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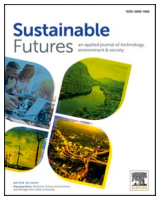

# Does Internet use help to achieve sustainable food consumption? Evidence from rural China

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ABSTRACT

Internet use is widely studied as an important socio-economic factor influencing agricultural productivity, income, the adoption of sustainable agricultural practices, and farmer welfare, but scant attention is given to its influence on sustainable food consumption. Using longitudinal data from the China Health and Nutrition Survey (CHNS), this study seeks to better understand the causal effect of Internet use on sustainable food consumption measured by food carbon and food water footprints and shed light on its underlying channels. The instrumental variable estimation is used to solve the endogeneity problem of Internet use and the propensity score matching (PSM) method is used for robustness check. The results show that Internet use significantly decreases food carbon and food water footprints by 18.1 % and 10.6 %, respectively. Internet use promotes the development of sustainable food consumption mainly by reducing the consumption of animal-based food such as pork and eggs. Further heterogeneity analysis results indicate that Internet use mainly affects the sustainable food consumption of young and high-income individuals. Policy implications for reducing food carbon and food water footprints and achieving a win-win situation for consumption and the environment are also discussed.

## 1. Introduction

The foremost challenges confronting humanity include climate change and sustainable development, and current food consumption patterns are significantly exacerbating to these issues [1]. The United Nations Sustainable Development Goals (SDGs) represent a global agreement on social, economic, and environmental targets that humanity aims to reach by 2030 [2]. The global transition to environmentally friendly and nutritionally adequate sustainable food consumption will be key to achieving several SDGs simultaneously. On one hand, the Global Burden of Disease Assessment [3] reports that >2 billion people are undernourished, and poor diet is a leading cause of premature death and disease. On the other hand, food production processes contribute to environmental issues such as greenhouse gas emissions, freshwater scarcity, land degradation, and biodiversity loss. These environmental impacts could impede progress on SDG 6 (clean water and sanitation), SDG 13 (climate action), SDG 14 (life below water), and SDG 15 (life on land). Addressing these challenges remains formidable, as the diets of most people worldwide either lack essential micronutrients, impose high environmental costs, or exhibit both issues [2]

China is one of the largest food carbon emitters in the world with emit 1.9 billion tons of $CO_2$ equivalent in 2020 [4]. Additionally, China's per capita water resources amount to only 25 % of the global average, placing it among the 13 countries identified by the United Nations as facing severe water shortages [5]. Between 1987 and 2017, China's per capita daily calorie intake from vegetables increased by 12 %, while meat consumption surged by 198 % [6,7]. Given that plant-based food chains generally have lower carbon and water footprints intensity than animal-based food chains [8,9], this dietary shift toward higher meat consumption places additional pressure on water resources and challenges China's emission reduction goals. Further, evidence shows that China's food-related water and carbon footprints nearly tripled from 1961 to 2017, underscoring the need for policymakers to prioritize strategies that reduce these environmental footprints and support sustainable food consumption [1,7].

Most prior research focuses on quantifying the environmental footprints of food and assessing consumers' willingness to pay for food

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labels, while relatively few studies examine sustainable food consumption from the perspectives of digital transformation. Internet use, however, reshapes food access patterns, broadening the range of available food and enhancing accessibility for consumers [10]. Moreover, the Internet lowers transaction costs in agricultural markets, promotes farmers' market participation, and increases food affordability for consumers [11]. Zamani et al. [12] find that the Internet also fosters competition within agricultural markets, which influences food prices and consumer behavior. As a primary information source, Internet use shapes public attitudes toward environmental protection and affects food consumption preferences. These shifts may increase the intake of plant-based foods in rural areas, potentially influencing the environmental footprints of food consumption. However, further empirical studies are needed to clarify whether Internet use ultimately has a positive or negative impact on the environmental footprints of food consumption.

The purpose of this study is to explore the potential impact of Internet use on sustainable food consumption. This study has the following three contributions. First, this study contributes to existing literature by investigating the effect of Internet use from the perspective of consumption behavior. Our research extends these two research topics of Internet use and sustainable food consumption. Second, we not only analyze the causal relationship between Internet use and sustainable food consumption, but also discuss the potential channels through which Internet use affects sustainable food consumption and its heterogeneity. The results show that Internet use reduces the food carbon footprints by 18.1 % and food water footprints by 10.6 %, primarily due to a reduction in the consumption of animal-based products such as pork and eggs. These findings could provide new lessons for achieving sustainable food consumption. Finally, we mainly focus on the impact of Internet use on sustainable food consumption in rural areas of China, which makes up for the gap that most research only focus on developed countries. It is worth noting that by the end of 2016, the number of Internet users in China reached 731 million, ranking first in the world. Given the rapid growth of Internet use in many developing countries, achieving sustainable food consumption is a common goal [13,14]. The results of this study are expected to provide important policy implications for sustainable development in China and may also provide valuable insights for other developing countries such as India, Vietnam and Thailand.

The remaining sections of this study include four parts. Section 2 reviews the literature, offering an insight into existing research. Section 3 presents the statistical methods and data. In Section 4, estimated results are presented in detail. Section 5 covers the conclusions and policy implications.

## 2. Literature review

A large body of literature examines the environmental impacts of diets, particularly in terms of food carbon and water footprints, as well as dietary patterns and footprints accounting. Kanemoto et al. [15] find that while meat consumption weakly explains differences in household carbon footprints, reducing meat intake can decrease food carbon footprints across all Japanese households. Similarly, Albert et al. [16] argue that restricting red meat and dairy consumption can reduce household carbon emissions, especially in larger urban areas. Vanham et al. (2021) investigate food consumption and water use in northern European cities, finding that a healthy diet with less meat can reduce the food water footprints. As urbanization increases, food consumption patterns in rural areas also shift, which affects the food water footprints [17]. Das et al. [18] conduct a study in India and find that the total food water footprints rises with increased consumption of animal-based foods. Liu and Savenije [19] offer international comparisons, noting that while China's food-related water use has tripled over the past 30 years, it remains lower than in most developed nations. Sommer and Kratena [20] divide income into five levels and find that the carbon footprints of Europe's lowest income group is >2.5 times lower than the average per capita footprints (15.7 tonnes of carbon), while the footprint of the highest income group is just under twice the average. Using data from the Global Diet Database (GDD) and the Food and Agriculture Organization (FAO), Yin et al. [21] find that global annual greenhouse gas emissions from aging will reach 288 million tons of $CO_2$ equivalent by 2100. Xu et al. [22] reach a similar conclusion by analyzing food carbon and water footprints. In general, research indicates that with population growth, urbanization, and rising incomes, diets shift from plant-based to animal-based foods. Since animal products, particularly red meat and dairy, generate significantly higher carbon emissions and water consumption than plant-based foods, these dietary shifts can lead to greater environmental impacts.

While these studies examine various factors influencing food carbon and water footprints, they remain limited, particularly in their lack of focus on how Internet usage affects sustainable food consumption. First, the Internet provides extensive information on the health benefits of plant-based diets, encouraging people to reduce their consumption of animal-based foods and incorporate more fruits, vegetables, and grains. For example, Internet use offers information about the negative environmental impacts of certain foods and exposes consumers to pro-environmental food choices [23,24,25]. Second, unlike conventional information channels such as television, newspapers, and broadcasts, the Internet offers a vast repository of information without the constraints imposed by specific publishers, and all at minimal cost. Internet use can improve market efficiency and affect food prices, as mobile coverage reduces search and transaction costs [26]. Consequently, the promotion and sale of whole grain foods and low-carbon labeled foods primarily occur online [27,28]. Third, studies indicate that information technology [29], particularly through social media, enhances public awareness of environmental risks and influences attitudes toward environmental protection, thereby promoting the consumption of plant-based foods. Gong et al. [30] find that Internet use actively promotes environmentally friendly behavior at the individual level. Wang and Hao [31] emphasize the Internet's role in providing tools to calculate food carbon emissions, enabling individuals to transition from environmentally friendly attitudes to sustainable behaviors, such as reducing the consumption of animal-based foods and selecting products with low-carbon labels. Huang and Tian [32] discover that Internet users are more likely to pay for food with environmental footprints labels, supporting the development of sustainable food consumption habits.

The Internet transforms the way people access food and serves as a primary channel for acquiring dietary knowledge. On one hand, the rise of food delivery services and online grocery shopping makes plant-based alternatives more accessible. Many platforms now offer vegan and vegetarian options alongside traditional choices, leading to an increase in plant-based food purchases [33]. However, many popular food delivery options, such as fast-food chains, heavily feature animal-based items on e-commerce platforms [34]. This ease of access can lead people to order animal-based foods for convenience, particularly in regions where plant-based options are limited. Overall, Internet use encourages greater openness to plant-based diets, especially through social media, digital communities, and environmental information. However, the Internet also promotes the consumption of animal-based foods through trends like high-protein diets, food delivery options, and cultural dietary content. At the same time, literature indicates that Internet use is associated with agricultural productivity [35], improved nutritional intake [36,13], increased income [37], reduced income inequality [37], and the adoption of sustainable agricultural practices. However, the effects of these factors on food carbon and water footprints remain unclear [38].

However, Internet use may also have some negative effect on sustainable food consumption to some extent. For example, Vatsa et al. [29] observe that Internet users are more inclined to order takeout, often choosing fast food and snacks, which frequently consist of animal-based

products that significantly contribute to environmental degradation. Furthermore, there is a prevalence of misleading information on the internet [23,29]. Food advertising may often emphasize flavor and nutritional aspects while overlooking the negative environmental impact of food [30]. For example, many advertisements for red meat, known for its high carbon footprints, often depict natural environments, creating a false impression of a low carbon footprints. As a result, the effect of Internet use on food consumption and its environmental consequences is mixed. This study examines the impact of Internet use on food consumption and its environmental footprints. Our research aims to expand the scope of investigations into food consumption and environmental footprints while exploring new approaches to mitigate the environmental effect of food consumption. Given the limited presence of grocery stores and supermarkets in rural China, which results in restricted food variety and compromised dietary quality, Internet use may have a more significant effect on farmer residents. Therefore, our study focuses on rural areas with farming communities. The theoretical framework illustrating the impact of Internet use on food consumption and its environmental footprints is presented in Fig. 1.

## 3. Methods and data

### 3.1. Methods

To examine the effect of Internet use on sustainable food consumption, we initiate the investigation with the following benchmark models:

$$Y_{it} = \alpha_0 + \alpha_1 Internet_{it} + \alpha_2 X_{it} + \varepsilon_{it}, \quad (1)$$

where $Y_{it}$ is dependent variables in year t for the $i$ th individual, including the food carbon footprints and food water footprints; $Internet_{it}$ is the key independent variable. It's a dummy variable, while $\alpha_1$ is the difference in environmental footprints between Internet user and non-user; $X_{it}$ represent the control variables, including age, education, marital status, work, household income, and household size; and $\varepsilon_{it}$ is the error term.

When $Internet_{it}$ is treated as exogenous variable, $\alpha_1$ in Eq. (1) can be utilized to assess the effect of Internet use on food environmental footprints. However, the potential endogeneity may introduce biased and inconsistent estimates due to unobserved heterogeneity and self-selection bias. For example, certain studies have shown that people with higher levels of education and income are more likely to express a preference for Internet use [37]. Other study also find that education and income play crucial roles in influencing individuals' dietary intake [39,40]. Note that the individual awareness of environmental protection is often challenging to quantify and is not included in our data. Therefore, overlooking the endogeneity of Internet use in food consumption might introduce bias into the estimation results.

The instrumental variable estimation is used to calculate the effect of Internet use on food environmental footprints. The number of residents using the Internet in the same village is used as an instrumental variable in this study. It should be noted that this instrumental variable has been widely used in existing studies [41,10,42], and the two-stage least square procedure is as follows:

$$Internet_{it} = \beta_0 + \beta_1 IV_{it} + \beta_2 X_{it} + \tau_{it}, \quad (2)$$

$$Y_{it} = \gamma_0 + \gamma_1 \widehat{Internet}_{it} + \gamma_2 X_{it} + \varphi_{it}, \quad (3)$$

where $IV_{it}$ denotes the instrumental variable; $X_{it}$ represents control variables; and $\widehat{Internet}_{it}$ is the predicted value of $Internet_{it}$ in Eq. (2), ensuring it is not correlated with $\varphi_{it}$. $\gamma_1$ provides a consistent estimate of the impact of Internet use on food environmental footprints.

The proportion of the Internet use sample to the total village sample, excluding the household itself, serves as a good instrument for Internet use for two main reasons. First, it is expected to directly influence individual Internet use, particularly in rural areas. In China, residents within the same village are closely interconnected, and Internet use often shows a replicative effect among neighbors [43]. Second, it could be considered an exogenous variable, as its influence on individuals' food consumption is limited to determining whether they use the Internet. Since all samples are randomly selected, and the number of responders in each village is approximately equal, this study treats the proportion of the Internet use sample to the total village sample a reliable proxy variable for Internet use at the village level [44].

This study uses a Hausman test to assess the endogeneity of the variable. If the test is rejected, it implies that the regular estimate results may be biased. Besides, when the instrument is weak, the estimator remains biased, and the reliability of the Wald test is compromised. To evaluate the validity of the instrument variable, the study employs Cragg–Donald Wald test and F test to check for weak instrument issues. As a general guideline, if the value of F statistic exceeds 10, concerns about the weak instrument problem are alleviated [24]. Alternatively, Anderson–Rubin test could be accepted if there is only one endogenous variable.

### 3.2. Data

Data used in this study are from the CHNS, an international collaboration between the National Institute of Nutrition and Food Safety of the Chinese Center for Disease Control and Prevention and the Carolina Population Center at the University of North Carolina in Chapel Hill. Spanning 10 waves (1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, and 2015), the CHNS covers 12 provinces (Jiangsu, Liaoning, Shandong, Shaanxi, Guangxi, Henan, Hubei, Hunan, Guizhou, Yunnan, Zhejiang and Heilongjiang) and 3 autonomous cities (Shanghai, Beijing and Chongqing), comprising approximately 7200 households and over 30,000 individuals as part of its longitudinal dataset. The CHNS dataset contains extensive individual and household information, encompassing factors such as economic development, geography, public resources, health, and other indicators for the respondents. Furthermore, comprehensive community data have been collected through surveys involving food markets, health facilities, family planning officials, and other social service and community leaders. Renowned for its richness, the CHNS database stands as one of the most widely utilized Chinese databases in the realms of economics and nutrition research.

For the purpose of this study, we used two criteria to narrow the sample range. Since 2004, the contents of the food consumption section of the CHNS questionnaire have remained consistent, but the food intake of responders is not available in CHNS 2015 (information other than that on food consumption is published). Thus, only data from the 2004–2011 waves are used in this study. Second, we only consider adults (older than 18 years at the survey year) and restrict the sample to rural areas. Finally, 20,105 observations in 167 villages are obtained.

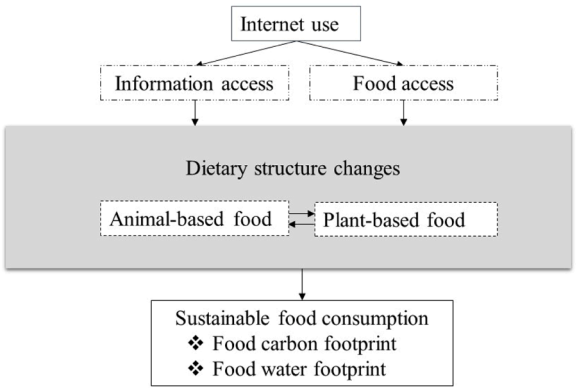


**Fig. 1.** Theoretical framework.

### 3.2.1. Internet use

The key independent variable is the Internet use. We assign a value of 1 to this dummy variable if the respondent uses the Internet, and a value of 0 if the respondent does not use the Internet.

### 3.2.2. Food environmental footprints

This study assesses the environmental effects of diet structures based on practical concerns related to food production and consumption, using food carbon and water footprints. These footprints are determined by multiplying food consumption (both purchased and self-produced) by the corresponding weighted environmental intensities, calculated through the Life Cycle Assessment (LCA) method. Specifically, we extract carbon and water footprints factors for each food group from over 100 LCA studies, encompassing the entire life cycle from cradle to farm gate [45]. As shown in Table A1, carbon LCA factor and water LCA factor in this study are the average values of these studies. Furthermore, CHNS also collects respondents' intake data for various food groups over the past three days, along with detailed nutritional information from the Chinese Food Composition Tables. We can calculate the average daily intake for each food group for each person [38,46]. Consequently, the carbon and water footprints can be computed using Eqs. (4) and (5), respectively:

$$CF_i = \sum_{j=1}^{n} f_j * Q_J, \tag{4}$$

$$WF_i = \sum_{j=1}^{n} w_j * S_J, \tag{5}$$

where $CF_i$ and $WF_i$ are the food carbon and water footprints for the $i$ th individual; $f_j$ and $w_j$ are the intakes of the $i$ th food group; $Q_J$ and $S_J$ are the weighted carbon intensity (g $CO_2$e/g food) and weighted water intensity (g/g food) respectively. It should be noted that differences in cooking methods across regions and ethnic groups are not considered in this study, but we have compared the relevant research literature, and the findings show that our results are consistent with it [6,47]. In addition, time and individual fixed effects are controlled for in the estimation of the parameters; hence, we believe that excluding these phases will not significantly change the outcomes.

In this study, dietary intakes include the 11 food groups of eggs, pork, poultry, red meat, fish and seafood, dairy, fruits, vegetables, tubers, beans, and grains. The per capita daily carbon and water footprints of each food group in rural China in 2004–2011 are shown in Fig. 2.

As depicted in Fig. 2, there is no notable shift observed in the ratios of the carbon and water footprints among different food groups in rural China from 2004 to 2011. However, substantial variations exist in the overall contributions of various food groups to the carbon and water footprints. The food carbon footprints of China's rural areas come mainly from red meat consumption, which exceeds 50 % of the total food carbon footprints and shows an increasing trend. The food water footprints are mainly produced by red meat, egg, and grain consumption. This suggests that if the Chinese could reduce their meat consumption, especially in terms of red meat, the environmental impact of their diet would be greatly reduced.

The average dietary carbon footprints and water footprints from 2004 to 2011 for Internet user and non- user are shown in Fig. 3. Between 2004 and 2011, the median and mean carbon and water footprints of Internet users are consistently higher than those of non–user. However, an overall decreasing trend is evident in the mean and median food carbon footprints of Internet user; there is also a decreasing trend in the food water footprints, but this is not as great as the decrease in the food carbon footprints. For non–user, the median and mean food carbon and food water footprints show an increasing trend. It's essential to highlight that we currently do not control for the individual and household characteristics of respondents in this analysis, and we are not addressing the endogeneity of Internet use either. Therefore, further results are needed to identify the causal effects of Internet use on the food environmental footprints.

### 3.2.3. Control variables

We controlled for the age of respondents because the probability of Internet use and dietary intake may change with age. As indicated in Table 1, the mean age of Internet user is 35.6 years, while the mean age of non-Internet user is 48.6 years, with a significant difference at the 1 % level. Education and income serve as additional control variables. First, most Chinese adults encounter the Internet later in life, and those with higher education levels are more likely to learn and use it. Second, as

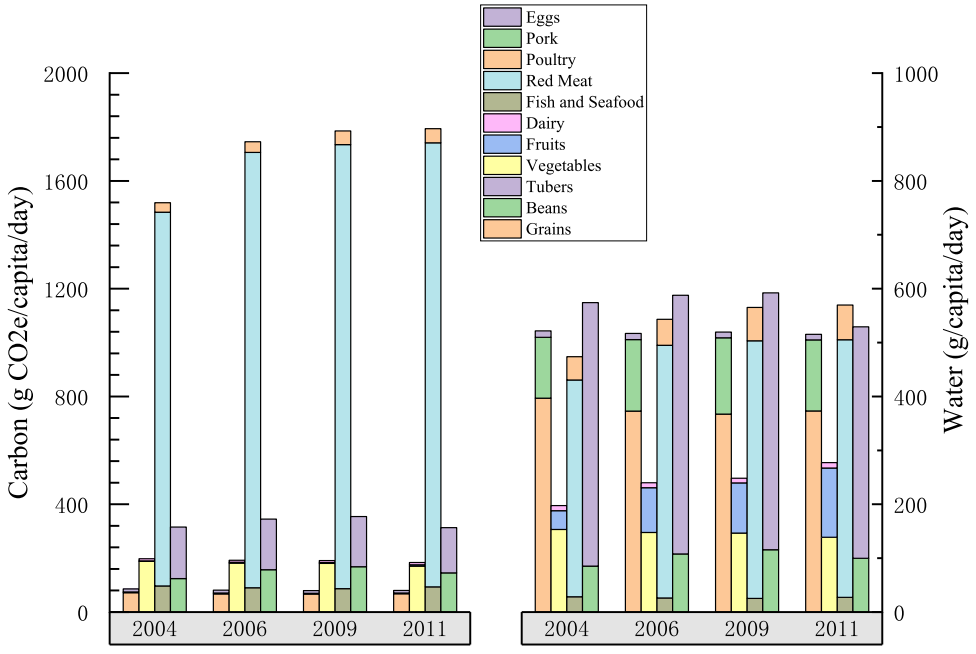


**Fig. 2.** Per capita daily average dietary carbon footprints (unit: g $CO_2$e/capita/day) and water footprints (unit: g/capita/day) of food groups in rural China in 2004–2011.

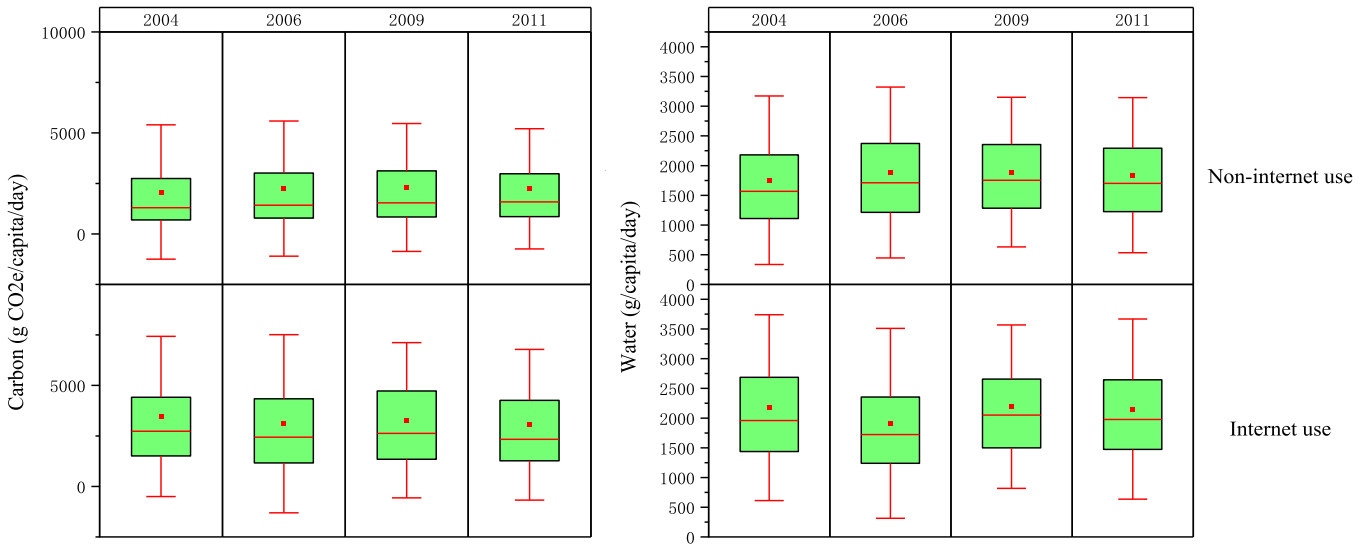


**Fig. 3.** Dietary carbon footprints (in g $CO_2e$/ per capita/day) and water footprints (in g/capita/day) in rural China for Internet-use and non-Internet-use groups. Note: The boxplots show the median, 1st quantile, and 3rd quantile information about the food carbon footprints and water footprints; the point in the boxplots is the mean value.

**Table 1**
The descriptive statistics of main variables.

| | Definition | Pooled (1) | Internet-use (2) | Non-Internet-use (3) | Diff [a] (2)-(3) |
|---|---|---|---|---|---|
| **Independent variables** | | | | | |
| Internet use | 1 if use Internet, 0 otherwise | 0.161 | | | |
| | | (0.368) | | | |
| **Dependent variables** | | | | | |
| Carbon | Food carbon footprints (unit: g $CO_2e$/capita/day) | 2315.650 | 3151.150 | 2208.940 | 942.210*** |
| | | (2223.040) | (2652.508) | (2138.760) | |
| Water | Food water footprints | 1867.907 | 2095.184 | 1838.879 | 256.305*** |
| | (unit: g/capita/day) | (922.527) | (1012.947) | (906.266) | |
| **Control variables:** | | | | | |
| Age | Age of the respondent (year) | 47.102 | 35.586 | 48.573 | −12.987*** |
| | | (14.528) | (13.210) | (14.023) | |
| Marriage | =1 if married, =0 otherwise | 0.886 | 0.767 | 0.901 | −0.134*** |
| | | (0.317) | (0.423) | (0.298) | |
| Education | Education attainment (year) | 8.067 | 12.050 | 7.558 | 4.492*** |
| | | (4.211) | (4.436) | (3.898) | |
| Work | =1 if working, =0 otherwise | 0.779 | 0.900 | 0.764 | 0.137*** |
| | | (0.415) | (0.299) | (0.425) | |
| Income | Household per capita income (unit: CNY) | 15,348.450 | 25,647.490 | 14,033.060 | 11,614.43*** |
| | | (17,991.360) | (24,531.380) | (16,520.370) | |
| Household size | Number of families | 4.060 | 3.742 | 4.087 | −0.345*** |
| | | (32.177) | (35.995) | (31.638) | |
| No. of observations: | | 20,105 | 3237 | 16,868 | |

Notes: Standard deviations are provided in parentheses; *** denotes $p < 0.01$; ** denotes $p < 0.05$; * denotes $p < 0.1$.
[a] T-test has been employed.

Internet use comes with a certain cost, an increase in income is associated with a higher likelihood of using the Internet. Additionally, at the individual level, we control for marriage status, work status, and household size. Household size is considered to account for heterogeneous effects on dietary intake and Internet use at the household level. All the control variables are selected with reference to the existing literature. More detailed descriptive statistics on main variables, refer to Table 1.

## 4. Results and discussion

### *4.1. IV estimations of the effect of Internet use on environmental footprints*

The IV estimation results for the impact of Internet use on food carbon and water footprints are presented in Table 2. The Hausman test of endogeneity, which assesses the validity of the instrumental estimation model, rejects the null hypothesis regarding the exogeneity of Internet use at the 1 % significance level. This indicates that the IV estimation is the appropriate model for further analysis. The significant coefficient of the IV at the 1 % level suggests that as more people in the village use the Internet, respondents are more likely to use it as well. Additionally, Internet use at the village level generally influences individual production and consumption behavior by determining whether individuals use the Internet [37,40]. Despite the exogenous correlation of this instrumental variable with Internet use, its validity is tested to ensure that the instrument is not weak. As shown at the bottom of Table 2, both the F-test and the Cragg–Donald Wald test values exceed the critical value of 10. Therefore, there is no significant concern regarding the presence of a weak instrument problem in this estimation

**Table 2**
The effect of Internet use on food environmental footprints.

| | Carbon [a] | | Water [a] | |
|---|---|---|---|---|
| | First stage | Second stage | First stage | Second stage |
| Internet use | | −0.181*** | | −0.106*** |
| | | (0.058) | | (0.032) |
| Age | −0.010*** | 0.006** | −0.010*** | 0.009*** |
| | (0.001) | (0.002) | (0.001) | (0.001) |
| Marriage | 0.016 | 0.090** | 0.016 | 0.024 |
| | (0.011) | (0.045) | (0.011) | (0.025) |
| Education | 0.004*** | −0.004 | 0.004*** | −0.001 |
| | (0.001) | (−0.420) | (0.001) | (0.500) |
| Work | 0.024*** | −0.003 | 0.024*** | 0.002 |
| | (0.006) | (0.02) | (0.006) | (0.011) |
| Income [a] | −0.001 | 0.065*** | −0.001 | 0.027*** |
| | (0.002) | (0.010) | (0.002) | (0.005) |
| Household size | 0.000 | 0.000 | 0.000 | 0.001** |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| Constant | 0.412*** | 6.438*** | 0.412*** | 6.688*** |
| | (0.036) | | (0.036) | |
| IV | 0.017*** | | 0.017*** | |
| | (0.000) | | (0.000) | |
| Endogeneity test p-value | | 0.000 | | 0.000 |
| F test | | 2925.180 | | 2925.18 |
| Cragg–Donald Wald test | | 5298.514 | | 5298.514 |
| weak instrumental test | | 16.380 | | 16.380 |
| Anderson–Rubin (AR) test | | 363.640 (0.000) | | 7.490(0.006) |
| R-squared | 0.323 | 0.002 | 0.323 | 0.009 |
| Observations | 20,105 | 20,105 | 20,105 | 20,105 |

*Notes:* *** denotes $p < 0.01$; ** denotes $p < 0.05$; * denotes $p < 0.1$. Year and individual fixed effects are controlled. Robust standard errors are presented in parentheses.

[a] is natural logarithm is used for regression.

[24]. In the first stage results, the coefficient for age is negative and significant at the 1 % level. Which can be explained by the fact that older individuals are less inclined to use the Internet. These results are consistent with some existing studies [36,35]. Notably, China's Internet user base has witnessed rapid growth only in the past two decades, extending from urban centers to rural areas. Some elderly individuals in rural China have already adapted to a life without the Internet and display less enthusiasm for embracing new technologies [48]. Hence, there may exists a negative relationship between age and Internet use.

The coefficients for both education and work status are positive and significant at the 1 % level. This indicates that respondents with higher levels of education are more inclined to use the Internet, and individuals with jobs are more likely to use the Internet compared to those without jobs. These findings align with existing literature [49,50,51]. Public courses in schools often incorporate Internet-related topics, and individuals with higher education levels typically have better access to the Internet. Moreover, respondents with higher education levels tend to possess better learning abilities, making them more likely to embrace and use the Internet.

In the second stage results, coefficients of Internet use on food carbon footprints and food water footprints are −0.181 and −0.106, respectively and significant at the 1 % level. This suggests that Internet use has the potential to decrease carbon footprints by approximately 18.1 % and water footprints by about 10.6 %, holding other conditions constant and addressing endogeneity. These results align with our expectations.

On one hand, the Internet provides a wealth of information about the health benefits of plant-based diets, which can encourage people to reduce their consumption of animal-based foods and incorporate more fruits, vegetables, and grains [52,53]. On the other hand, Internet use increases public awareness of environmental risks and influences attitudes toward environmental protection, which further promotes the consumption of plant-based foods. Since plant-based food chains have lower carbon and water footprints intensities than animal-based food chains [54,55], the Internet can contribute to sustainable food consumption by reducing food carbon and water footprints. Furthermore, Internet use improves agricultural market performance and pricing, which serves as another important channel through which the Internet supports sustainable food consumption [12].

The coefficients of age concerning food carbon and food water footprints are 0.006 and 0.009, respectively and significant at the 1 % level. This suggests that for each year of reduction in average age, the food carbon and food water footprints would be reduced by 0.6 % and 0.9 %, respectively. Studies find that more and more young people are willing to buy organic and environmentally certified food to reduce carbon emissions and water consumption in the food production process [56,57]. Studies have also found that young people are more inclined to choose locally sourced ingredients to reduce the carbon footprints caused by long-distance transportation [58]. This environmentally friendly food choice reflects not only young people's awareness of consumption but also their sense of responsibility for environmental issues. Besides, this study found that young people are more inclined to choose vegetarian and plant-based foods, which reduces the demand for carbon-intensive and water-intensive foods to some extent, thereby reducing their food carbon and food water footprints [59]. As shown in Table 2, income is also significantly positive. This suggests that, as incomes rise, the food carbon and water footprints increase. In rural areas of China, some foods with high carbon emissions and higher water consumption, such as beef, pork, fish, and milk, usually have higher prices, which limits the consumption of these foods for rural residents. As incomes increase, the intake of these foods also increases, which raises the food carbon and water footprints. The coefficients of marriage and household size are also positive. One explanation for this could be that married families and larger families often have more social activities and meals, which can lead to more food waste and overconsumption, thereby increasing the food carbon and food water footprints.

### 4.2. Robustness check

To examine the robustness of our main findings, we conduct two additional analyses using different methods to address the endogeneity problem of Internet use. First, we use the propensity score matching (PSM) method to address potential endogeneity arising from self-selection bias due to observable factors. The results are presented in columns (1)-(2) of Table 3. It shows that the effect of Internet use on the environmental outcomes of food consumption is largely consistent with the estimate presented in Table 2, although the magnitudes differ. The possible reason is that PSM can only partially deal with the endogeneity problem if there is self-selection bias due to observable factors the estimates from PSM may be biased. Fortunately, the IV estimation method can address the endogeneity issue caused by both observable and unobservable variables. To further validate the reliability of the IV estimates, we use an alternative instrument variable to test the robustness of our results. Following the strategies in the previous studies [11,37,35],

**Table 3**
Robustness tests.

| | PSM method | | Use another IV | |
|---|---|---|---|---|
| | Carbon | Water | Carbon | Water |
| Internet use | −0.094*** | −0.037** | −0.150*** | −0.062*** |
| | (0.032) | (0.017) | (0.037) | (0.020) |
| First stage | | | | |
| Ratio | | | 0.028*** | 0.028*** |
| | | | (0.007) | (0.007) |
| R-squared | −0.796 | −0.791 | 0.006 | 0.005 |
| Observations | 19,973 | 19,973 | 20,105 | 20,105 |

*Notes:* *** denotes $p < 0.01$; ** denotes $p < 0.05$; * denotes $p < 0.1$. Year and individual fixed effects are controlled. Robust standard errors are presented in parentheses.

the ratio of Internet use in the community (excluding individual him/-herself) is applied as a potential instrument. As a valid IV, it is required to be correlated with the endogenous variable (Internet use) but has no significant effect on the dependent variables (environmental outcomes of food consumption). Normally, individuals' Internet use can be affected by their peers, but Internet use of their peers can hardly have a direct effect on their food consumption. The estimation results are presented in columns (3)-(4) of Table 3. Evidence from F-Statistics at the first stage further proves that the ratio of Internet use in the community tends to increase the probability of Internet use for each individual. Regarding the effect of Internet use, we can find our main findings remain and the magnitudes are almost the same as those presented in Table 2. Thus, we can conclude that Internet use has a significantly negative effect on the environmental outcomes of food consumption, and this finding is consistent by using various methods.

### 4.3. Heterogeneity analysis

This study explores the heterogeneous effect of Internet use on food environmental footprints across three dimensions: region, age, and income. The sample is divided into an eastern region and a middle and western region. Table 4 reveals that Internet use significantly reduces both carbon and water footprints from food consumption in both regions. It is noteworthy that the effect of Internet use is more pronounced in the eastern region, possibly attributed to its more developed network infrastructure, higher network coverage, and faster Internet access. In contrast, the middle and western regions have relatively weaker network infrastructure, with some rural areas lacking high-speed Internet access. Additionally, the eastern region of China is more economically developed, with higher education levels and richer natural resources, further amplifying the impact of Internet use on the food environmental footprints in this region.

Age is categorized into three stages: 18–35, 35–60, and over 60 years old. Table 5 illustrates the effects of Internet use on these different age groups. Our findings indicate that Internet use does not significantly impact the food carbon or food water footprints of respondents over 60 years old. Meanwhile, Internet use significantly reduces the food carbon and food water footprints of respondents under 60 years of age. Furthermore, the effectiveness coefficient of Internet use in people aged 18–35 years is larger than that in people aged 35–60 years. These results may be attributed to potential differences in food consumption habits among age groups. Young individuals may have a good preference for fresh and healthy food, opting for items that are low in carbon and water consumption. Conversely, older age groups might adhere to more traditional food consumption patterns, showing less concern for environmental factors. Additionally, young people are typically more adept at using the Internet, facilitating their access to diverse information on food consumption and environmental protection, thereby strengthening their environmental awareness and food consumption behavior.

The results in Table 6 indicate that Internet use primarily reduces the food carbon and food water footprints of the high-income group. More specifically, Internet use results in a 27.2 % reduction in food carbon footprints and a 12.9 % reduction in food water footprints for this group. However, the coefficient of Internet use for low-income groups, though negative, is not statistically significant. It is plausible that low-income groups experience more pronounced economic pressures and financial constraints, leading them to rely on affordable and convenient food options, which, unfortunately, are often less healthy and have a more significant environmental impact. While the Internet's proliferation may offer more shopping choices for low-income groups, economic considerations might limit their capacity to enhance their food environmental footprints. Furthermore, high-income groups typically have better access to education and information, making them more likely to understand the significance of a healthy diet and how to improve their food environmental footprints. This knowledge empowers them to make healthier and environmentally conscious decisions when purchasing and selecting food. Conversely, low-income groups might lack equivalent access to such knowledge and information, resulting in less significant changes in their food environmental footprints.

**Table 4**
Heterogeneity analysis in different regions.

| | Eastern region | | Middle and western region | |
|---|---|---|---|---|
| | Carbon | Water | Carbon | Water |
| Internet use | −0.197* | −0.170*** | −0.160** | −0.068* |
| | (0.102) | (0.056) | (0.071) | (0.039) |
| R-squared | 0.007 | 0.005 | 0.019 | 0.020 |
| Observations | 7210 | 7210 | 12,895 | 12,895 |

*** denotes $p < 0.01$.
** denotes $p < 0.05$.
* denotes $p < 0.1$. Year and individual fixed effects are controlled. Robust standard errors are presented in parentheses.

### 4.4. Influencing channel

In this section, we analyze the channels through which Internet use influences food carbon and water footprints. We classify foods into two categories: animal-based foods and plant-based foods. Animal-based foods include eggs, pork, poultry, red meat, fish and seafood, and dairy, while plant-based foods consist of fruits, vegetables, tubers, beans, and grains. Our findings highlight that Internet use predominantly and significantly reduces the consumption of animal-based foods. More specifically, it reduces the intake of eggs and pork, while having a positive effect on poultry consumption. However, the coefficient for plant-based foods is not statistically significant, primarily due to the Internet's role in reducing the consumption of grains and beans but concurrently increasing the intake of fruits. It is noteworthy that Internet use primarily reduces the environmental impact of food by mitigating the consumption of animal-based sources with higher environmental footprints. Given that, in rural China, the consumption of grains and beans often exceeds the recommended dietary guidelines, whereas the consumption of fruits tends to fall below the recommended dietary quality intake, we suggest that Internet use not only reduces the environmental footprints of food but also encourages a more rationalized food consumption structure (Table 7).

## 5. Conclusions and implication

Reducing food carbon and water footprints is a crucial step toward achieving sustainable food consumption. However, the effect of Internet use on these footprints, particularly in rural China, remains poorly understood. In this study, we leverage CHNS data from 2004 to 2011 to examine the causal relationship between Internet use and food carbon and water footprints. Our analysis also explores the pathways through which dietary changes occur. Additionally, we investigate the heterogeneity of Internet use in relation to food environmental footprints across regions, age groups, and income levels. We employ the instrumental variable method to address the endogeneity issue associated with Internet use, and the estimation results from PSM reinforce the robustness of our findings.

The empirical analysis yields three key findings. First, Internet use significantly reduces the food carbon and water footprints of rural residents. Specifically, Internet use reduces the food carbon footprints by 18.1 % and the food water footprints by 10.6 %. Additionally, education and age are key variables that influence whether consumers use the Internet, while income and age also affect food carbon and water footprints. Second, our results highlight that Internet use promotes the adoption of sustainable food consumption practices, primarily by reducing the consumption of animal-based foods. Finally, we find that Internet use has a more significant impact on lowering food carbon and water footprints for individuals with higher incomes and younger age

**Table 5**
Heterogeneity analysis at different age.

| | Group 1 (18 ≤ age < 35) | | Group 2 (35 ≤ age < 60) | | Group 3 (60 ≤ age) | |
|---|---|---|---|---|---|---|
| | Carbon | Water | Carbon | Water | Carbon | Water |
| Internet use | −0.503** | −0.269** | −0.146** | −0.092** | −0.175 | −0.070 |
| | (0.220) | (0.121) | (0.070) | (0.038) | (0.154) | (0.085) |
| R-squared | 0.007 | 0.000 | 0.004 | 0.000 | 0.018 | 0.000 |
| Observations | 3567 | 3567 | 12,353 | 12,353 | 4185 | 4185 |

*Notes:* *** denotes $p < 0.01$; ** denotes $p < 0.05$; * denotes $p < 0.1$. Year and individual fixed effects are controlled. Robust standard errors are presented in parentheses.

**Table 6**
Heterogeneity analysis at different levels of income.

| | Low-income group | | High-income group | |
|---|---|---|---|---|
| | Carbon | Water | Carbon | Water |
| Internet use | −0.081 | −0.073 | −0.272** | −0.139** |
| | (0.087) | (0.049) | (0.108) | (0.059) |
| R-squared | 0.003 | 0.012 | 0.007 | 0.011 |
| Observations | 9947 | 9947 | 10,158 | 10,158 |

*Notes:* *** denotes $p < 0.01$; ** denotes $p < 0.05$; * denotes $p < 0.1$. Year and individual fixed effects are controlled. Robust standard errors are presented in parentheses.

**Table 7**
The impact of Internet use on food consumption.

| Animal-based food | | Poultry | Eggs | Pork |
|---|---|---|---|---|
| Internet use | −31.233** | 8.945** | −24.059** | −14.775*** |
| | (12.774) | (3.648) | (11.006) | (5.319) |
| R-squared | 0.000 | 0.002 | 0.001 | 0.005 |
| Observations | 20,105 | 20,105 | 20,105 | 20,105 |
| | Plant-based food | Grain | Beans | Fruits |
| Internet use | 2.913 | −19.271* | −4.937** | 34.516*** |
| | (2.972) | (10.031) | (2.077) | (11.486) |
| R-squared | 0.001 | 0.002 | 0.002 | 0.001 |
| Observations | 20,105 | 20,105 | 20,105 | 20,105 |

*Notes:* *** denotes $p < 0.01$; ** denotes $p < 0.05$; * denotes $p < 0.1$. Year and individual fixed effects are controlled. Robust standard errors are presented in parentheses. We examined the effect of Internet use on each specific food, and here we do not show results that are not statistically significant.

groups, while its impact is more limited for those with lower incomes and older individuals.

These findings provide important insights into current discussions on dietary change and environmental sustainability. First, digitization plays a crucial role in influencing sustainable food consumption, with the Internet serving as a platform to promote reductions in the carbon and water footprints associated with food. Additionally, there are significant differences in food carbon and water footprints across income levels and age groups, suggesting that policy interventions should account for factors such as income and age. For example, online education can help younger people develop sustainable food habits, while offline training might be more effective for older adults. Second, Internet use is associated with reduced consumption of eggs and pork and increased consumption of fruits, reflecting its impact on consumer behavior. Governments can leverage the Internet to encourage shifts in dietary patterns, such as promoting reduced animal-based food intake and increased plant-based consumption. Third, we find that Internet use does not significantly influence the food carbon and water footprints of low-income households, likely due to their limited food purchasing options. Given that income is a key factor affecting food carbon and water footprints, raising the incomes of low-income households may be a more effective strategy for advancing sustainable food consumption. Of course, there are some limitations in this study. First, the data used in this study spans from 2004 to 2011. While this period includes several years of rapid Internet development in China, future studies could benefit from using more recent panel data. Second, this study focuses on the short-term effects of Internet use on sustainable food consumption, and future research could explore its long-term effects.

## CRediT authorship contribution statement

**Jian Liu:** Writing – review & editing, Writing – original draft, Validation, Software, Resources, Methodology, Formal analysis, Data curation. **Yanjun Ren:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology. **Yu Hong:** Writing – review & editing, Validation, Supervision, Project administration, Methodology. **Thomas Glauben:** Writing – review & editing, Validation, Supervision, Resources, Project administration. **Qiang Li:** Writing – review & editing, Validation, Formal analysis.

## Declaration of competing interest

The authors declare that there are no conflicts of interest related to the research described in this paper.

## Appendix

**Table A1**
Carbon and water LCA factors.

| | Carbon LCA factors | Water LCA factors |
|---|---|---|
| Grains | 0.260 | 1.432 |
| Beans | 0.060 | 2.700 |
| Tubers | 0.250 | 0.272 |
| Vegetables | 0.450 | 0.366 |
| Fruits | 0.072 | 1.856 |
| Dairy | 1.070 | 1.280 |

(*continued on next page*)

**Table A1** (*continued*)

| | Carbon LCA factors | Water LCA factors |
|---|---|---|
| Fish | 3.424 | 1.000 |
| Red meat | 33.50 | 9.717 |
| Poultry | 3.250 | 3.971 |
| Pork | 6.470 | 4.445 |
| Eggs | 1.210 | 3.094 |

*Notes:* The author calculated the factors from the relevant literature. Literature sources are available on request from the corresponding author.

## Data availability

Data will be made available on request.

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