1545.62 million tons. Remarkably, the implied carbon emission of urban residents' consumption was around twice that of their rural peers. This is noteworthy given that the urban population in Shandong Province is more than twice that of the rural population (Shandong Statistical Yearbook-2017[EB/OL]). In sum, the numerical outcomes of both measurements are essentially identical.

In terms of the carbon emission of residents' consumption, the consumption patterns of households in urban and rural regions of Shandong Province exhibit notable differences. Specifically, urban residents tend to concentrate their consumption on categories such as food and residence, while rural residents exhibit a substantial variation in their consumption categories. The "Others" category, for example, is the least expensive category, while "Clothing" represents the largest category, with a difference of 435.55 million

TABLE 3 Implied carbon emissions of different industries.

| Consumption Categories | Industry | Implied Carbon Intensity (Million t/100 Million RMB) |
|---|---|---|
| 1. Food | Manufacture of Foods and Processing of Tobacco | 0.231 |
| 2. Clothing | Manufacture of Textile Wearing Apparel, leather, Fur, Feather & Its Products | 0.384 |
| 3. Supplies and Services | Processing of Timbers and Manufacture of Furniture + Manufacture of Electrical Machinery & Equipment | 0.276 |
| 4. Medical Care | Health, Social Security and Social Welfare | 0.387 |
| 5. Transport and Communications | Manufacture of Transportation Equipment + Manufacture of Communications Computer, and Other Electronic Equipment + Transport, Storage and Postal Services + Information Transmission, Software and Information Technology Services | 0.306 |
| 6. Recreation Education and Cultural | Manufacture of Paper, Culture, Education, Arts and crafts, Sport and Entertainment Goods + Education + Culture, Sports and Entertainment | 0.530 |
| 7. Residence | Construction Enterprises + Manufacture of Non-Metallic Mineral Products + Manufacture of Metal Products + Leasing and Business Services | 0.157 |
| 8. Others | Wholesale and Retail + Hotels and Catering Services + Households' Service, Repair and Other Services | 0.214 |

tons. Conversely, the differences among other items are not significant. For rural residents, consumption is primarily focused on four aspects: clothing, food, recreation education and cultural, transport and communications, which account for 29.01%, 17.45%, 15.43%, and 13.36%, respectively. In contrast, urban residents' carbon emission of consumption is mainly concentrated in food, recreation education and cultural, and transport and communications, accounting for 21.45%, 20.88%, and 15.10%, respectively. Clothing, residence, and medical care are relatively similar, at around 15%.

## 3.3 Total carbon emission

Table 5 presents the carbon emission of living consumption by residents of Shandong Province in 2017. The total carbon emission was calculated to be 9407.67 million tons, comprising of both direct and implied carbon emission that accounted for 40.69% and 59.31%, respectively. The analysis also shows that the consumption carbon emissions of urban and rural residents of Shandong Province were 7029.21 million tons and 2378.46 million tons, respectively, with urban residents accounting for 74.72% and rural residents accounting for 25.28%. The findings suggest that the major focus for reduction of carbon emissions and potential for improvement of residents' life and consumption carbon emissions in Shandong Province lies in the embodied carbon emissions of urban residents.

Regarding per capita carbon emission, the direct and implied carbon emissions of rural inhabitants in Shandong Province are notably lower than those of their urban counterparts. Specifically, the per capita direct carbon emission and implied carbon emission of rural residents are 0.21*t*/person and 0.39*t*/person, respectively, whereas urban residents have per capita direct and implied carbon emissions of 0.49*t*/person and 0.67*t*/person, respectively. In terms of per capita total carbon emission, urban inhabitants of Shandong Province have a carbon emission that is 0.56*t*/person higher than that of rural inhabitants, which corroborates previous research by Huijuan Dong (Huijuan and Yong, 2012), Wei (Wei et al., 2007), and others. These findings suggest that the per capita carbon emission of rural and urban inhabitants in Shandong Province is attributable to implied carbon emissions resulting from consumption of food, recreation education and cultural, transport and communications, clothing, and others. Therefore, there is little difference in the carbon emission of living consumption between rural and urban inhabitants in Shandong Province. Consequently, the focus of emission reduction regarding the carbon emission of life consumption of rural and urban inhabitants in Shandong Province should differ.

## 3.4 Spatial variation of per capita carbon emission

Based on the Statistical Yearbook (Shandong Province Statistical Yearbook-Division of Administrative Area (Year-end of 2017)[EB/OL]) and administrative divisions (which conform with the 2017 government divisions), Shandong Province comprises of 17 prefecture-level cities, including Jinan City, Qingdao City, Zibo City, Zaozhuang City, Dongying City, Weihai City, Jining City, and Weifang City. In light of the research findings presented in this study, it has been observed that the embodied carbon emission of urban and rural residents in Shandong Province constitutes a significant proportion. Hence, this section focuses on maximizing the efficiency of energy conservation and emission reduction by primarily examining the per capita embodied carbon emissions of various prefecture-level cities.

Figure 4 displays the per capita implied carbon emission of urban inhabitants in Shandong Province for the year 2017. ①The concentration of the carbon emission in terms of food is observed to be around 0.20*t* for Qingdao, Yantai, Weihai, and Jinan, whereas Linyi City, Dezhou City, Liaocheng City, Heze City, Tai'an City, Laiwu City, Zaozhuang City, and Weifang City exhibit concentration around 0.10*t*. Overall, the distribution is relatively concentrated. ②Similarly, the per capita carbon emission for clothing is maximum for Qingdao (0.12*t*) and minimum for Heze City (0.04*t*). ③Furthermore, in terms of residence, Yantai, Qingdao,

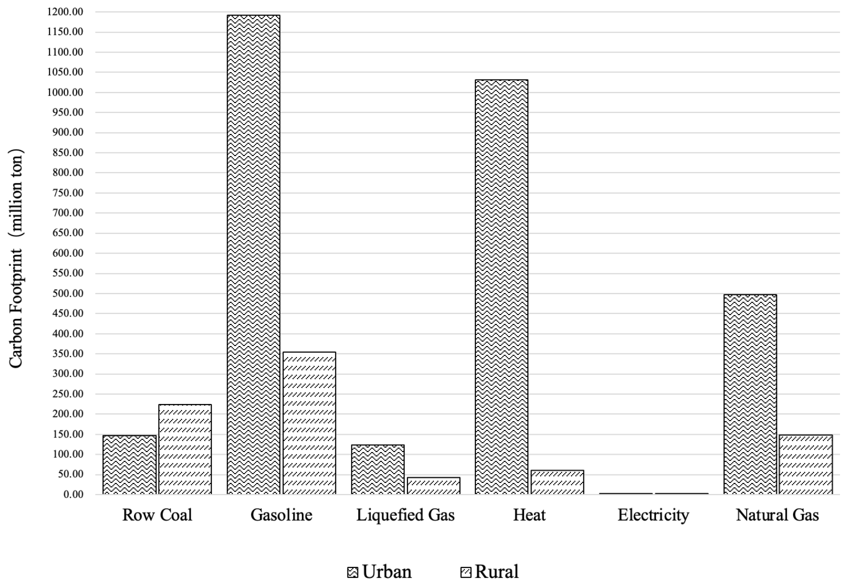


FIGURE 2
Direct carbon emission of residents' consumption in Shandong Province in 2017.

and Jinan exhibit a carbon emission of 0.10*t* or more per capita, whereas the remaining cities are below 0.10*t*, with the least carbon emission being observed for Liaocheng City, Linyi City, and Rizhao City (all 0.05*t*). ④The maximum and minimum per capita carbon emission for supplies and services are observed in Jinan (0.07*t*) and Liaocheng and Dezhou (both 0.02*t*), respectively, while the rest of the cities are around 0.05*t*. ⑤The per capita carbon emission of 8 cities (Zibo, Yantai, Jinan, Rizhao, Qingdao, Weihai, Weifang, and Dongying) in Shandong Province exceeds 0.10*t*, while Heze City has the lowest carbon emission of only 0.05*t*. ⑥Zibo City has the largest carbon emissions (0.17*t*) in terms of recreation education and cultural, while Dezhou City has the smallest carbon emissions, with a difference of approximately 0.1*t* between the two. The classification of this category includes 12 cities (Zaozhuang City, Jining City, Yantai City, Laiwu City, Tai'an City, Binzhou City, Weihai City, Weifang City, Qingdao City, Dongying City, Jinan City, and Zibo City). ⑦Weihai City has the largest carbon emission in terms of medical care, with three times more carbon than Linyi City, which has the least carbon emission; the rest of the cities have approximately 0.8*t*. ⑧Others show little difference among all cities and towns in Shandong Province, with an average of about 0.01*t*.

TABLE 4 Implied carbon emission of residents' consumption in Shandong Province.

| Consumption Categories | Urban (million *t*) | Rural (million *t*) |
|---|---|---|
| 1.Food | 865.28 | 269.73 |
| 2.Clothing | 473.35 | 448.39 |
| 3.Supplies and Services | 290.51 | 75.14 |
| 4.Medical Care | 417.70 | 172.38 |
| 5.Transport and Communications | 609.20 | 206.44 |
| 6.Recreation Education and Cultural | 842.51 | 238.50 |
| 7.Residence | 465.82 | 122.21 |
| 8.Others | 70.07 | 12.84 |
| Total | 4034.43 | 1545.62 |

Figure 5 illustrates the per capita implied carbon emission of rural residents in Shandong Province in 2017. ①The distribution of carbon emissions across cities is concentrated for food, with Yantai City having the highest value (0.108*t*) and Linyi City having the lowest (0.054*t*). ②Clothing, Weihai City has the highest carbon emission (0.040*t*) while Linyi City has the lowest (0.018*t*). ③For residence, the carbon emission does not vary significantly across cities, except for Dezhou City with a value above 0.05*t*. ④In terms of transport and communications, Dongying City has the highest value while the remaining cities are relatively similar. ⑤In the recreation education and cultural, Dongying City and Zibo City have the highest values (close to 0.1*t*), while the rest of the cities are around 0.05*t*. ⑥Medical care has a carbon emission of approximately 0.03*t*, while the carbon emission of other supplies and services is the lowest among all items, with little variation across urban and rural areas in Shandong Province, all of which are approximately 0.01*t*.

## 4 Discussion

It is imperative that the global community prioritize carbon emission reduction and address the issue of climate warming. The rise in global temperature has become a significant concern in human history with the average global temperature having increased by 0.48°

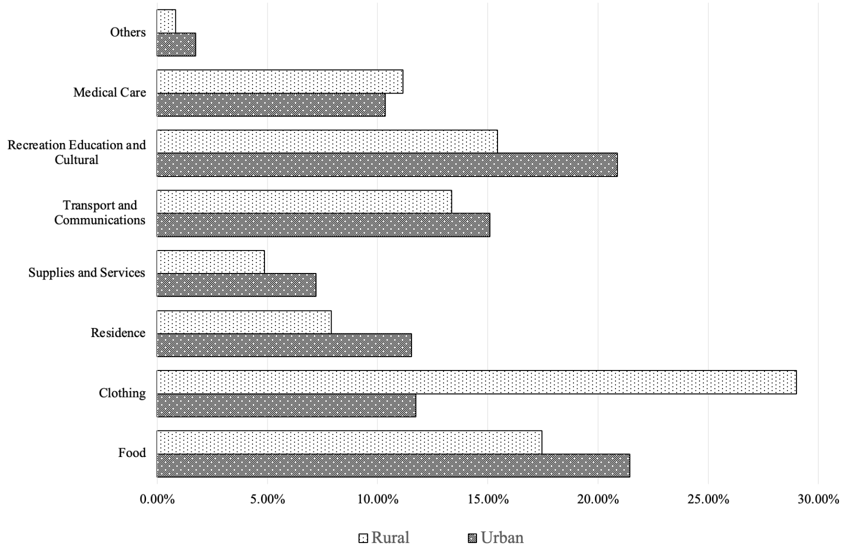


FIGURE 3
The composition of the implied carbon emission of residents' consumption in Shandong Province.

C from 1981 to 1990 compared to that of 100 years prior (Jie and Lian, 2013). It is predicted that the global average temperature will rise by 0.3-0.7°C in the next 20 years as compared to the period of 2001-2020 (Xiaojian et al., 2023). Despite a 3.1% growth in the global economy in 2016, greenhouse gas emissions reached an alarming 32.1 billion tons, which is attributed to the rampant and unchecked use of fossil fuels such as crude oil and coal that has resulted in the release of large amounts of greenhouse gases like $CO_2$ (Yu, 2022). In the 20th century, the average global temperature increased by about 0.6°C and the spring thaw period in the Northern Hemisphere is now observed to occur nine days earlier than it did 150 years ago. The United Nations developed the "United Nations Framework Convention on Climate Change" in 1992 to curb the acceleration of global warming. This Convention was signed and entered into force in Rio de Janeiro, Brazil in the same year, with developed countries agreeing to reduce their greenhouse gas emissions to the 1990 level before 2000. Additionally, countries responsible for 60% of global $CO_2$ emissions have committed to transferring relevant information and technologies to developing countries (What is the United Nations Framework Convention on Climate Change?). Furthermore, climate warming is expected to have a significant impact on human health. First, the impact of heat waves is a significant factor affecting human health before and after global warming. The rise in temperature stimulates the activity of parasites, viruses, and germs, which can attack human immunity and cause low immunity. Second, Climate warming can also increase the speed of photochemical reactions between chemical pollutants in the atmosphere. This can lead to the development of diseases such as acute upper respiratory infections and chronic bronchitis. Although an appropriate amount of ultraviolet rays can enhance human immunity by killing viruses and bacteria, excessive amounts can endanger human health. Research shows that a 1% reduction in ozone may increase the prevalence of skin cancer in Caucasians by about 3% due to the increased UV-B (Climate Warming and Human Health[EB/OL]). Third, Climate warming can cause ancient viruses frozen in permafrost or glaciers to overflow (Scientists warn: Warming climate may cause Arctic virus spillover risk[EB/OL]). The impact of climate warming on animals and plants cannot be ignored (Xiuxiu et al., 2017). Temperature rise can alter the yield and proportion of litter components in evergreen broad-leaved forests, as well as change the rhythm of litter fall. Rising sea temperatures can cause coral bleaching and inhibit coral self-repair (Xiaojian et al., 2023). If the emission of greenhouse gases is not controlled, a large number of coral reefs will be devastated by the end of the 21st century (Yanda and Liang, 2021).

It is necessary for China to respond to the national call and steadily achieve the dual carbon targets. First of all, as a major carbon emitter globally, China faces a severe challenge in reducing its carbon emissions. In 2016, the total carbon emissions of China amounted to 10 billion tons, representing approximately 30% of the

TABLE 5 Carbon emission of residents' consumption in Shandong Province.

| | Carbon emission (*million ton*) | | | Per Capita carbon emission (*t/person*) | | |
|---|---|---|---|---|---|---|
| | Direct | Implied | Total | Direct | Implied | Total |
| Rural | 832.84 | 1545.62 | 2378.46 | 0.21 | 0.39 | 0.60 |
| Urban | 2994.78 | 4034.43 | 7029.21 | 0.49 | 0.67 | 1.16 |
| Total | 3827.62 | 5580.05 | 9407.67 | – | – | – |

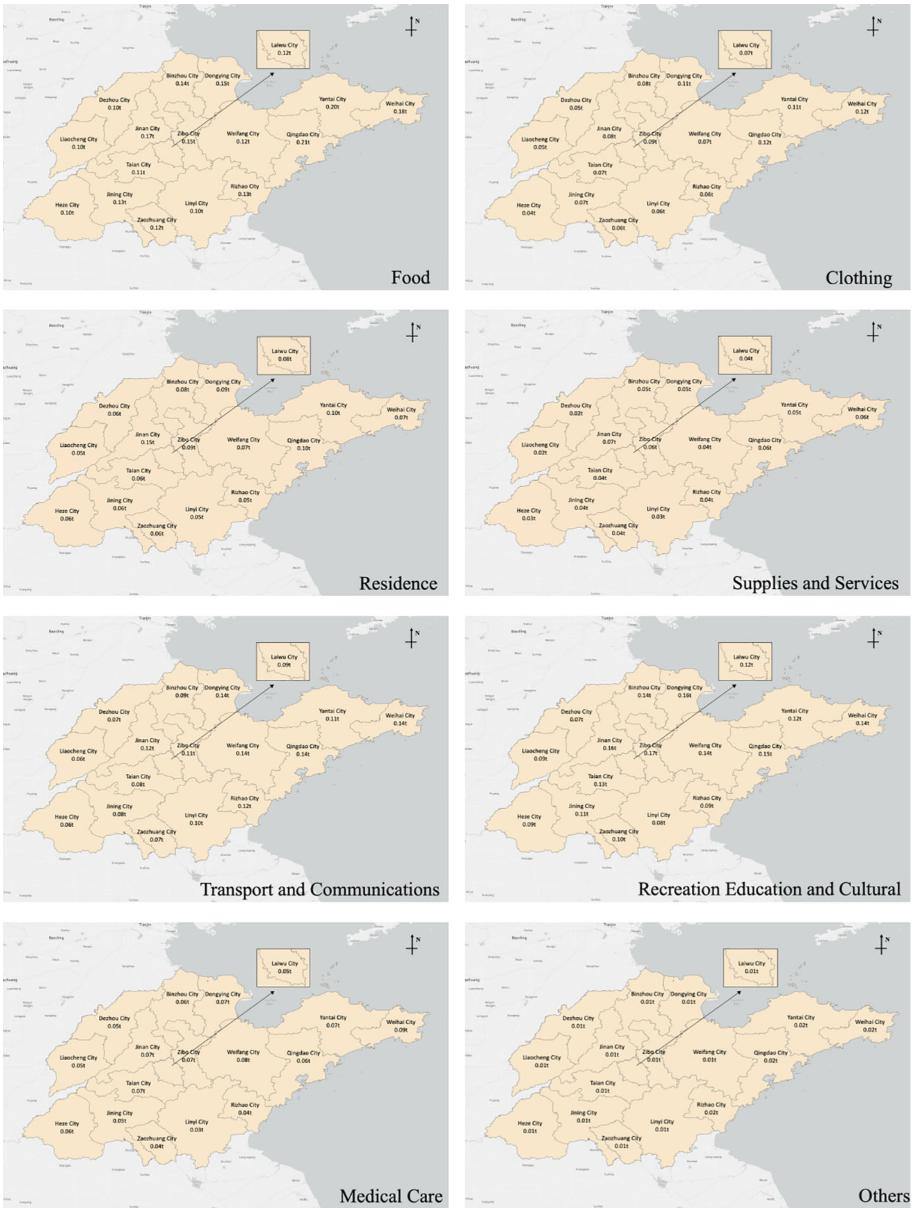


FIGURE 4
Per capita implied carbon emission of urban inhabitants in Shandong Province.

world's carbon emissions. This figure exceeds the combined carbon emissions of Europe and the United States, making China the largest carbon emitter worldwide, with an annual growth rate of 6% to 9% (Yu, 2022). In 2019, China's $CO_2$ emissions accounted for 28% of global carbon emissions, reaching 10.5 billion metric tons. To further define greenhouse gases, China released the "Second Biennial Update Report on Climate Change of the People's Republic of China" in July of the same year (Lu, 2022). However, China is still undergoing industrialization and urbanization, resulting in a high energy intensity in its economic structure, with fossil energy accounting for over 80%. This makes China's energy transformation task even more challenging compared to developed countries in Europe and the United States, where the service industry contributes to approximately 80% of GDP (Min et al., 2023). Second, China must fulfill its obligations to reduce greenhouse gas emissions and demonstrate its responsibility as a major country. The Copenhagen Conference, the Cancun Conference, and the South Africa Conference were held in 2009, 2010, and 2011 respectively, in response to climate change (Yu, 2022). Additionally, the Paris World Climate Conference and the United Nations Climate Change Conference are scheduled for 2015, 2019, and 2021 respectively, which highlights the urgency and necessity of energy conservation and emission reduction. Thirty-three countries, including Russia, Germany, and France, had already reached their carbon dioxide peaks in 2000. Eight countries, including Sweden and Iceland, are expected to achieve their carbon neutrality goals by 2050. In 2020, President Xi Jinping announced at the general debate of the 75th session of the United

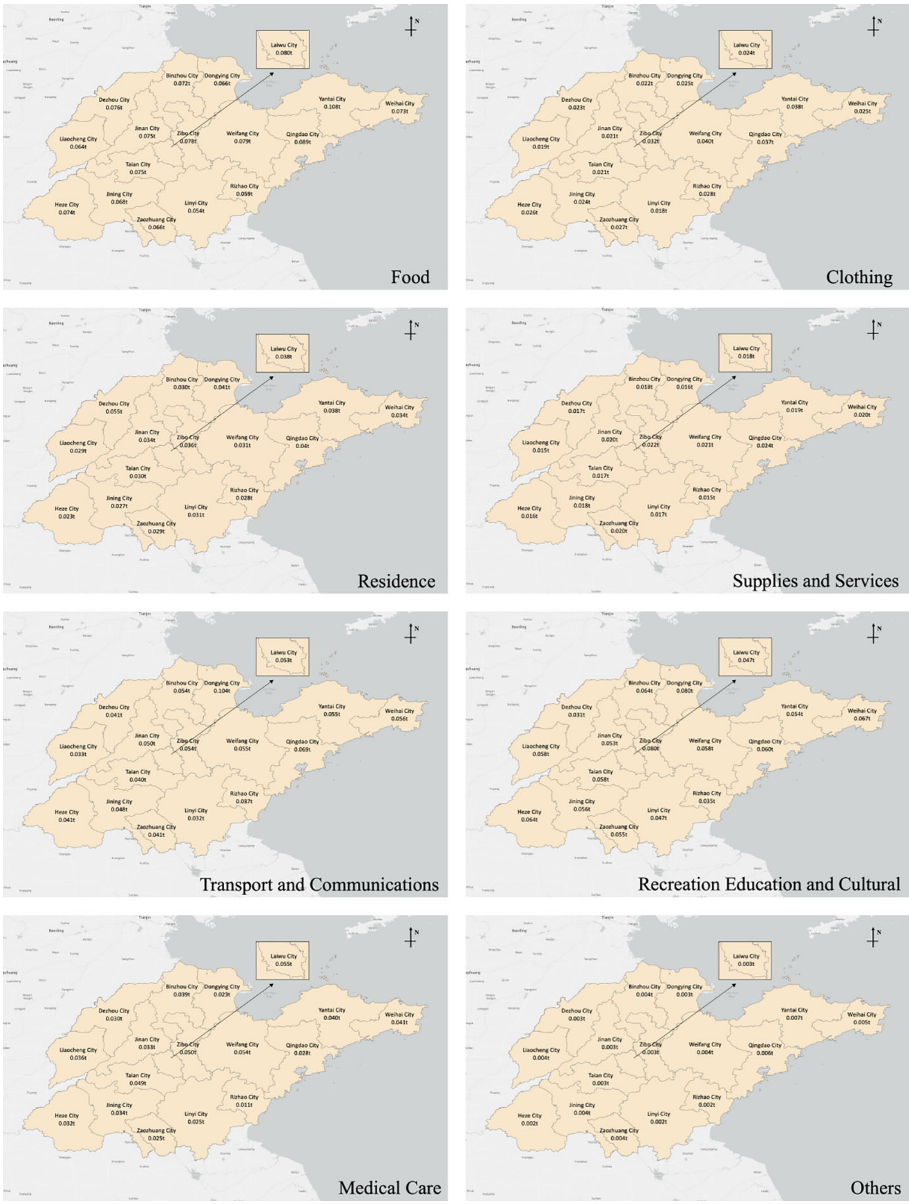


FIGURE 5
Per capita implied carbon emission of rural inhabitants in Shandong Province.

Nations General Assembly that China will work to achieve its peak carbon dioxide emissions by 2030 and carbon neutrality by 2060 (Speech by Xi Jinping at the General Debate of the 75th Session of the United Nations General Assembly (full text)[EB/OL]). Finally, the proposal of China's dual carbon targets has brought new vitality to global climate governance and presents an opportunity for China to firmly establish its position in the field. The right to speak in global climate governance has become a focal point for sovereign states worldwide, and China must construct a governance framework with Chinese characteristics to take a more proactive role in climate negotiations.

To ensure that the research is ongoing, we focus on the most recent data available as of 2017 via statistical yearbooks, statistical bulletins, etc., including the urban and rural population, per capita disposable income of urban and rural residents, the level of urbanization development, etc., covered in this article index. At the same time, we also pay attention to the policies on energy saving and pollution reduction issued by the Chinese government as well as the specific actions announced by local governments, because some government-mandated policies could somewhat affect the findings of our research. This is consistent with the research results of Zhao Kuokuo et al. They showed that "population is still a significant factor affecting Shandong Province's carbon emissions" and discovered "the ability to change regional development to a low-carbon model through actions including slowing the urbanization process, expediting industrial structure transformation, and energy adjustment" (Kuokuo, 2022).

## 5 Recommendations

Based on the above understanding, in view of the different characteristics of the consumption carbon emission of urban and rural residents in Shandong Province, we put forward different emission reduction strategies for the consumption of urban and rural residents.

The emission reduction strategies for urban residents to consume carbon emissions. First, changes in resident status will increase urban carbon emissions. Shandong Province has a large population of urban residents, and its per capita carbon emission is higher than that of rural residents. As China's urbanization continues to accelerate, more and more rural residents will become urban residents. The carbon emission of urban residents will increase due to changes in resident status. After rural residents become urban residents, the carbon emissions generated by the consumption of urban residents in Shandong Province will also increase accordingly. Second, for Shandong Province, the carbon emission of urban residents' consumption is the focus of emission reduction. The carbon emission of urban residents' living consumption in Shandong Province is mainly due to the implicit carbon emission generated by the consumption of non-energy products and services. However, the main sources of these products and services are three major industries, of which industry accounts for the larger part. Third, Based on this, we put forward corresponding policy suggestions. ① Adjusting the industrial and energy structure of Shandong Province and improving energy utilization can reduce emissions to a certain extent. For example, focus on the development of informatization and drive industry through information. While ensuring economic benefits, look for development paths with less environmental pollution and low resource consumption. The ultimate goal is to promote the development and transformation of the economic growth mode in the province. ② Vigorously publicize and guide healthy consumption patterns of residents. For example, optimize the urban bus network and expand the coverage of public transport. The government can attract investment and cooperate with shared bicycle companies to increase the distribution points and overall number of shared bicycles, and try its best to solve the problem of the last mile of residents' lives.

Finally, we summarize the key points for controlling urban carbon emissions. That is:

① Restructuring the industrial and energy system.
② Improving energy utilization.
③ Promote the development and transformation of the economic growth mode.
④ Vigorously publicize and guide healthy consumption patterns of residents.

The emission reduction strategies for rural residents to consume carbon emissions. First of all, the carbon emission of rural residents in Shandong Province is mainly caused by direct energy consumption, especially coal and gasoline consumption. The main uses of coal and gasoline are heating, cooking and machine work. On the one hand, for the rural areas of Shandong Province, carbon emission reduction in rural areas should focus on adjusting the energy consumption structure of residents. For example, advocate and encourage rural residents to use low-carbon, environmentally friendly and efficient electricity and liquefied petroleum gas instead of coal for living and cooking. At the same time, purchase discounts can be implemented for the above-mentioned energy within a reasonable range to increase the attractiveness of consumption. Relevant supporting policies and preferential policies can also be introduced to promote the popularization of rural biogas. Central heating, on the other hand, is more efficient than coal heating in individual homes. However, in the actual rural environment in China, different households are far apart, living in scattered places, and the infrastructure in rural areas is not as good as that in urban areas. Therefore, it is also possible to increase scientific and technological investment and support and develop heating technologies that are in line with rural conditions. Finally, new energy technologies can be widely used in rural areas. Part of the agricultural machinery can be optimized to realize the source of gasoline-electric hybrid power. The main source of electric energy is solar energy. When the sunlight is not enough to support the operation of agricultural machinery, oil can be used as supplementary power.

Finally, we summarize the key points for controlling rural carbon emissions. That is:

① Adjusting the energy consumption structure.
② Purchase discounts on main energy could be introduced.
③ Increase scientific and technological investment.
④ New energy technologies could be widely spread.

## 6 Conclusions

The primary objective of this study is to examine the carbon emission associated with the living consumption patterns of urban and rural residents in Shandong Province during 2017, utilizing the input-output methodology.

Urban residents generate a total carbon emission of approximately 70.2921 million tons, which is three times higher than that of rural residents at 23.7846 million tons. The carbon emission in Shandong Province is mainly attributed to embodied carbon emission. The population, level of urbanization, and income of inhabitants in Shandong Province in 2017 all had a significant impact on both urban and rural residents' carbon emissions. First, population. In 2017, there were 6,099 urban residents and 3,934 rural residents in Shandong. The urban population was 2,165 more than the rural population. The population bases of urban and rural areas are very dissimilar, which causes significant variations in carbon emissions. Second, level of urbanization. The level of urbanization in Shandong province continued to advance in 2017, with the permanent population's urbanization rate rising to 60.58%

from the end of 2016 by 1.56 percentage points. The transition from rural to urban living has resulted in a rise in urban population, which ultimately affects the measurement of carbon emissions. Third, income of inhabitants. Shandong Province's urban people had a per capita disposable income of 36,789 yuan in 2017, while rural residents had a per capita disposable income of 15,118 yuan. Because urban residents have a strong purchasing power than rural residents due to having a per capita disposable income that is 21,671 yuan more, urban residents will generate more carbon emissions than rural residents. For both rural residents and urban residents, an increase in income level will lead to an increase in consumption carbon footprint.

The carbon emission of both urban and rural residents is primarily attributed to their embodied carbon emission. In examining the composition of the implied carbon emission of residents' consumption in Shandong Province, urban residents' carbon emission is concentrated in three areas, namely, food, culture, education, entertainment, transportation, and communication, accounting for 21.45%, 20.88%, and 15.10%, respectively. Conversely, rural residents' carbon emission is concentrated in four areas, including clothing, food, culture, education, entertainment, transportation, and communication, accounting for 29.01%, 17.45%, 15.43%, and 13.36%, respectively. Food consumption is the primary consumption category for urban residents.

Finally, we summarize the conclusions. That is:

① Disparity in carbon emission between urban and rural communities in Shandong Province is evident (Urban emissions = 70.2921 million tons, three times higher than rural emissions).

② Disparity in carbon emission between urban and rural communities in Shandong Province is evident in different categories and regions (Both urban and rural carbon emissions are mainly tied to embodied emissions, with urban residents primarily emitting through food consumption).

This investigation, however, is not exempt from limitations. Firstly, the scope of this study is confined to the carbon emission data of Shandong Province. The constraints of funding and manpower along with the cultural and behavioral disparities in certain regions can potentially impose certain limitations on the dissertation. To address this, it is recommended that comparative research be carried out by collecting data from other provinces based on this study. Secondly, the underlying reasons responsible for the variations observed in embodied carbon emissions warrant further investigation. For instance, the distinctions between several sub-categories of urban and rural residents within the same category could be evaluated in the analysis of implied carbon emissions. The follow-up research can delve into more detailed exploration from diverse perspectives. Lastly, the family size of residents, population density, and age composition in Shandong Province can also influence the carbon emission of inhabitants, which is not explored in this article. Further research can be conducted to examine the impact of residents' carbon emissions by incorporating relevant data, thereby enriching the research findings in this field. Third, while this paper has derived research outcomes, further investigation is required to provide support, thereby enhancing the reliability and interpretability of the results. Possible directions for future research include expanding the sample size, collecting additional data, and employing alternative analytical methods to validate and deepen the findings.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary files, further inquiries can be directed to the corresponding author/s.

## Author contributions

QW: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing. RY: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. YZ: Resources, Visualization, Writing – review & editing. YLY: Resources, Validation, Writing – review & editing. AH: Writing – review & editing. YSY: Writing – review & editing. YL: Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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