Characteristics and Drivers of the Household Carbon Footprint: An Age Structure Perspective

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Introduction

1.Introduction

- Amid profound shifts in global population structures, the environmental impact of consumption patterns among different age groups has received increasing attention (Lenzen et al., 2006; Dalton et al., 2008).

- The relationship between carbon footprints and shifts in age structure is increasingly being studied as a key issue in global climate change (Hu et al., 2025).

- How does the aging population in China affect carbon emissions?

Literature review

- The measurement of carbon emissions
  - Most research examines carbon footprints from specific consumption categories, such as housing (Cho et al., 2022), tourism (Tan et al., 2024), shopping (Long et al., 2023), and transportation (Song et al., 2019).
  - Some researchers take a broader approach by estimating both direct (Shi et al., 2020) and indirect emissions (Mi et al., 2020) across all household consumption types.

- Methodologically
  - Direct emissions are usually calculated with emission coefficient methods (Hirano et al., 2016),
  - Indirect emissions are often measured through life cycle assessment (LCA) (Dong et al., 2025) or input-output (IO) models (Wang and Chen, 2020; Feng et al., 2014).

- The factors influencing household carbon emissions
  - Macro-level analyses mainly focus on technological efficiency (Xia et al., 2019), levels of economic development (Jiang et al., 2022; Pang et al., 2022), energy mix (Oswald et al., 2020), low-carbon policies (Tian et al., 2023), industrial structure (Wei et al., 2020), and population size (Ivanova et al., 2016).
  - Micro-level studies explore household income (Imbulana Arachchi and Managi, 2022; Mi et al., 2020; Owen and Barrett, 2020), family composition (Ivanova and Büchs, 2022), consumption preferences (Ivanova et al., 2016; Hirano et al., 2016), and lifestyle factors (Bruckner et al., 2022).

- First, most studies focus on specific demographic groups (e.g., elderly or children) rather than systematically analyzing carbon footprint differences across all age groups.
- Second, there is a notable lack of macro-level measurement of the socio-economic factors that influence carbon footprints among different age groups.

- This paper seeks to contribute to the following areas：

First, it uniquely combines an age-specific consumption model with an input-output model to measure carbon footprints by age groups.

Second, the study not only identifies the main drivers but also quantifies each driver's contribution, rather than merely describing how they influence the system.

Third, going beyond traditional policies, this study proposes an “age-policy” coordinated emission reduction pathway.

This personalized approach supports the development of sustainable and targeted environmental policies, marking a significant advancement in environmental policy research.

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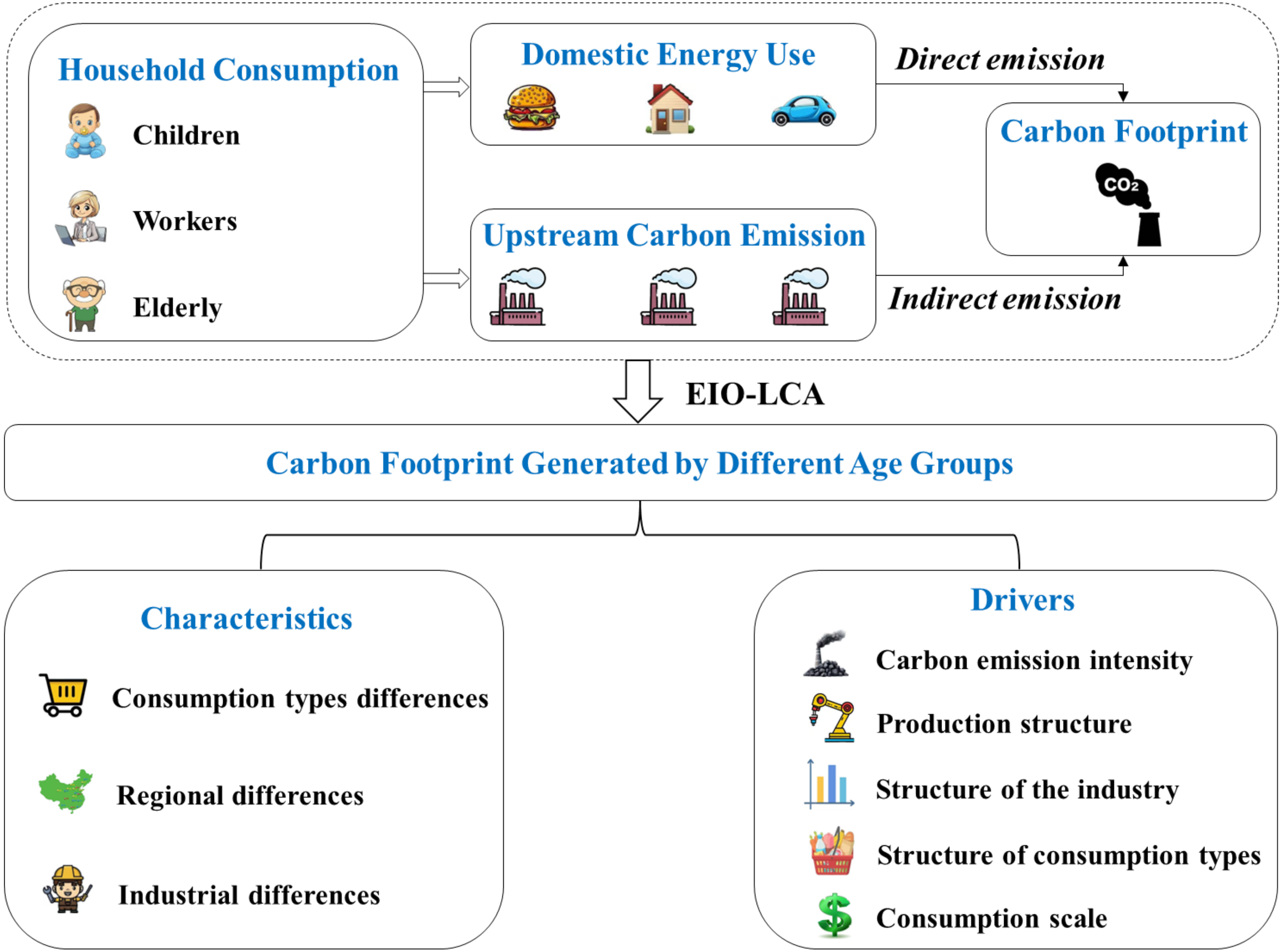
Accounting framework

2.Accounting framework



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Methods

1.Age-specific consumption model

$$\begin{cases} lnE = a + blnI + c(lnI)^2 + \sum_{j=0}^{85} d_j Y_j + u \\ lnE_k = \alpha_k + \beta_k lnE + \sum_{j=0}^{85} \gamma_{k,j} Y_j + \varepsilon_k \end{cases}, (i, =, 1,2, \ldots, N, \ j = 0,5 \ldots 85) \qquad (1)$$

Among them, E represents the total per capita household expenditure, E_k represents the average expenditure of the product k, and I represents the per capita net income of the household. $Y_j = \sum_{i=1}^{N} D_{i,j}$ represents the number of family aged j. $D_{i,j}$ is a dummy variable that indicates whether the age of the member i in the family is j. If the age of the member i is in the age group j, then $D_{i,j} = 1$, otherwise $D_{i,j} = 0$. $j = 0, 5, 10, \ldots, 85$ represent age groups with intervals of 5 years old, namely 0-4 years old, 5-9 years old, 10-14 years old, ……, 80 years old and above. N is the number of family members. a, b, c, d, as well as $\alpha_k, \beta_k, \gamma_{k,j}$ are all parameters to be estimated, while u and ε_k are random errors.

1.Age-specific consumption model

Rewrite eq. (1) to obtain the per capita total consumption expenditure of the j -year-old population and its consumption expenditure on k consumption types:

$$\begin{cases} \tilde{E}_j = exp\left(a + bln\bar{I} + c(ln\bar{I})^2 + d_j\right) \\ \tilde{E}_{k,j} = exp\left(\alpha_k + \beta_k ln\bar{E} + \gamma_{k,j}\right) \end{cases} \quad (2)$$

$\tilde{E}_j$ is the total consumption expenditure of members in the age group j, and $\tilde{E}_{k,j}$ is the consumption of the product k by members in the age group j. $\bar{I}$ and $\bar{E}$ are the average per capita income and per capita expenditure of the sample, respectively.

2.Environmental input–output life cycle assessment (EIO-LCA) model

- The EIO-LCA model is a method that assesses the carbon emissions linked to the consumption of goods and services by incorporating environmental stress factors, such as greenhouse gases, into the input–output model (Su and Ang, 2012). This method has become a common tool for analyzing the environmental footprint of household consumption (Wei et al., 2017).

$$CF = qly = q(I - A)^{-1}y \qquad (3)$$

3. Structural decomposition analysis (SDA)

- To investigate the driving forces of the changes in carbon emission, the final demand matrix y in Eq. (4) can be decomposed into three factors:.

$$\mathbf{CF} = \boldsymbol{qLy} = \boldsymbol{qLstv} \tag{4}$$

- The main idea of the SDA model is that changes in the carbon footprint can be decomposed into the sum of the changes in various factors. That is,

$$\triangle \boldsymbol{Q} = \triangle \boldsymbol{qLstv} + \boldsymbol{q} \triangle \boldsymbol{Lstv} + \boldsymbol{qL} \triangle \boldsymbol{stv} + \boldsymbol{qLs} \triangle \boldsymbol{tv} + \boldsymbol{qLst} \triangle \boldsymbol{v} \tag{5}$$

where $\triangle q$, $\triangle L$, $\triangle s$, $\triangle t$, and $\triangle v$ represent the contributions of carbon emission intensity, production input structure, sector structure, consumption structure, and consumption scale, holding other variables constant.

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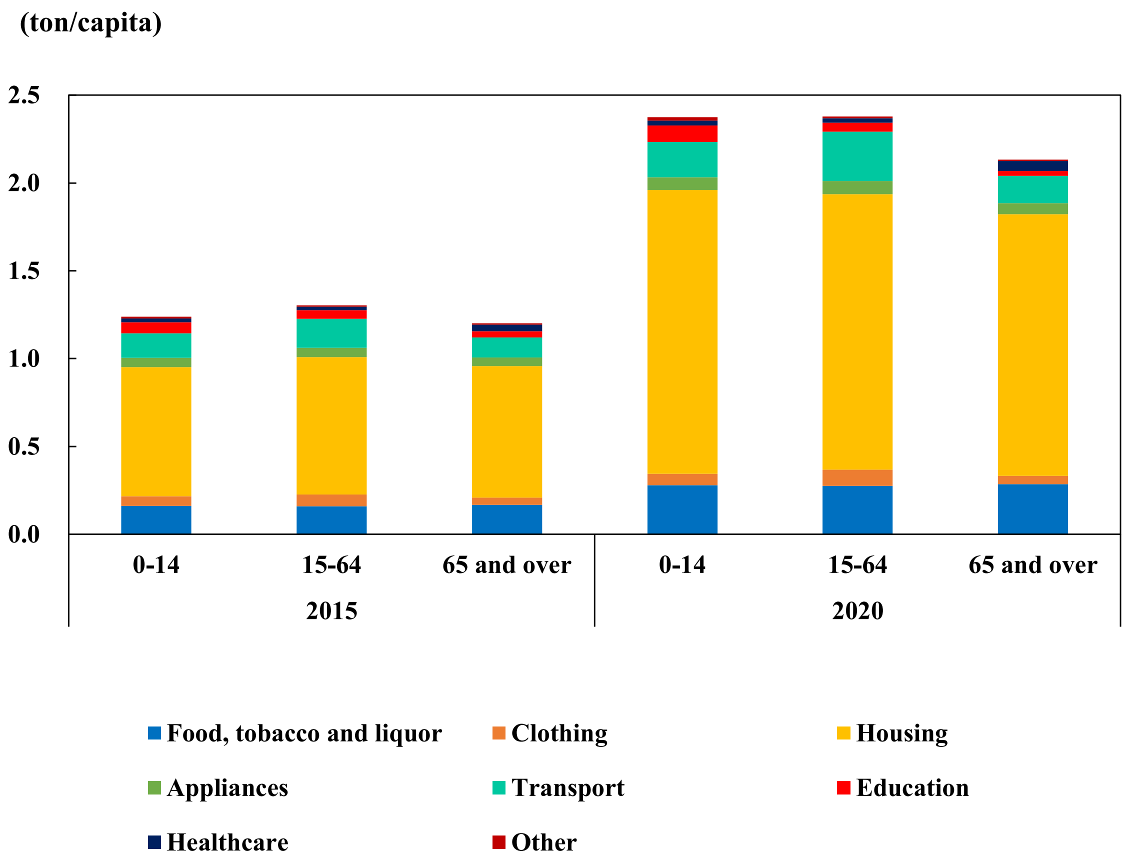
result

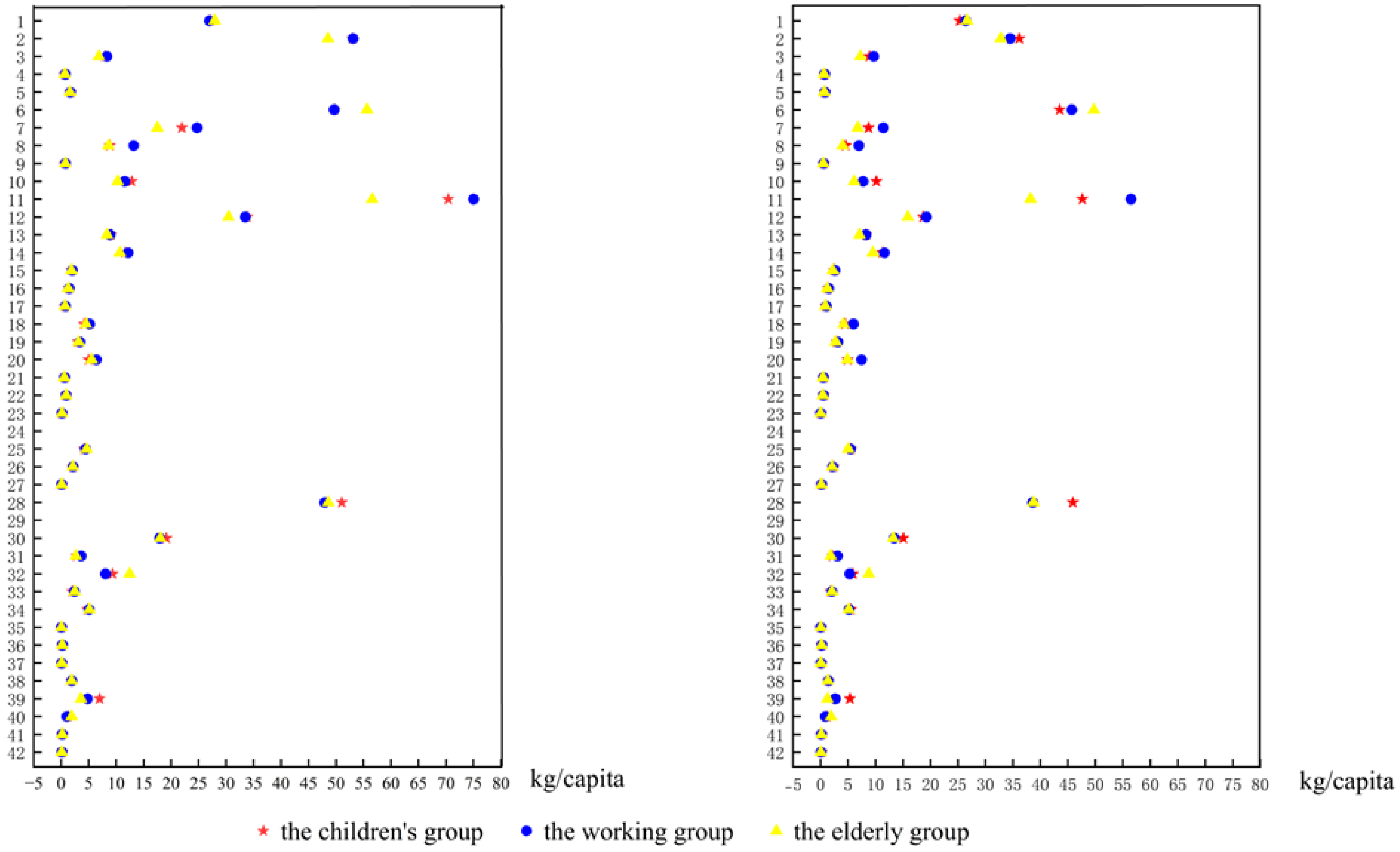
Consumption characteristics



- From 2015 to 2020, the most rapid increase in per capita carbon emissions occurred in the children's group .

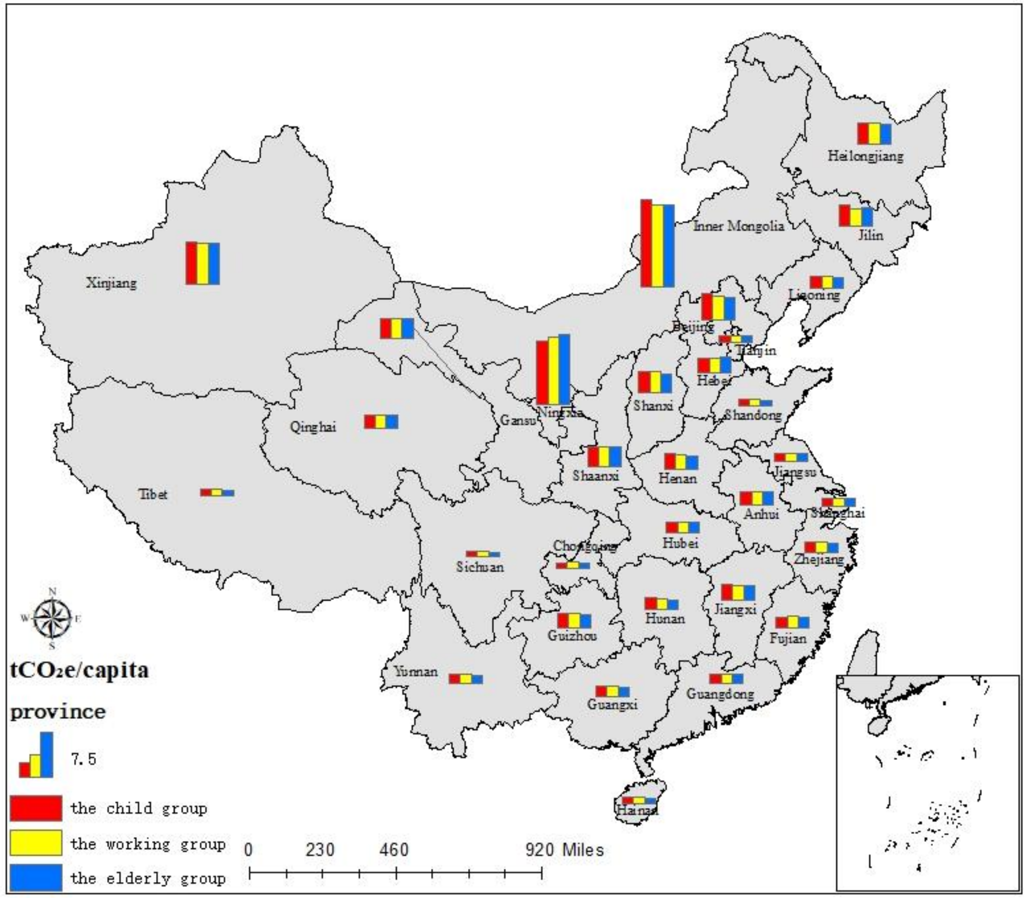
- The growth rates of per capita carbon emissions for the children's group, working group, and elderly group are 91.87%, 82.49%, and 77.67%, respectively, with per capita footprints of 2.37 t, 2.38 t, and 2.13 t.

Consumption characteristics



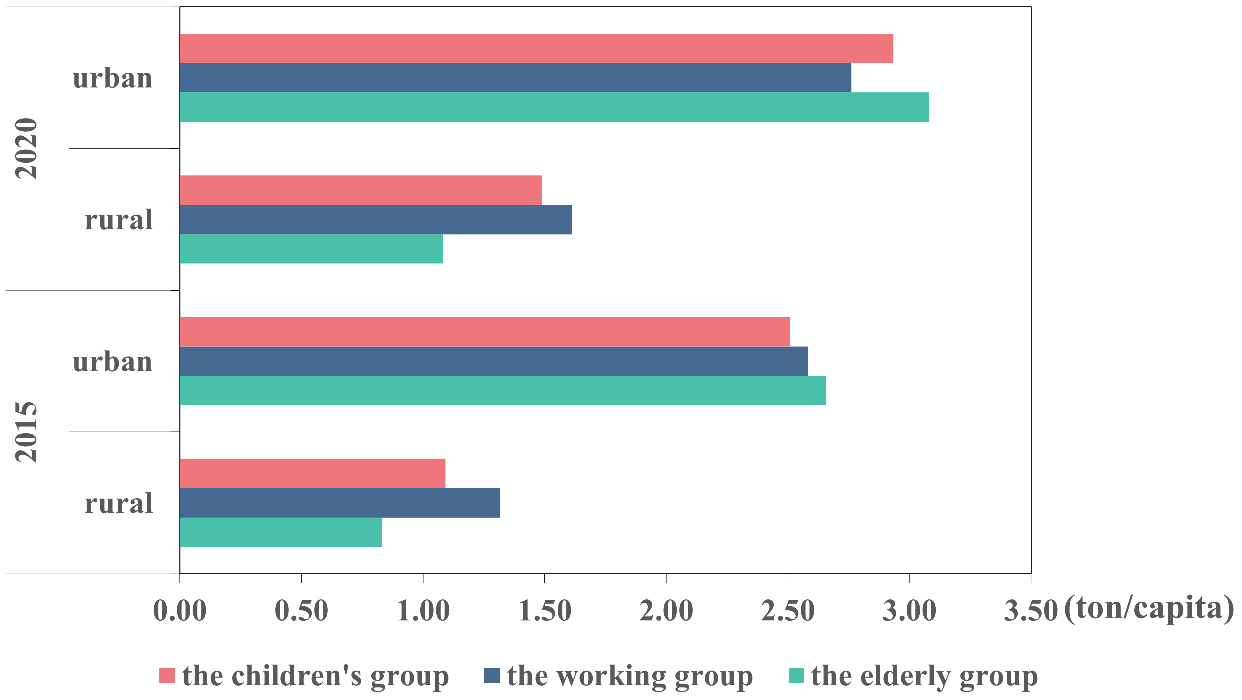
- The consumption preferences of various age groups contribute to increased carbon footprints in related downstream sectors.
- The elderly significantly contributes to the carbon footprints in Financial Intermediation (32) .

Regional disparity



- The provinces of northern area exhibited high per capita carbon footprints, whereas southern region have low per capita carbon.
- The regions where the per capita carbon footprint of the children group is the largest are Beijing and the three northeastern provinces. The carbon emissions of the working group in some eastern regions are higher than those of the children's group. The per capita carbon emissions of the elderly group in Ningxia are higher than those of the other two groups.

Urban-Rural gap



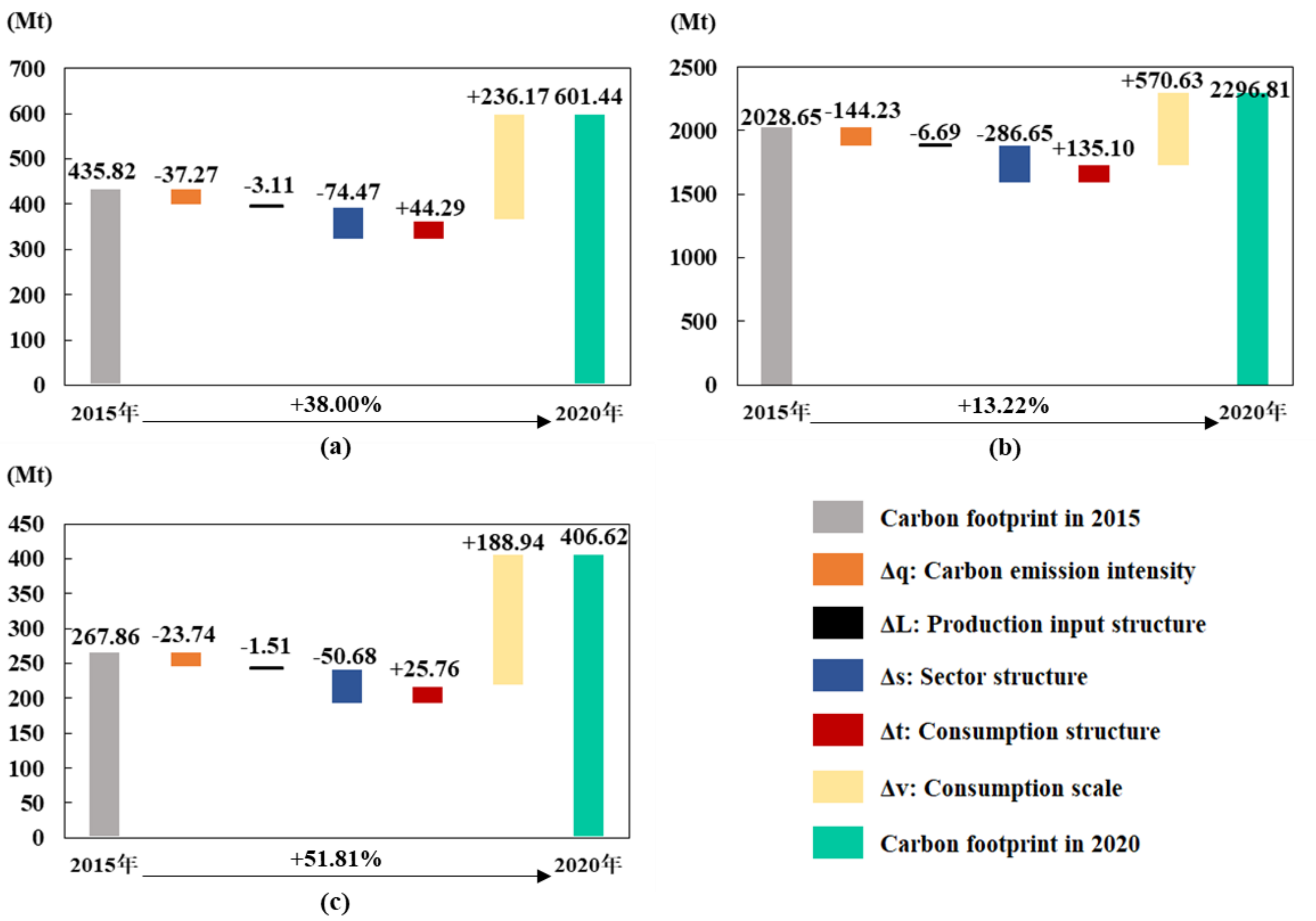
- In 2020, the ratio of per capita consumption expenditure between urban and rural residents (referred to as the urban-rural ratio) for children, working group, and the elderly was 1.97, 1.71, and 2.85, respectively.

Urban-Rural gap

		Food, tobacco and liquor	Clothing	Residence	Appliances	Transport	Education	Healthcare	Others
Children	Urban	0.34	0.08	2.01	0.09	0.24	0.12	0.03	0.03
	Rural	0.18	0.04	1.00	0.05	0.14	0.05	0.02	0.01
Working Group	Urban	0.32	0.11	1.84	0.09	0.31	0.06	0.03	0.01
	Rural	0.20	0.06	1.03	0.05	0.21	0.03	0.02	0.01
Elderly	Urban	0.42	0.07	2.16	0.09	0.20	0.04	0.08	0.01
	Rural	0.13	0.02	0.75	0.03	0.10	0.01	0.03	0.00

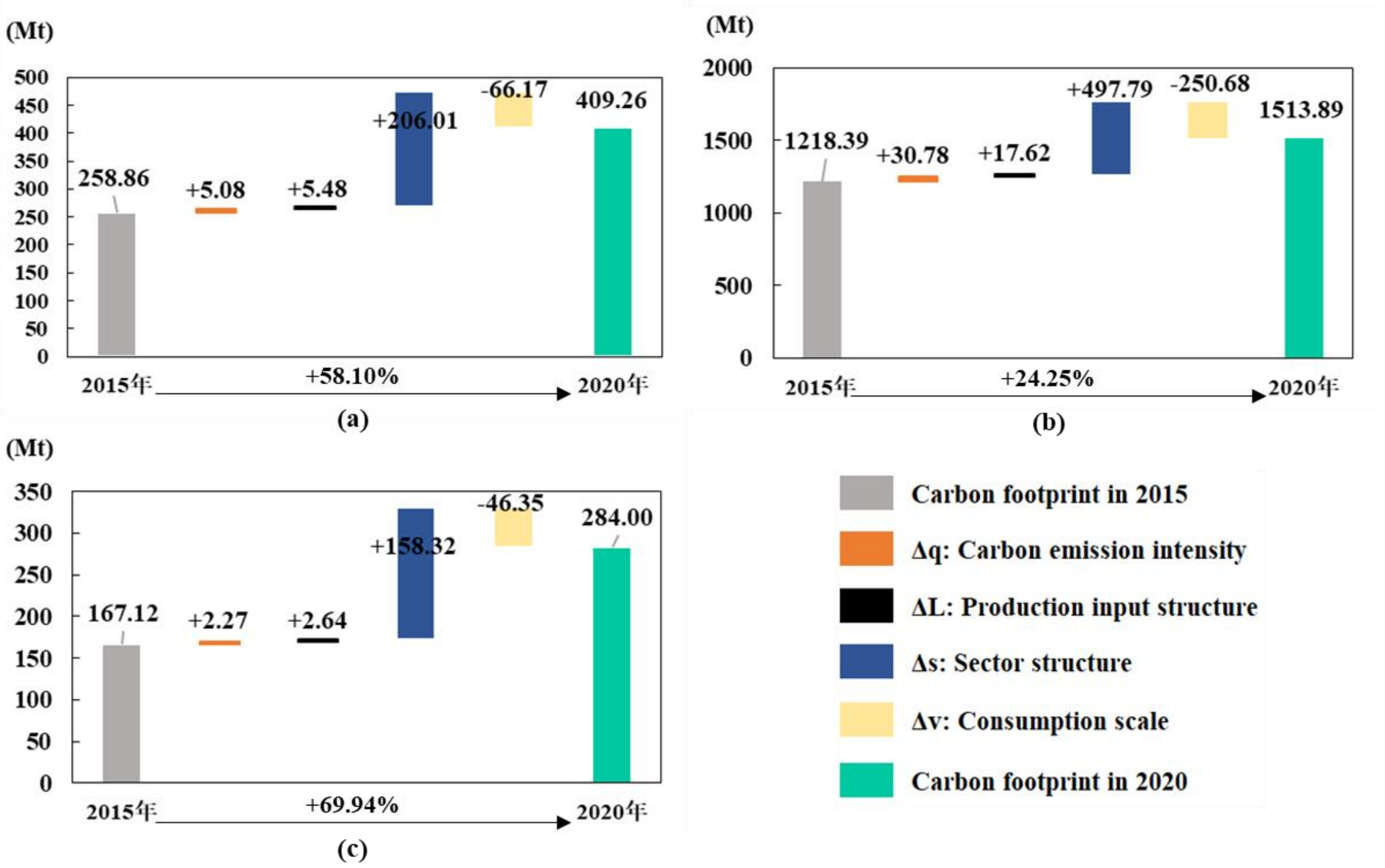
- The urban-rural gap is the largest in the elderly group. Education is the key driver of the urban-rural disparity in per capita emissions among the elderly.
- The urban-rural gap in the children group is shrinking the fastest. The decline in the urban-rural carbon footprint gap for the children's group is mainly due to a notable decrease in clothing and healthcare consumption for children

Drivers of change in overall carbon footprint



- The consumption structure and consumption scale increase the carbon footprint in three age groups, while carbon emission intensity, production input structure, and sector structure decrease it. Among the driving effects of the consumption structure on the carbon footprint, the impact of the working group is the most significant, with the strongest impact seen in Beijing and Jiangsu.

Drivers of change in housing carbon footprint



- Housing consumption is the largest source of carbon emissions across all age groups,
- In a quarter of the provinces, the elderly group have a consumption scale that accounts for 100% of carbon emissions.

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Discussion

Discussion

- Child-Focused Carbon Mitigation: Integrating Education and Regional Strategies
- Emission control for workers: Bridging Consumption and Regional Gaps
- Emission reduction policies for the elderly: Balancing Medical Needs with Low-Carbon Transformation Strategies
- The Collaborative Governance Emission Reduction Plan of ‘Age-Region-Consumption’

6 Conclusions

Conclusions

- The children exhibited the fastest per capita emission growth, primarily driven by consumption related to education. The working age group showed the highest absolute emissions from transportation and clothing expenditure. The elderly demonstrated distinctive emissions related to medical care.
- A pronounced 'north-high, south-low' regional pattern emerged, with Inner Mongolia representing high-carbon provinces due to its coal-dependent energy structures. Meanwhile, Beijing's education-intensive emissions from children and Ningxia’s emissions from heating for the elderly constituted exceptional cases. Urban-rural disparities were most pronounced for the elderly, though the gap for children narrowed most rapidly.

Thank You

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