Journal of Education and Educational Research
ISSN: 2957-9465 | Vol. 11, No. 3, 2024

Carbon Emissions from Northern Households based on the Emission Factor Method Impact Factor Studies

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Abstract: With the improvement of living standards, household carbon emissions have exhibited a significant upward trend. In northern regions, the substantial influence of seasonal heating demand results in higher energy consumption and carbon emission levels among households. However, micro-level studies examining the characteristics of per-household carbon emissions and their influencing factors in these areas remain scarce and limited. Consequently, there is an urgent need for more comprehensive research to provide a theoretical foundation for formulating precise carbon emission reduction policies and strategies. this study employs the emission coefficient method to quantify the carbon emissions resulting from energy consumption by urban and rural households in northern regions. The findings indicate that electricity consumption and transportation-related travel are prominent sources of carbon emissions among northern households; additionally, the use of natural gas, liquefied petroleum gas, and other energy sources also contributes significantly to overall emissions. Notably, coal-fired heating has a particularly pronounced impact on household carbon emissions during winter months.

Keywords: Emission Factor Approach; Urban and Rural Households; Household Carbon Emissions; Energy Consumption.

1. Introduction

Carbon emissions have emerged as a critical concern for governments and the global community, particularly in light of the escalating issue of climate change. In response to this pressing challenge, China has committed to achieving a reduction in carbon emission intensity ranging from 60% to 65% by the year 2030, relative to levels recorded in 2005[1]. This commitment imposes significant pressure and presents considerable challenges for China in its endeavors to reduce carbon emissions. Research indicates that domestic living has emerged as a major source of carbon emissions, with household consumption contributing approximately 40% of China's total carbon output. Furthermore, family life is identified as a key factor driving the increase in these emissions. The report underscores that household consumption accounts for nearly 40% of China's overall carbon emissions [2], underscoring the importance of examining the internal mechanisms behind household carbon emissions from a familial perspective. [3] Analyzing the characteristics and critical influencing factors associated with household carbon emissions is of considerable academic and practical significance. In addition to fostering green low-carbon initiatives, such investigations will also play a vital role in mitigating the accelerating rate of carbon emissions.[4] Additionally, this research contributes to effectively addressing the growing trend of carbon emissions. The study of household carbon emissions is currently progressing rapidly, resulting in a substantial body of relevant findings. However, scholars often define household carbon emissions using various criteria and perspectives that reflect the specific focus of their investigations. This diversity in definitions underscores the complexity inherent in this field and highlights the urgent need for a systematic examination of household carbon emissions. Such an examination would facilitate the establishment of a more cohesive conceptual framework and standardized measurement approaches at both theoretical and practical levels. According to Jinlong Ma and other researchers, household carbon emissions are characterized as the direct or indirect carbon emissions arising from energy consumption associated with daily living and work activities within households.[5] Indirect carbon emissions refer to the carbon emissions associated with non-energy goods and services consumed by households across various sectors, including food, clothing, housing, and transportation. In contrast, direct carbon emissions are further classified by Shuangjiang Li et al. into two categories: residential energy consumption and transportation energy consumption.[6] Indirect carbon emissions arise during the production, distribution, and waste treatment of heat, electricity, and other goods and services utilized by households. Rahmani et al. define direct carbon emissions as those resulting from the energy that households consume directly. Similarly, Jinliang Xie and his colleagues characterize direct carbon emissions as originating from the energy that is consumed directly by households.[7,8] Furthermore, researchers such as Rahmani and Omeid highlight that energy sources—including electricity and liquefied petroleum gas (LPG)—as well as energy consumption across various sectors, including housing, transportation, and industry, are closely linked to household carbon emissions.[9] The various definitions and classifications highlight the necessity of establishing a cohesive theoretical framework and standardized evaluation criteria in the development of effective emission reduction strategies, as well as in advancing sustainable development. Moreover, they reflect significant scholarly insights into household dynamics and consumption patterns.

China's population and the designated areas for construction have witnessed steady growth in recent years, propelled by the swift trend of urbanization within the country, which has exceeded its actual carrying capacity.[5]Scale expansion and structural modifications have resulted in an agglomeration impact of carbon emissions.[10]In light of this, houses in the northern areas in particular consume a lot of energy for winter heating, which makes the problem of carbon emissions more noticeable and the work of reducing emissions more challenging[11] and reducing emissions is a

much more challenging undertaking.[12]Thus, by analyzing the characteristics of carbon emissions from urban and rural households in northern regions, along with the factors that influence these emissions, and employing both quantitative and visual methodologies for evaluation, it becomes feasible to explore the micro-level contributions of household carbon emissions. This investigation can subsequently lead to the identification of effective strategies for emission reduction. The reduction of greenhouse gas emissions, enhancement of citizens' quality of life, and attainment of sustainable development have emerged as paramount priorities for China.[13]

2. Data Sources

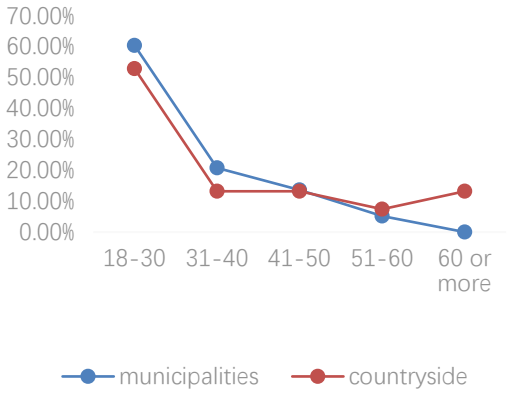

Fig 1. Age Distribution of Respondents in Urban and Rural Households

This study's primary research region encompasses both urban and rural areas of Hebei Province, as well as Xifeng County in Liaoning Province. To facilitate a stratified analysis of the results across different regions, carbon footprint data from urban and rural households were collected through online questionnaires and field visits. Among the 275 valid samples ultimately gathered, 154 originated from metropolitan areas, accounting for 56% of the total, while 121 came from rural areas, representing 44%. These sample sizes provide a robust data foundation for subsequent analyses and adequately fulfill the essential requirements of the questionnaire survey. Fig. 1 and Fig. 2 present a detailed breakdown of basic information.

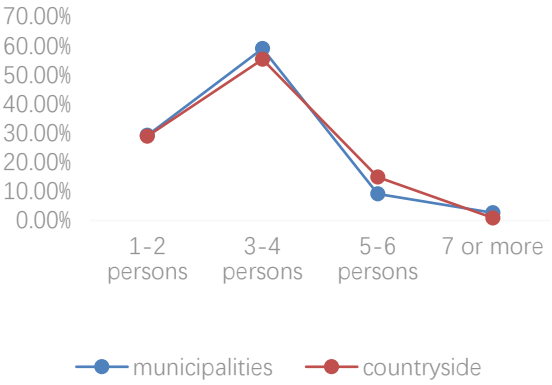

Fig 2. Permanent Residents of Urban and Rural Households (residing for more than six months per year)

3. Research Methodology

Carbon dioxide emissions resulting from energy-related household consumption activities, as well as those produced by transportation, are collectively referred to as household carbon emissions. This study places particular emphasis on home energy consumption—encompassing coal burning, electricity usage, and other related activities—and the subsequent carbon dioxide emissions arising from these practices. The primary focus is to measure household carbon emissions through the lens of intra-household consumption. Carbon dioxide generated by domestic activities can be categorized into two main types: direct carbon emissions and indirect carbon emissions. Direct carbon emissions primarily stem from household transportation and energy use. In contrast, indirect carbon emissions refer to the energy consumption and associated CO2 outputs that result from residents' daily utilization of non-energy goods and services. Fig. 3 illustrates the breakdown of carbon emissions attributable to households.

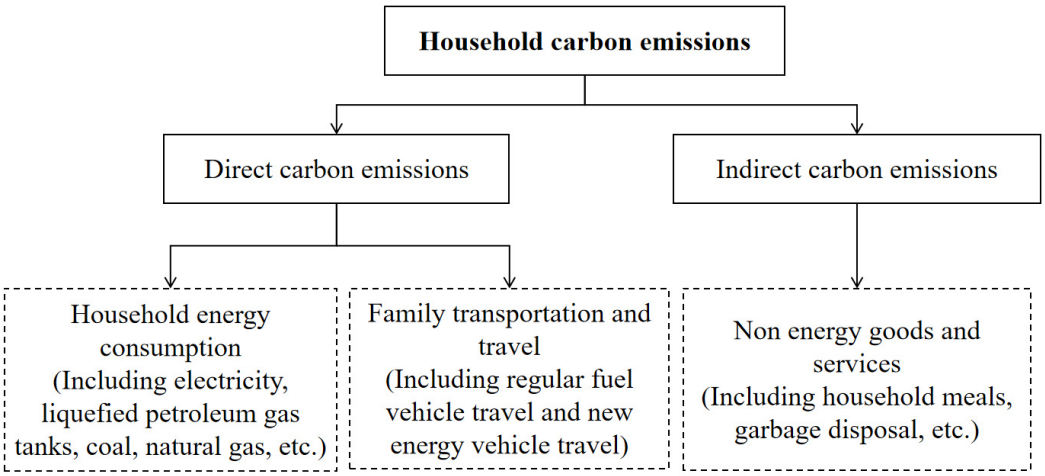

Fig 3. Composition of household carbon emissions

Currently, methods such as Life Cycle Assessment (LCA), Input-Output Analysis (IOA), and Consumer Lifestyle Approach (CLA) are predominantly employed to estimate indirect carbon emissions. Conversely, the carbon emission factor method and the calculation model for assessing a household's carbon footprint are primarily utilized for quantifying direct carbon emissions across various categories of household-related sources. [14] One notable approach within this framework is based on standard coefficients provided by the International Intergovernmental Panel on Climate Change (IPCC). By accounting for diverse forms and quantities of energy consumption, the IPCC enables a more

precise quantitative assessment of direct household carbon emissions.

The present article exclusively examines the energy consumption directly associated with households and the corresponding carbon dioxide emissions generated. In terms of transportation, this study highlights the energy utilized by domestic automobiles and their related CO2 emissions, which encompass those from new energy vehicles, motorcycles, and private cars. To effectively analyze household consumption patterns while addressing the complexities encountered by interviewees during data collection—thereby minimizing duplications and omissions in calculating carbon emissions from various types of energy use—the study selects specific indicators. These indicators include household consumption levels of electricity, coal, natural gas, liquefied petroleum gas (LPG), as well as the mileage accrued by motorcycles, private cars, and new energy vehicles used for travel. This approach aims to provide a comprehensive understanding of actual energy consumption scenarios in both urban and rural contexts. Furthermore, to ensure consistency in carbon emission accounting coefficients across different metrics, these units are standardized concerning electricity tariffs, water rates, and natural gas charges prevalent in Liaoning and Hebei Provinces. This standardization serves as a foundational aspect of the research methodology employed herein.

As indicated in Table 1, the household carbon emission coefficients used in this work to account for residential household carbon emissions are primarily derived from the literature on carbon emissions and are supported by household data. The following four components make up the accounting of carbon emissions from residential household transportation trips, household water and natural gas usage, and household power consumption:

$$\mathrm{Cele} = (\mathrm{Mele} / \mathrm{Dele})\ \mathrm{Xele} \quad (1)$$

In Eq. (1), Cele is the carbon emission generated by the monthly electricity consumption of the household; Mele is the total average monthly electricity bill of the household; Dele is the price per unit of electricity; and Xele is the carbon emission coefficient of the household's electricity consumption.

$$\mathrm{Cwater} = (\mathrm{Mwater} / \mathrm{Dwater})\ \mathrm{Xwater} \quad (2)$$

In Eq. (2), Cwater is the carbon emissions generated by the monthly water consumption of the household; Mwater is the total amount of water bill of the household. Dwater is the price per unit of water, and Xwater is the carbon emission factor for household water use.

$$\mathrm{Cgas} = (\mathrm{Mgas}/\mathrm{Dgas})\mathrm{Xgas} \quad (3)$$

In Eq. (3), Cgas is the carbon emission generated by the monthly gas consumption of the household; Mgas is the total amount of gas bill of the household; Dgas is the price per unit of gas; and Xgas is the carbon emission coefficient of gas consumption of the household.

$$\mathrm{Ctra} = \sum(\mathrm{Ntrai} \times \mathrm{Atrai}) \quad (4)$$

In Eq. (4) where Ctra is the carbon emissions generated by transportation trips; Ntrai is the per capita unit km of transportation in category i generated; Atrai is the carbon emission factor for type i transportation.

Table 1. Carbon emission types and carbon emission factors

Sources of carbon emissions	Type of carbon emissions	Carbon emission factor	Data sources
people's livelihood	Electricity (kWh/month)	0.89kgCO_2 /kWh	Northwest Regional Grid Baseline Emission Factor Announcement
	Water (t/month)	0.91kgCO_2 /t	PRC Ministry of Science and Technology (MOST)
	Natural gas (m3/month)	2.67kgCO_2 /m	Cai Bofeng[15]etc.
	liquefied petroleum gas (Cans/year)	3.16kgCO_2 /tank	Cai Bofeng [15] etc.
	Coal (tons/year)	2.68tCO_2 /t	national standard
	foods	2.34kgCO_2 /kg	PRC Ministry of Science and Technology (MOST)
Family transportation	Private vehicles (km/month)	19.59kgCO_2 /10^2 km	Huang Yu [16] etc.
	Motorcycles (km/month)	6.68kgCO_2 /10^2 km	Huang Yu [16] etc.
	new energy vehicle (km/month)	146.5 to 331.3 gCO_2 e/km	China Automotive Low Carbon Action Plan Research Report (2021)

4. Data Analysis

The carbon emission coefficient method was used to compile and analyze the data. The household energy consumption is displayed in Table 2, and the corresponding carbon dioxide emissions were computed by converting the consumption behaviors related to household carbon emissions to the actual energy consumption. In order to visualize the link between the variables, this thick bubble diagram (shown in Fig. 4) was ultimately created and displayed using the collected data. The following deductions were made:

1. Overall, residential electricity consumption and transportation represent the primary sources of carbon emissions for both urban and rural households. Notably, electricity usage during the summer and winter months is significantly higher than in other seasons. On average, households generate approximately 182.36 kg of carbon emissions per month due to their power consumption, with summer electricity use contributing 195.45 kg and winter electricity use accounting for 184.98 kg—both figures considerably exceeding those recorded in spring and fall. The average annual consumption of liquefied petroleum gas (LPG) canisters among urban and rural households is roughly 2.815 canisters, resulting in an estimated annual carbon emission of about 8.90 kg from LPG usage. These statistics suggest that there remains substantial potential to optimize the energy

structure within households. Furthermore, the contribution of domestic water usage and liquefied petroleum gas (LPG) to overall carbon emissions is relatively low.

Table 2. Average monthly household electrical energy consumption

	Average daily monthly electricity cost/¥	Family Summer Average monthly electricity cost/¥	Family Winter Average monthly electricity cost/¥	quantity of electric charge or current Unit price yuan/kWh
municipalities	108	113	109	0.51
countryside	101	111	103	0.51
city and countryside	104.5	112	106	0.51

2. When it comes to transportation-related carbon emissions, urban households primarily use private vehicles for trips, whilst rural households primarily utilize motorcycles, both of which contribute to a larger proportion of carbon emissions. It's important to note that households that utilize new energy cars generate substantially reduced transportation-related carbon emissions, demonstrating the enormous potential and wide range of opportunities for encouraging low-carbon travel, lowering pollution levels, and halting climate change. Furthermore, it is impossible to overlook the contribution of residential rubbish disposal to carbon emissions. The carbon emission factor of household garbage is around 2.06 kgCO_2/kg, meaning that the carbon emission from household rubbish is approximately 78.69 kg. On average, houses produce 38.2 kg of garbage every month. Households can successfully cut their greenhouse gas emissions and mitigate the environmental impacts by implementing garbage sorting, boosting the recycling rate of recyclables, and lowering the landfilling and incineration of hazardous waste. Households can efficiently cut their greenhouse gas emissions and mitigate negative environmental consequences by segregating rubbish, boosting the recycling rate of recyclables, and lowering landfills and the incineration of hazardous waste.

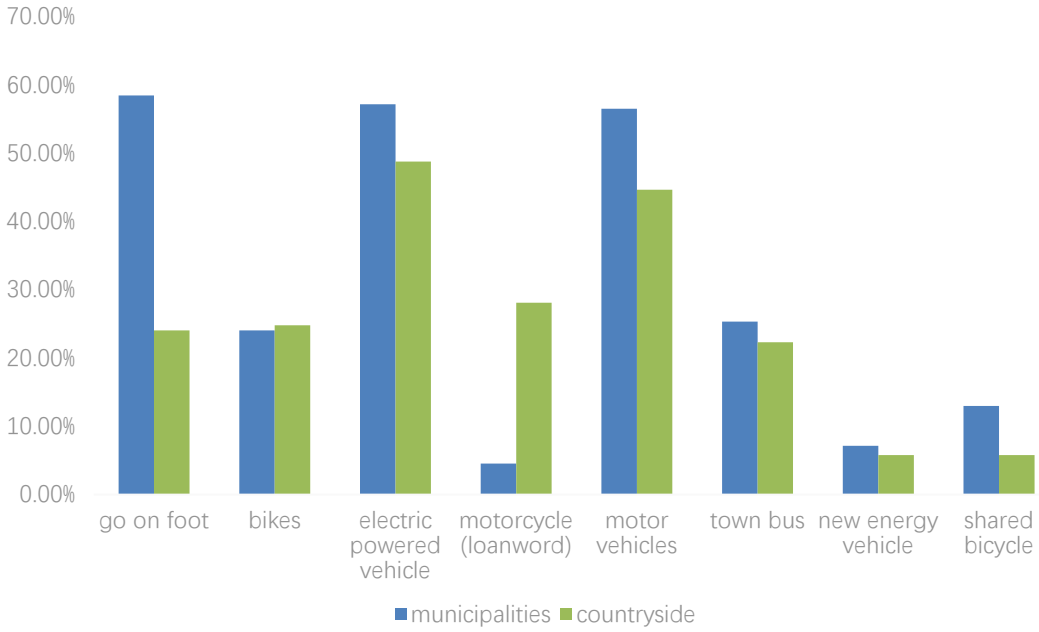

Fig 4. Urban and Rural Household Transportation Use

Table 3. Household waste generation in urban and rural areas

	Less than 5kg	5-10kg	10-20kg	Greater than 20kg	Average weekly waste generation/kg
municipalities	18.18%	55.84%	23.38%	2.60%	9.12
countryside	22.31%	45.45%	19.83%	12.40%	9.98

3. Natural gas is a cleaner fossil fuel with substantially lower carbon emissions than coal when it comes to energy utilization. Natural gas burning contributes significantly to the residential energy mix, with an average monthly carbon emissions of roughly 65.2 kg. Natural gas still contributes to a portion of overall home carbon emissions, even if its carbon emissions are smaller. Natural gas can therefore be used as a transitional energy source, but in order to further lower household carbon emissions and ease the shift to a more sustainable energy mix, its usage must also be coupled with other energy-saving and emission-reduction strategies. Coal use for winter heating continues to be a significant source of household carbon emissions in rural areas, particularly in the north. With an average annual coal use of roughly 1.56 tons, the use of coal for winter heating still has a significant impact on household carbon emissions, even though the use of coal is concentrated to a greater extent during the long winter months in the north.

Table 4. Household natural gas use

	Average monthly household Natural gas consumption/¥	Unit price of natural gas Yuan/m3	Average monthly household natural gas use/kg
municipalities	102.6	3.14	32.68
countryside	105.83	3.14	33.7
city and countryside	104.215	3.14	33.19

Data on household carbon emissions were compiled using the emission factor approach, and a thick bubble chart was used for visualization. Using the coordinates and sizes of the bubbles, the dense bubble chart, a two-dimensional representation of multidimensional data, illustrates the link between three variables. With the size of the bubbles representing carbon emissions, the analysis of household carbon emissions graphically illustrates the relationship between variables such household energy use and mode of transportation and carbon emissions. In addition to offering statistical support for emission reduction programs and carbon footprint management, the graphic aids in identifying the traits of families with high carbon emissions.

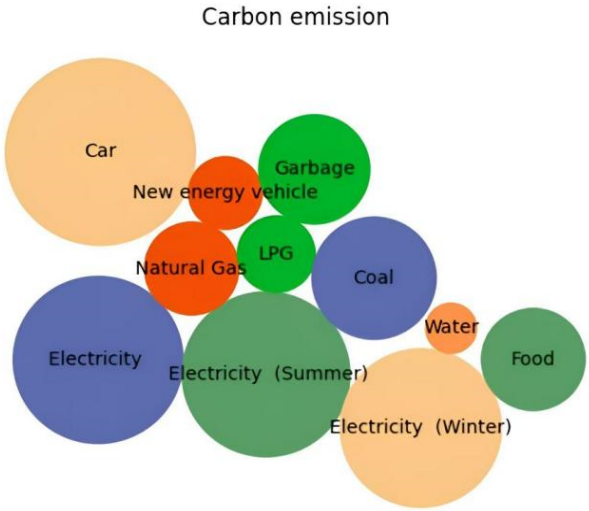

Fig 5. Dense bubble map

5. Conclusion

The provinces of Liaoning and Hebei play a pivotal role in driving economic growth in China. These two provinces have successively issued the "Implementing Opinions on the Establishment of a Sound Green, Low-Carbon, and Recycling Development Economic System," as well as the "Tasks and Measures for the Accelerated Establishment of a Sound Green, Low-Carbon, and Cycling Development Economic System in Liaoning Province." The primary objective is to establish an effective economic system that promotes green, low-carbon, and recycling development. Furthermore, these provinces are actively implementing China's directives aimed at expediting the establishment of such policies. The overarching goal is to ensure that China meets its targets for carbon peaking and carbon neutrality while simultaneously creating a robust economic framework conducive to the advancement of green, low-carbon, and recycling industries.

While the issues of home energy consumption and carbon emissions are becoming increasingly prominent, the living standards of residents in Liaoning and Hebei provinces are gradually improving against the backdrop of sustained economic expansion. Policymakers should implement comprehensive strategies to support low-carbon development at multiple levels in order to address this challenge. These strategies should encompass the following two elements:

Reducing household energy consumption and carbon emissions is essential for fostering a low-carbon lifestyle. The government should actively promote this lifestyle, enhance public education initiatives, and implement strategies to decrease residential energy use, as domestic power consumption significantly contributes to overall carbon emissions. This can be achieved by advocating for green building practices, integrating smart home technologies, and encouraging the adoption of energy-efficient household appliances to improve energy efficiency and minimize waste at its source. Simultaneously, it is imperative to develop a low-carbon transportation infrastructure that enhances the effectiveness of sustainable travel options. The government ought to prioritize improvements in travel comfort and convenience by expanding and optimizing public transportation systems while promoting environmentally friendly modes of transport among individuals. Additionally, the promotion of new energy vehicles can substantially mitigate both air pollution and carbon emissions. Encouraging low-carbon transportation alternatives such as walking, cycling, and ride-sharing will not only help alleviate traffic congestion during peak hours but also contribute further to the reduction of carbon emissions.

To enhance resource efficiency, it is essential to acknowledge that both waste management and energy mix optimization are of equal importance. A frequently overlooked source of carbon emissions is the disposal of household waste. By promoting waste separation, increasing

the recovery rate of recyclables, and minimizing the incineration and landfilling of hazardous materials, significant reductions in carbon emissions can be achieved. To facilitate resource recycling, government initiatives should prioritize raising public awareness regarding effective waste separation practices, upgrading relevant infrastructure, and providing incentives or discounts for individuals who actively engage in the separation process. Concurrently, optimizing the energy structure remains critical. Coal continues to serve as the primary energy source for winter heating—particularly in rural areas—resulting in substantial environmental strain due to associated carbon emissions. Accelerating efforts to promote clean energy sources is vital for effectively reducing reliance on coal while fostering diversification within the energy structure and supporting a green transition. This approach will ensure a sustained reduction in carbon emissions by prioritizing renewable energy sources such as solar and wind power.

Acknowledgments

Funding 1: This research was funded by the Innovation and Entrepreneurship Project for College Students of Hebei Provincial Department of Education. This project is a national innovation project titled "Construction of a Digital Intelligent Household Carbon Emission Accounting Model Based on Carbon Footprint", grant number T202410081043.

Funding 2: This study is affiliated with the 2024 Hebei Social Science Development Research Project, titled "Research on Rural Living Environment and Low Carbon Development Path in Hebei Province", grant number 202401 036.

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