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Dietary patterns and greenhouse gas emissions: a household-level analysis in Hue City, Vietnam

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Abstract. This study examines the relationship between food consumption at the household level and greenhouse gas emissions in Hue City, Vietnam, using a survey of 400 households and emission factors derived from Life Cycle Analysis. The study underscores the significant contribution of household food consumption patterns to greenhouse gas emissions, with animal-based products, particularly beef and seafood, the primary drivers because of their high emission factors. In 2023, the city's households generated around 3,068,534 tons of CO_2e from food consumption, highlighting the urgent need for dietary shifts toward plant-based foods to mitigate environmental impact. Additionally, the substantial food waste of 23,658 tons per year—caused by unplanned food shopping, poor meal planning, and improper storage—results in greenhouse gas emissions of 21,055 tons of CO_2e. The reliance on traditional markets for locally sourced food offers a positive note, as it reduces transport-related emissions, but current consumption and waste management practices remain unsustainable. The study argues for promoting plant-based diets, improved food waste management strategies, increased awareness of sustainable consumption, improved food systems, and comprehensive education on climate-resilient practices. These results highlight gaps in the policy framework of Hue City and other fast urbanising cities while aiding in formulating climate mitigation and sustainability policies for Vietnam.

Keywords: food consumption, greenhouse gas emissions, Life Cycle Analysis, food waste

1 Introduction

The sustainability of the planet and its ecosystems is being challenged severely because of climate change. Human activities such as agriculture, deforestation, and industrialisation are the primary underlying causes of climate change. One noticeable effect of climate change is the increasing occurrence of extreme weather phenomena and the destruction of entire ecosystems. This can largely be attributed to the continued rise of greenhouse gas emissions (GHG) in the atmosphere. The global food system, from production to consumption, directly contributes to one-third of worldwide GHG, rendering it one of the most significant contributors [1].

The changing patterns in the consumption of meat and other processed foods are of great concern because of their impact on the environment, especially in the context of an increasing world population [2]. These shifts in diet, particularly in emerging economies because of increasing urbanisation, lead to higher income levels and greater consumption of food, posing challenges to the sustainability of resources such as water and land [3, 4].

Vietnam is known for its development pace, but it has particular challenges concerning

food security, environmental preservation, and climate change management. Agriculture, the mainstay of the economy and the employment cornerstone for many, also contributes immensely towards environmentally damaging activities and GHG emissions [5]. In this context, food consumption at the household level significantly affects the carbon footprint of the food system via dietary choices, consumption behaviour, and waste generation. Responsible food consumption has the potential to mitigate GHGs and improve the efficiency of the food system globally [4].

Hue City (Thua Thien Hue province until 2025), a rapidly urbanising area in Central Vietnam, provides a compelling case study for examining the relationship between household food consumption and GHG emissions. Urbanisation often drives dietary shifts toward meat, processed foods, and sugary drinks, which have higher carbon footprints than traditional Vietnamese cuisine [6]. These changes, linked to economic development, are likely to increase household GHG emissions because of the energy-intensive production of such foods.

Even though people are increasingly concerned about how food systems affect the environment, there is limited research connecting the consumption of food at the household level to GHG emissions in Vietnam, especially at the sub-national scale [7]. The vast majority of studies analyse the data at the country level or concentrate on one particular part of the food system, ignoring the urban household scale dynamics. Closing this gap is important for formulating tailored policies for contexts like Hue City [8].

This study analyses residential eating habits and related GHG emissions in Hue City to facilitate low-emission food systems and climate adaptation. Its findings aim to support targeted interventions in Hue City and provide insights for other cities in Vietnam and beyond, contributing to national and global efforts to mitigate food system GHG emissions.

2 Methods

2.1 Household survey using questionnaires

A survey using questionnaires was used to collect household information regarding shopping habits, food consumption, the amount of food waste generated, and food waste management. To determine the sample size of surveyed households, Yamane's (1967) formula (Equation 1) was applied.

$$n = \frac{N}{1 + N(e)^2} \quad (1)$$

where n is the minimum sample size; N is the population (total number of households) of Hue City based on 2023 data; e is the desired margin of error.

According to the Thua Thien Hue Statistical Yearbook 2024, the total number of households in Hue City (formerly Thua Thien Hue Province) is 284,524 in 2023 [9]. Applying the above formula with a chosen margin of error of 5%, the calculated sample size was 399 households, rounded up to 400.

To avoid bias and ensure statistical representativeness of the surveyed households in Hue City, the stratified sampling technique was employed. The entire city of Hue was divided into strata based on geographical characteristics: mountainous areas, plains, and coastal areas. The population, consisting of 284,524 households based on 2023 data, was stratified accordingly. Random sampling (using simple random sampling) was then conducted within each stratum. Nam Dong and A Luoi Rural Districts, based on 2023 administrative boundaries (with Nam Dong currently being merged into Phu Loc

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District), represent the mountainous areas; Thuan Hoa and Phu Xuan Districts denote the plains; and Phu Loc and Phu Vang Rural Districts stand for the coastal region (Fig. 1).

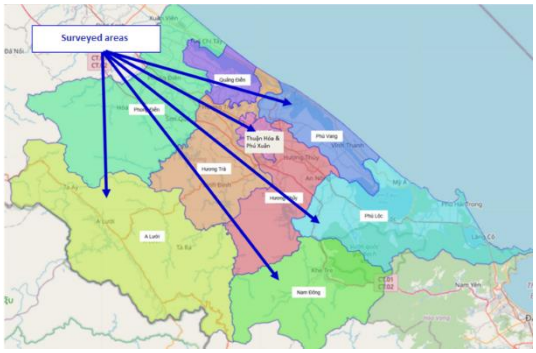

Fig. 1. Location of the surveyed areas in Hue City

The 2024 survey targets official household members aged 18 and older who live in the surveyed homes, are knowledgeable about the survey's subject, actively participate in household food consumption, and can respond to the survey questions.

A questionnaire, which acted as a survey instrument, was formulated to collect primary household data. It was pretested on a sample of five households before being administered for data collection.

2.2 Calculation of greenhouse gas emissions

The calculation of GHG emissions related to household food consumption involves a three-step process, considering the entire life cycle of food from production, processing, distribution, to consumption and disposal.

1) Data collection: Data on the types and amounts of food consumed by households over a defined period (daily or weekly) was obtained through the household survey described above.

2) Application of emission factors: Each type of food is associated with its corresponding life cycle stages, such as production (cultivation, livestock farming, fishing, etc.), processing (cleaning, milling, canning, etc.), distribution (transportation, storage, retail, etc.), consumption (purchasing, preparation, eating, etc.), and waste management (composting, landfilling, etc.) [10].

Greenhouse gas emissions based on the Life Cycle Analysis (LCA) per kilogram (referred to as emission factors) of basic food products, as established by Poore and Nemecek (2018) using the functional unit of retail weight, were used to calculate the GHG emissions of food across all stages of its life cycle (Fig. 2).

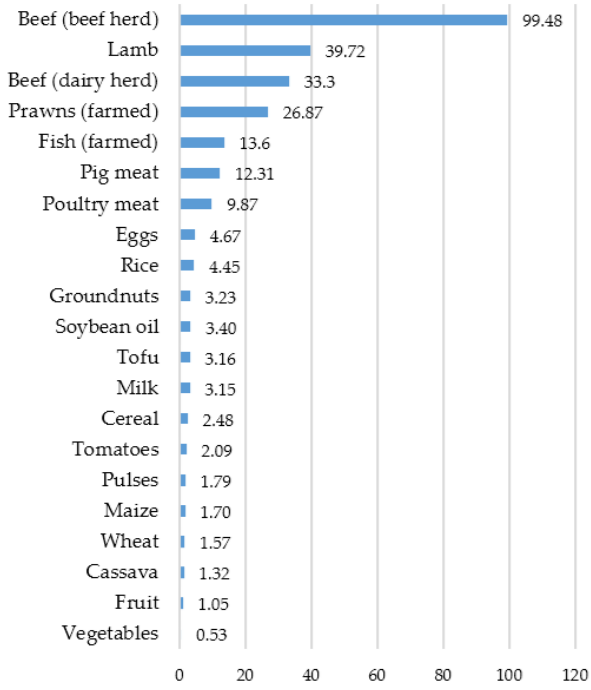

Fig. 2. LCA-based GHG emissions (kg of CO_2e) per kg of major food products [11] (processed by Our World in Data)

3) Estimation of greenhouse gas emissions: The emission factor for that item is multiplied by the corresponding quantity consumed to obtain the emissions linked to a particular food item. For each food item consumed by the household over the selected period (day/week/month/year), this method is repeated. The total GHG emissions resulting from a household's food consumption are calculated by summing emissions from all individual food items, as illustrated in formula 2.

Total GHG emissions = Σ (*Emission factor_i* × *Quantity_i*) (2)

where *i* represents each food item, excluding beverages; *Emission factor_i* is the average GHG emissions per unit for stage/item *i*; *Quantity_i* is the amount of food item *i* consumed.

2.3 Data analysis

The data collected from the questionnaire-based interviews and the GHG emissions were analysed with the Data Analysis tool in MS Excel, specifically an add-in called Analysis ToolPak Plus. This tool was used to quickly calculate the mean value and the standard deviation (SD) related to the data.

3 Results and discussion

3.1 Greenhouse gas emissions from food consumption

Food consumption

The survey results from 400 households, presented in Table 1, indicate the average weekly food consumption per household, categorised by food type and quantity. With an average of 4.1 members per household, the average per capita consumption of each food type is also provided in Table 1. Specifically,

– The most frequently eaten product is rice, constituting almost 29.5% of the total food quantity, with a weekly consumption of 6.67 kg per household.

– Fruits and vegetables rank as the second most commonly consumed category, making up 21.8% of total consumption at 4.92 kg per household per week.

– The proportion of total meat consumption reaches 13.8%. Of this, beef accounts for the smallest share, which is 3.1% or 0.71 kg per household per week.

– Milk and dairy products account for 10.2% of the total weight of consumption, which corresponds to a weekly intake of 2.31 kg per household.

– Other types, including legumes, snacks, and condiments, are consumed at 7.4 % or 1.68 kg per household per week.

Table 1. Types of food items and average weekly consumption

Type of food	Household food consumption/week (kg)	Proportion (%)
Beef	0.71	3.1
Pork	1.11	4.9
Goat and lamb	0.10	0.4
Poultry	1.21	5.4
Milk and dairy	2.31	10.2
Fish and other seafood	2.52	11.2
Vegetables and fruits	4.92	21.8
Rice	6.67	29.5
Bread	0.38	1.7
Cereal	0.20	0.9
Soybean oil	0.78	3.5
Other types	1.68	7.4
Total	**22,60**	**100**

Greenhouse gas emissions

From Table 2, GHG emission estimates related to household food consumption indicate that meat products, especially beef, account for a large portion of emissions because they have high emission factors, even if they are consumed in small amounts. Farmed fish and seafood have higher emission factors alongside their

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consumption levels, marking them as the second greatest source of emissions.

Regarding rice, vegetables, fruits, and other plant-based foods, they have lower emission factors, yet make a sizable contribution to emissions owing to their large-volume consumption. Other significant emission sources include the 'Other types", which incorporates assorted processed and packaged foods.

Overall, the survey results show that GHG emissions related to household food consumption are significant, particularly from animal-based products. This demonstrates the need to take into account the eco-friendlier food choices to reduce GHG emissions.

Table 2. GHG emissions from household food consumption

Type of food	Emission factor (kg CO_2e/kg)*	Weekly food consumption (kg/household)	Emissions/ week (kg CO_2e/ household)
Beef	99.5	0.71	70.6
Pork	12.3	1.11	13.7
Goat and lamb	39.7	0.10	4.0
Poultry	9.9	1.21	12.0
Butter and milk	3.2	2.31	7.4
Fish and other seafood	20.2	2.52	50.9
Vegetables and fruits	1.6	4.92	7.9
Rice	4.5	6.67	30.0
Bread	1.6	0.38	0.6
Cereal	2.48	0.20	0.50
Soybean oil	3.40	0.78	2.65
Other types	4.24**	1.68	7.12
Total		**22.60**	**207.37**

Note: **The emission factors were developed by Poore and Nemecek as mentioned above. **The emission factor for "Other types" is the weighted average of the food types listed immediately above, which excludes high emitters, including beef, lamb, and fish.*

Considering the household GHG emissions per week (207.4 kg CO_2e) presented in Table 2 and the total number of households of 284,524 in 2023 [9], the household GHG emissions from food consumption-based activities in Hue City are 59,010 tons of CO_2e/week, equivalent to 3,068,534 tons of CO_2e per annum.

According to the Food and Agriculture Organisation of the United Nations [12], the household distribution at the retail level of the global food supply from various sources in 2019 in developing countries is as follows: Cereals (e.g., wheat, rice, corn): 47.7%; Vegetable oils: 9.4%; Sugar crops: 6.8%; Meat: 5.9%; Dairy: 3.4%; Fruits and vegetables: 3.2%; Other plant-based sources: 18.6%; Other animal-based sources (e.g., eggs, fish): 5.0% [12]

The plant-based foods' share of the total global food supply is approximately 85.7%, with animal-based products (meat, dairy, eggs, and fish) accounting for only 14.3%. However, Table 1 indicates that household consumption of animal-based products in Hue City is much higher, at 35.2%, than the figure for an average developing country, which results in higher GHG emissions from food consumption. Reducing emissions from

food-related GHG emissions requires addressing issues related to the sheer volume of the available food, including shopping patterns, consumption habits, and food waste.

3.2 Factors influencing food consumption

Food shopping

The survey findings indicate that most respondents in the city buy their food from traditional markets (Fig. 3). This can be attributed to the shopping behaviours of residents, as the people of Hue City in particular and Vietnam as a whole are used to shopping at traditional markets. This is because such markets have the advantages of product variety, competitive pricing, and convenience. It is also noted that nearly 86% of households indulge in purchasing regionally grown food frequently. The reasons include geographical proximity, certainty regarding the source of the food, and inclination towards supporting local farmers and food producers.

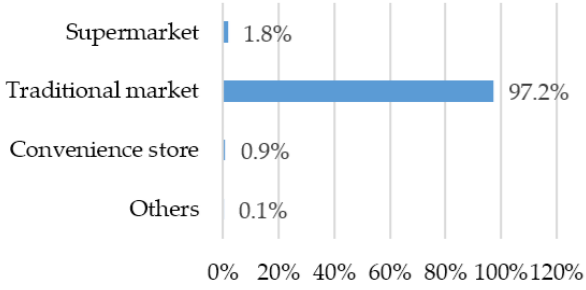

Fig. 3. Proportion of household preferences for food shopping locations

The food offered in traditional markets is often sourced from farms within the vicinity or nearby locations. This is in stark contrast to imported foods or those sold in supermarkets, which are located further away. Furthermore, less fuel consumed means lower emissions. In addition, focusing on local foods further reduces GHG emissions since food produced nearby is almost always grown near where it is consumed, therefore these foods need considerably less transport. Local food, in particular, greatly diminishes the requirement for refrigeration and long-term storage in temperature-controlled environments.

Fig. 4 shows that occasional unplanned food shopping has the highest proportion (56.9%), which is significantly higher than other levels. This reflects a common phenomenon in most families today: food shopping is not likely to be well planned but rather to occur impulsively, driven by spontaneous inspiration or personal preferences at the time of purchase. If purchasing is not well planned and guided, shoppers will purchase more than they need, and the result will be food piling up in refrigerators, spoiling, and then being thrown away.

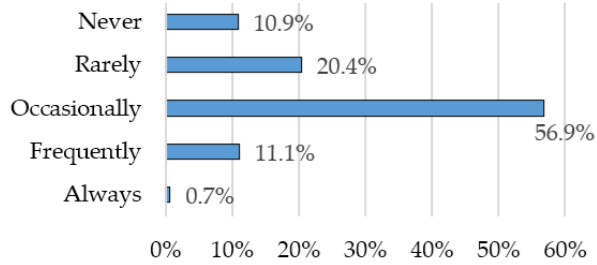

Fig. 4. Level of household unplanned food shopping

This behaviour not only causes financial waste for households but also contributes to an increase in food waste, one of the significant sources of GHG emissions today. Therefore, encouraging households to develop a habit of detailed and organised food shopping planning is extremely necessary.

The results in Table 3 present the factors influencing food selection decisions based on a 5-point Likert scale. "Food safety" and "Quality" were rated the highest, meaning that these are the most important factors respondents consider when choosing food. "Brand" has a moderate impact, while the factors "Culture and religion factors" and "Food diversity" have the lowest average scores, indicating they have the least

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influence on food selection. However, it should be noted that this is only a general overview, and the importance of each factor may vary depending on the individual or household.

While Table 3 identifies various factors influencing food choice, only a few have been discussed about their implications for GHG emissions. In reality, several factors listed, such as price, nutritional value, convenience, and sustainability, can indirectly influence household-level GHG emissions through their effect on dietary patterns. For example, price sensitivity may lead consumers to choose cheaper, often plant-based food, which tends to have lower emission factors. On the other hand, a preference for convenience may promote processed or packaged foods, which typically involve higher emissions because of industrial processing and packaging. The high score for nutritional value suggests that health-conscious consumers might prefer fresh, unprocessed food, possibly resulting in a lower carbon footprint. The relatively high influence of sustainability (mean = 4.1) is promising, as it indicates growing awareness of environmental concerns in food selection. Thus, the interplay between these factors and actual food choices can significantly shape the household's overall emissions.

Identifying the degree of influence of various factors on food selection will help guide appropriate communication strategies and policies to promote sustainable consumption behaviours, thereby contributing to reducing GHG emissions through the selection of safe, high-quality, and environmentally friendly food sources.

Table 3. Descriptive statistics and influence levels of factors on food choice

Factors	Mean	SD	Rank
Price	3.8	±0.9	7
Quality	4.4	±0.6	2
Nutritional value	4.3	±0.6	3
Brand	3.6	±1.0	5
Food diversity	3.7	±0.9	9
Diet	3.4	±1.1	11
Food safety	4.5	±0.6	1
Advertising and marketing	3	±1.2	13
Promotions	3.2	±1.1	12
Availability	3.6	±1.0	8
Convenience	3.6	±1.1	6
Sustainability	4.1	±0.9	4
Cultural and religious factors	3.3	± 1.3	10

Note: *The mean scores are the average ratings from 400 respondents based on a 5-point Likert scale.*

Food consumption habits

The eating of processed and fast-food types in the modern world has resulted in increased GHG emissions at various levels and stages of the supply chain. Industrial processing requires a significant amount of energy and resources. In addition, these goods are commonly kept in cold storage, which increases emissions because of energy consumption. Moreover, the primary component in fast food, particularly red meat, has high emissions because of livestock farming, which produces substantial amounts of methane (CH_4).

As illustrated in Fig. 5, there are five levels of household consumption: Always, Frequently, Occasionally, Rarely, and Never. The results show that the majority of households consume fast food or processed food at the "Occasional" level (67.3%), while only a very small proportion (4.1%) consumes them at the "Frequent" level.

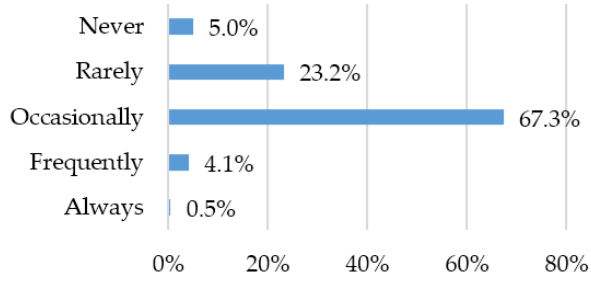

Fig. 5. Proportion of households consuming fast food and processed food

Fig. 6 shows the proportion of different dietary choices. "Traditional diet" has the highest rate (33.2%), while "Strict vegetarian" is the lowest (4.2%). The "Traditional diet" often involves a high use of processed foods and meat, significantly contributing to GHG emissions due to production and transportation. In contrast, "Strict vegetarian" and "Periodic vegetarian" (21.6%) can mitigate the GHG emissions with less meat intake. Thus, encouraging vegetarian diets could be a solution to reduce environmental impact.

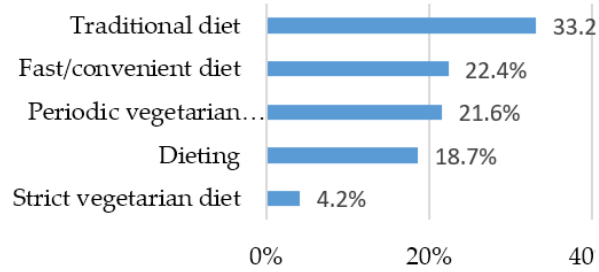

Fig. 6. Proportion of households choosing different dietary patterns

Management of leftovers and food waste

The survey results show that approximately 0.39 kg of food waste is discarded weekly by each household member. With 1,166,548 people residing in Hue City [9], the entire city generates approximately 454.9 tons of food waste per week, corresponding to 23,658 tons per year. Before 2023, the municipal solid waste in Hue City was mainly treated in landfills. With Vietnam's average landfill emission factor of 0.89 tons of CO_2e per ton of domestic solid waste [13], the GHG emissions from unreused or unrecycled food waste are estimated at 21,055 tons of CO_2e.

The proportion of methods used by households in managing leftovers is illustrated in Fig. 7. Feeding livestock is the most prevalent way, followed by composting, discarding in the trash, and burying in the garden to improve soil. Only a very small proportion (0.6%) uses other methods, such as placing leftovers in a "water barrel" at the end of the alley.

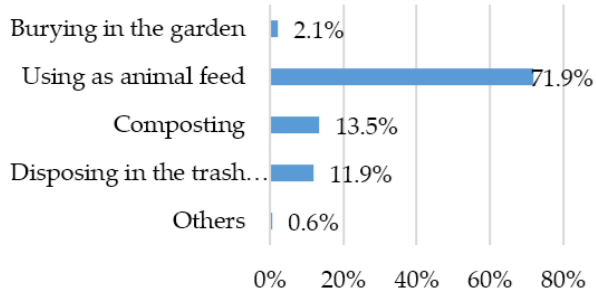

Fig. 7. Proportion of households using different methods to handle leftover food

Table 4 presents the survey results on certain habits that contribute to food waste in households. A surprising finding is that a significant proportion of households "frequently" or "always" cooks more food than needed, leaves food in the refrigerator for too long, forgets to store leftovers, plans meals irrationally, and stores leftovers improperly. Overall, these findings indicate a significant need for improvement in household food management practices to reduce food waste. Educational campaigns focusing on meal planning, proper portioning, effective storage practices, and efficient use of leftovers could help address this issue.

The factors influencing food waste based on a 5-point Likert scale are provided in Table 5. As a whole, the results of the survey suggest that food waste in households relates more to improper storage habits and poor meal planning than social concerns or environmental awareness. The

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following are some findings worth noting: "Expiration date" has the highest average score, meaning it is the most important factor relative to food waste in the surveyed households; Forgetting to refrigerate leftover food, improper storage, and overcooking were the most cited reasons for wasting food; Social norms and aesthetics scored the least, indicating that these factors have the least influence on food waste habits.

Table 4. Household behaviours related to food waste

Household behaviour	Never (%)	Rarely (%)	Occasi- nally (%)	Often (%)	Always (%)
Poor meal planning	10.7	26.6	9.3	39.1	14.3
Ignoring expiration	29.1	28	12.7	18	12.3
Improper storage of leftovers	16.6	30.2	5	40.7	7.5
Food label misreading	26.1	35.5	3.9	30.7	3.9
Letting food expire	33	35	3.9	24.5	3.6
Neglect of refrigerated food	13.2	34.3	3.4	42.7	6.4
Failure to refrigerate leftovers	13.4	35.7	3.2	42.7	5
Disposal of unspoiled food	23.2	31.4	4.5	35.2	5.7

Table 5. Factors affecting food waste

Factors	Mean	SD	Rank
Planning and shopping			
Buying food without a plan	3.1	±0.5	12
Poor meal planning	3.3	±0.6	8
Misunderstanding food labels	3.2	±0.4	11
Storage and preparation			
Improper food storage	3.8	±0.7	2
Over expiration date	4	±0.8	1
Forgetting food in the refrigerator	3.7	±0.4	3
Forgetting to store food in the refrigerator	3.6	±0.6	5
Social and psychological issues			
Refusal to consume leftovers	3.3	±0.4	9
Aesthetic (throwing away food because it doesn't look good)	2.9	±0.3	14
Social norms (ethics and culture of food waste)	3	±0.2	13
Environmental and economic impact of food waste	3.2	±0.6	10
Knowledge and awareness			
Poor knowledge of food storage and preservation techniques	3.4	±0.8	6
Poor understanding of environmental and social impacts of food waste	3.4	±0.7	7

These findings reveal critical gaps in Hue City's policy framework, particularly in promoting sustainable food systems and climate-resilient practices. To address these challenges, targeted interventions are essential, including

public awareness campaigns to encourage plant-based diets, improved food waste management strategies, and education on responsible shopping and consumption behaviours. Policymakers should also consider integrating these insights into urban planning and climate mitigation strategies, fostering collaborations with local markets and producers to enhance sustainability.

3.3 Uncertainties in GHG emission estimates

The GHG emission estimates presented in this study provide important insights, but they also include uncertainties inherent in the methodology. Identifying these factors is crucial for accurately interpreting the results and guiding future research.

Uncertainties from emission factors

Generality of emission factors

The study uses Life Cycle Analysis (LCA)-based emission factors established by Poore and Nemecek (2018). These factors are global averages and may not accurately reflect the specific conditions of Vietnam and Hue City. Factors such as local agricultural practices, types of animal feed, energy sources used in processing, and actual transportation distances can differ significantly from the global average, leading to discrepancies in actual emissions.

Simplification in food categories

For the "Other types" category, the emission factor is calculated by averaging the factors of the listed food items. This is a simplification that can create considerable uncertainty, as this category includes a large quantity of different processed and packaged foods, each with its own distinct carbon footprint.

Uncertainties from calculation and extrapolation

Data extrapolation

The city's total annual GHG emissions (3,407,352 tons of CO_2e) were calculated by extrapolating from the average weekly emissions of the 400 surveyed households. Similarly, the total annual food waste (23,658 tons) was also extrapolated from the sample data. This extrapolation assumes that the households in the sample perfectly represent the entire population, which may not be entirely accurate.

Use of a national average emission factor for waste

The GHG emissions from food waste (21,055 tons of CO_2e) were estimated by using Vietnam's average emission factor for solid domestic waste in landfills. However, the specific conditions of landfills in Hue City, such as treatment technology and methane recovery systems, may differ from the national average, altering the actual emissions.

Uncertainty in calculating emissions from food waste

Landfill emission factor

The study uses Vietnam's average emission factor (0.89 tons of CO_2e/ton of domestic solid waste) to estimate emissions from the 23,658 tons of food wasted annually. However, this factor may not be accurate for landfills in Hue City, where management conditions (e.g., methane control and recycling rates) might differ. Furthermore, this factor does not account for other disposal methods like composting, which may be common in some households.

Classification of wasted food

The study does not analyse the specific composition of the wasted food (e.g., the proportion of animal-based versus plant-based

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food), whereas different food types have varying methane emission levels as they decompose. This leads to uncertainty in the estimate of 21,055 tons of CO_2e from food waste.

Acknowledging these uncertainties does not diminish the study's value but rather highlights the critical need for more in-depth research. Such research should utilise localised data and emission factors, coupled with analyses like sensitivity or Monte Carlo simulations, to quantify uncertainties and enhance the accuracy of future GHG inventories.

4 Conclusion

This study in Hue City demonstrates that household food consumption significantly contributes to GHG emissions, primarily from animal-based products such as beef and seafood. While food safety and quality remain the dominant factors guiding food choice, other elements such as sustainability, price, and convenience can indirectly affect emissions through dietary behaviours. Recognising these linkages highlights the importance of addressing consumer behaviour in policies targeting sustainable food systems. The study also provides a valuable foundation for developing evidence-based interventions in Hue City to promote climate-friendly consumption. Future studies should further explore the complex interactions between food choice motivations and environmental outcomes, assess the long-term impacts of dietary transitions, and identify social and economic barriers to behaviour change. By integrating these insights into urban planning, public education, and food policy, Hue City can lead the way toward a more sustainable and climate-resilient food system, offering practical lessons for other rapidly urbanising regions in Vietnam and beyond.

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Conflict of interest

The authors declare no conflicts of interest related to the publication of this article.

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