



Carbon footprint and nutrition estimation of Chinese eight cuisines

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Keywords:

Greenhouse gas emissions, cooking methods, carbon labelling, nutrition, life cycle assessment

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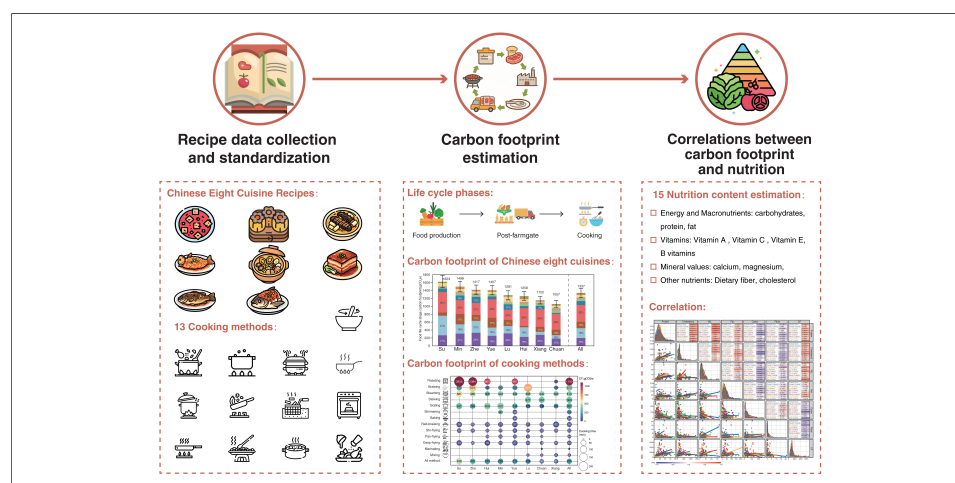
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Abstract

Sustainable dietary choices can yield synergistic benefits for both human health and the environment, highlighting the importance of recipe-level analysis to provide actionable guidance for consumers. Chinese cuisines are highly diverse and are often classified into regional cuisines, with the Chinese eight cuisines as the most widely recognized grouping. The environmental and health impacts of these diverse cuisines remain unclear. This study quantified the cradle-to-table carbon footprint and nutritional profiles of 320 recipes from the Chinese eight cuisines, covering nine food categories and 13 cooking methods. The results show that the average carbon footprint of the Chinese cuisines was 1,337 (1,224-1,453) g CO₂e, some 60%-73% lower than that of Western meals. Among the eight cuisines, Sichuan Cuisine had the lowest greenhouse gas (GHG) emissions, with an average of 1,057 (970-1,144) g CO₂e. The main contributors to GHG emissions from Chinese cuisine were non-ruminant meat production (30%) and cooking (17%). The most common Chinese cooking methods were stir-frying (16 min, 25 g CO₂e, 20-30) and boiling (46 min, 287 g CO₂e, 231-352), both of which generated significantly lower emissions than

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the Western roasting method (112 min, 1,447–2,127 g CO₂e). A correlation analysis between nutrition and carbon footprint reveals that protein, cholesterol, and niacin were positively correlated with GHG emissions, whereas dietary fiber and carbohydrates showed negative correlations. This study provides standardized recipe-level data characterizing the environmental and nutritional performance of Chinese dishes, providing a scientific basis for promoting carbon labeling policies and the transition to low-carbon diets.

INTRODUCTION

Diet links the environment and human health^[1]. The food system accounts for more than one-third of global anthropogenic greenhouse gas (GHG) emissions^[2], and inadequate diets lead to overweight, obesity, and “hidden hunger”, micronutrient deficiencies underlying iron-deficiency anaemia and other diseases^[3]. Healthier diets typically have smaller environmental impacts^[4], suggesting that recipe choices can promote a win-win outcome for both health and environmental sustainability^[5]. Global organizations and governments have developed dietary guidelines that integrate health and sustainability considerations^[6], exemplified by the EAT-Lancet Planetary Health Diet, which advocates substantial reductions in red meat and sugar consumption while increasing the share of vegetables, whole grains, and legumes^[7]. Systematic reviews indicate low adherence to these guidelines^[8], which may stem from the influence of culinary cultures and traditions on dietary behaviors^[9]. In the absence of recipe-level information, consumers cannot readily assess whether a dish combining multiple foods meets the dietary guidelines. Promoting culturally acceptable low-carbon diets could reduce an individual’s carbon footprint by 20%^[10]. Carbon labeling quantifies the carbon footprint of diets and empowers consumers to make more sustainable dietary choices^[11,12]. A global shift toward low-carbon, healthy diets requires environmental and nutritional food labeling to guide consumer behavior toward sustainable dietary patterns.

Chinese cuisine is one of the world’s three most popular cuisines, encompassing representative dishes such as Kung Pao Chicken and MaPo Tofu (Sichuan cuisine) and Dim Sum and Char Siu (Cantonese cuisine). The global diffusion of Chinese cuisine has fostered cross-cultural culinary integration and exerted a profound influence on global dietary habits^[13,14]. Dietary cultures differ markedly across China, where historical variation in natural environments, lifestyles, and socioeconomic development has given rise to the distinctive system of the “Chinese eight cuisines”^[15]. These cuisines are distinguished by their unique ingredient selections, flavor profiles, and cooking methods^[16], as shown in Table 1^[17–20]. Characterizing the environmental and nutritional profiles of Chinese recipes would provide consumers with better information for meal selection, nudge dietary patterns toward sustainability, and contribute to the transition towards more sustainable global dietary patterns^[21].

Recent studies on the environmental impacts of food have expanded from dietary patterns to recipes, focusing mainly on recipes from cookbooks^[4,22] and online platforms^[4,22,23]. These studies have evaluated environmental impacts using life cycle assessment (LCA)^[22,24,25] and environmentally extended input-output analysis^[23], while health evaluations have employed aggregate health indicators^[4] and nutrient content^[23]. Cambeses-Franco *et al.*^[26] quantified the carbon footprint, energy consumption, and costs of 60 Atlantic recipes, demonstrating that higher proportions of animal products (particularly red meats) were associated with increased costs and carbon footprints, while vegetable-based recipes consistently reduced both. Existing research has predominantly focused on either the environmental impacts or the nutritional quality of recipes, with limited attention to the relationship between the two at the recipe level. Angelsen, *et al.*^[4] evaluated 600 dinner recipes from Norway, the United Kingdom (UK), and the United States (US), and found negative correlations between aggregate health indicators and environmental impacts (GHG emissions and land use). Studies of recipes have mainly analyzed those from high-emission Western countries, assessing environmental impact or nutritional quality in isolation. No study has yet provided a comprehensive

Table 1. Characteristics of the Chinese eight cuisines

Cuisine	Origin	Characteristics	Representative dish
Chuan cuisine	Sichuan province	Known for bold, spicy and numbing flavors; frequently uses stir-frying ^[17]	MaPo tofu, kung pao chicken
Yue cuisine	Guangdong province	Prioritizes ingredient freshness to achieve delicate, natural tastes ^[17]	Dim sum, char siu
Lu cuisine	Shandong province	Features salty and fresh profiles with an emphasis on seafood ^[18]	Moo shu pork, sweet and sour carp
Su cuisine	Jiangsu province	Noted for meticulous ingredient selection and elegant presentation ^[19]	Stewed meatball, beggar's chicken
Min cuisine	Fujian province	Distinguished by soup-based dishes and the use of fermented red yeast rice ^[20]	Fotiaoqiang, braised sea clam with chicken soup
Zhe cuisine	Zhejiang province	Favors light, refined flavors with tender textures ^[20]	West lake vinegar fish, longjing shrimp
Xiang cuisine	Hunan province	Characterized by hot and spicy tastes, aromatic intensity, and deep coloration ^[20]	Chopped pepper fish head, stir-fry pork with chili peppers
Hui cuisine	Anhui province	Emphasizes salty, fresh flavors through stewing and steaming techniques ^[20]	Smelly mandarin fish mao tofu

assessment of the environmental impacts, nutrition, and their interrelationships in Chinese cuisine recipes. Regarding cooking, Frankowska *et al.*^[27] assessed GHG emissions associated with different cooking methods and appliances in the UK. They surveyed 700 respondents on cooking methods, utensils, and times for specific portions of 30 foods and found that unsustainable cooking practices, such as long oven heating or overcooking foods, increased unnecessary GHG emissions. No recipe-level study has yet covered the unique ingredient combinations and diverse cooking techniques characteristic of Chinese culinary traditions, nor has it jointly assessed the environmental and nutritional dimensions of Chinese cuisines.

In this study, we collected 320 recipes from the Chinese eight cuisines, covering food ingredients, weights, cooking methods and cooking times. The carbon footprints of 320 recipes, including the production, postharvest handling, storage, and processing, distribution, and retailing, and cooking stages, were evaluated with a particular focus on 13 cooking methods, and the differences in carbon footprint across Chinese cuisines and cooking practices were analyzed. The nutritional quality of Chinese eight cuisines and their correlation with carbon footprint were quantified. The results provide data to support the design of carbon labels on menus in Chinese restaurants worldwide and to facilitate offline and online dietary interventions and the transitions to low-carbon and healthy diets.

METHODS AND DATA

Chinese cuisines recipes data

To reflect the dishes most likely encountered by consumers in restaurants and on online platforms, the most popular recipes from each of the Chinese eight cuisines were selected as representative samples for analysis. The 2023 White Paper on Chinese Cuisine^[28] provided the names of contemporary mainstream recipes for these cuisines. The Baidu Index, which reflects public attention through internet search frequency^[29], served as the metric for recipe popularity. Based on the Baidu Index values recorded in December 2023, the top 40 recipes from each cuisine were selected, yielding a popularity-based sample of 320 recipes across the Chinese eight cuisines. This popularity-based recipe dataset could provide the reference data needed for menu carbon emission labeling and consumer dietary guidance.

The dataset includes ingredient names, weights, cooking methods and cooking times for each recipe. Ingredient names, weights, and cooking methods were sourced from cookbooks, including Chinese Famous Recipes^[30], Selected Dishes from China's Eight Regional Cuisines^[31], and regional culinary standards such as

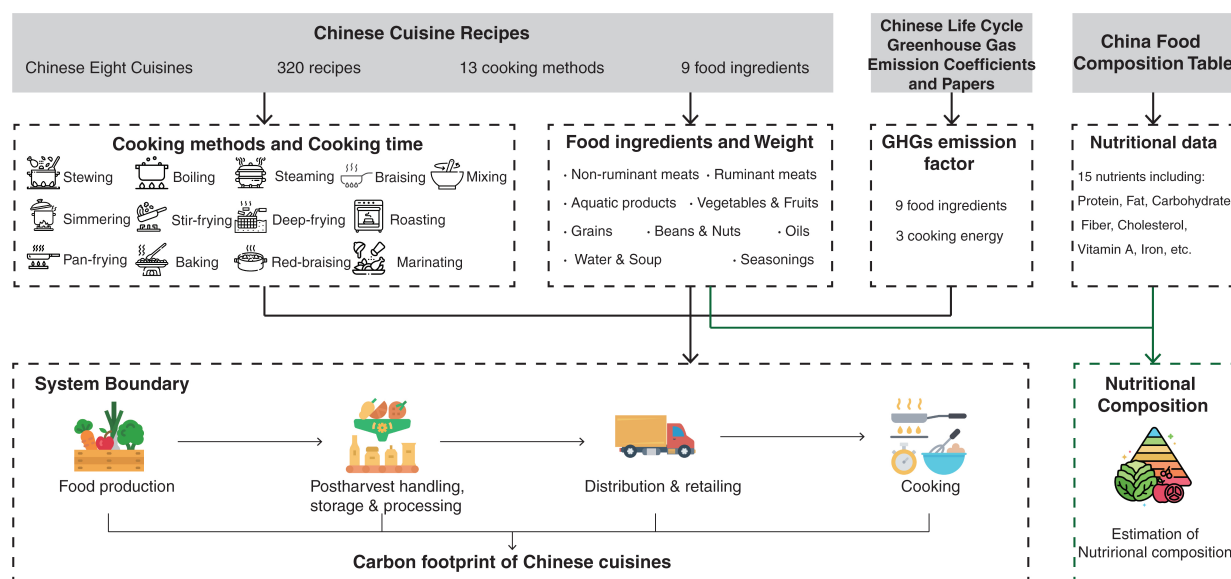


Figure 1. System boundary of carbon footprint and nutrition estimation of Chinese eight cuisines.

Technical Specifications for Classic Sichuan Cuisine^[32] and Shandong Cuisine Standard System^[33]. Because the published literature and regional standards lacked estimated cooking times, this parameter was obtained by averaging the cooking times from 10 online recipes with identical names across two platforms: Meishi.cc (<https://www.Meishi.cc>) and Meishichina (<https://www.meishichina.com/>).

To standardize carbon footprint calculation and analysis, ingredients were classified into nine food categories aligned with the China Food Composition Table^[34]. The food types comprised non-ruminant meats, ruminant meats, aquatic products, vegetables and fruits, oils, water and soup, seasonings, grains, and beans and nuts. The 320 recipes encompassed 13 cooking methods: stewing, boiling, steaming, braising, simmering, stir-frying, deep-frying, roasting, pan-frying, baking, red-braising, marinating, and mixing. For recipes involving multiple methods, the dominant method contributing to the flavor profile was prioritized. To quantify the carbon footprint per serving of Chinese dishes, the ingredient weight in each recipe was standardized to a reference portion of 300 g. This value was consistent with previous studies^[35] and was cross-checked against the Chinese Dietary Guidelines (2022)^[36] and the Report on Chinese Residents' Nutrition and Chronic Diseases (2020). According to these references, the recommended per-meal weight range for non-cereal foods is 202–354 g, within which the 300 g portion falls within this range. The complete dataset documenting the carbon footprint and nutritional profiles of Chinese cuisine is publicly available on Figshare^[37].

Carbon footprint accounting

This study employed a LCA framework, following ISO 14010 and 14044 guidelines^[38,39], to quantify the cradle-to-table carbon footprint of 320 sample recipes from the Chinese eight cuisines, as shown in Figure 1. The carbon footprint was defined as the total GHG emissions, quantified in carbon dioxide equivalents (CO₂e) by converting carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) using the 100-year Global Warming Potential (GWP) values from the Intergovernmental Panel on Climate Change (IPCC). A functional unit of 300 g per recipe was adopted, with system boundaries encompassing three lifecycle stages: food production, post-farmgate, and cooking stages. To ensure cross-cuisine comparability, the total carbon footprint of each cuisine was normalized by dividing the aggregated carbon footprint (CF) by its sample size ($n = 40$), yielding the average carbon footprint per cuisine $\overline{CF}_i$ (g CO₂e). The calculation formula is expressed as Equation (1):

$$\overline{CF_i} = \frac{\sum_j (CF_{pij} + CF_{tij} + CF_{cij})}{n} \quad (1)$$

where, $\overline{CF_i}$ represents the average carbon footprint of cuisine i , CF_{pij} , CF_{tij} , CF_{cij} are the production, post-farmgate, and cooking stages carbon footprints (g CO₂e) for recipe j in cuisine i , respectively; and n is the sample size (40 recipes per cuisine).

Food production stage

The CF of the food production stage for recipe j in cuisine i was calculated as Equation (2):

$$CF_{pij} = \sum_k W_{ijk} \times F_{pk} \quad (2)$$

where CF_{pij} (g CO₂e) represents the food production stage CF of cuisine recipe j in cuisine i , W_{ijk} (g) is the weight of ingredient k , and F_{pk} (g CO₂e/g) is the production stage carbon emission factor of ingredient k . Emission factors for food production were sourced from the consolidated database compiled by Petersson *et al.*^[40] and the Chinese Life Cycle Greenhouse Gas Emission Coefficients for Products^[41].

Food post-farmgate stage

The CF of the post-farmgate stage for recipe j in cuisine i was calculated as Equation (3):

$$CF_{tij} = \sum_k W_{ijk} \times (F_{ak} + F_{bk}) \quad (3)$$

where CF_{tij} (g CO₂e) represents the food post-farmgate stage CF of cuisine recipe j in cuisine i , F_{ak} (g CO₂e/g) represent the GHG emission factor of ingredient k for the postharvest handling, storage, and processing stages, and F_{bk} (g CO₂e/g) represent the GHG emission factor for the distribution and retailing stages. These emission factors were derived from Xue *et al.*^[42].

Cooking stage

The carbon footprint of the cooking stage was quantified using methodologies and parameters established by Inaba *et al.*^[43] and Long *et al.*^[23]. Energy consumption was calculated for 13 cooking methods, and emission factors were applied to energy sources to derive cooking-phase carbon footprints. For boiling, steaming, braising, simmering, stir-frying, deep-frying, pan-frying, baking, and red-braising, household stoves utilizing fossil fuels (natural gas or liquefied petroleum gas, LPG) were assumed. The CF of cooking for recipe j in cuisine i was calculated as Equation (4):

$$CF_{cij} = \frac{E_{ij} \times F_n \times b_n}{h_n} + \frac{E_{ij} \times F_l \times b_l}{h_l} \quad (4)$$

where CF_{cij} (g CO₂e) represents the food cooking stage CF of cuisine recipe j in cuisine i , E_{ij} (J) is the energy consumption for cooking (calculation methods per cooking technique are detailed in Equations 6-14), F_n and F_l are the emission factors of natural gas (2,800 g CO₂e/Nm³) and LPG (5.11 g CO₂e/g) from the Chinese Life Cycle Emission Coefficients for Products (2022)^[41], b_n (82.5%) and b_l (17.5%) are the household usage proportions of nature gas and LPG^[44], h_n (35,608.5 kJ/m³) and h_l (50,242 kJ/kg) are their calorific values from the national standard General Rules for Comprehensive Energy Consumption Calculation^[45].

Roasting dishes were assumed to use electric ovens. The cooking carbon footprint for roasting recipes was calculated as Equation (5):

$$CF_{ij} = \frac{E_{ij} \times F_e}{h_e} \quad (5)$$

where F_e (530 g CO₂e/kWh) is the electricity emission factor^[41], h_e (3,602.005 kJ/kWh) is the electricity calorific value^[45]. Marinating and mixing methods, which require no thermal energy input, were assigned zero cooking stage carbon emissions.

Energy consumption for different cooking methods was structured as follows:

(1) Boiling, braising, stewing, and simmering

Energy consumption comprises three components: energy to boil water, energy to maintain boiling, and energy to heat the ingredients. The calculation formulas are expressed as Equation (6-9)^[23]:

$$E_b = E_{bw} + E_{baw} + E_{bh} \quad (6)$$

$$E_{bw} = \frac{m_w \times c_w \times \Delta k_b}{\eta h} \quad (7)$$

$$E_{baw} = \frac{\nu \times S_p \times H_w \times \Delta T}{\eta b} \quad (8)$$

$$E_{bh} = \frac{\sum_k Q_k \times c_k \times \Delta k_b}{\eta b} \quad (9)$$

where E_b (J) is the total energy consumption, E_{bw} , E_{baw} , and E_{bh} (J) are the energy to boil water, maintain boiling, and heat ingredient, m_w (g) is water mass, assumed to be 5/3 times the ingredient weight based on practical culinary practices, c_w [4.18 J/(g·K)] is the specific heat capacity of water, Δk_b is the temperature differential (80 K, 20 °C to 100 °C); ηh (0.37) and ηb (0.42) represent heating and boiling thermal efficiencies; ν is the evaporation rate [0.06 g/(min·cm²)]; S_p is the pot base area (314 cm²); H_w is the water's latent heat of vaporization (2,250 J/g); ΔT is the post-boiling heating time (assumed as 2/3 of total cooking duration); Q_k and c_k are the ingredient mass (g) and specific heat capacity [J/(g·K)].

(2) Steaming

Energy consumption follows Equations 6-9, with m_w set as 60% of pot volume. A standard household steamer was modeled with a 15 cm depth and 20 cm inner diameter.

(3) Stir-frying, baking, pan-frying, and red-braising

Energy consumption for these dry-heat methods was calculated as Equation (10)^[23]:

$$E_s = \frac{\sum_k Q_k \times c_k \times \Delta k_f}{\eta h \times \alpha} \quad (10)$$

where E_s (J) is the energy consumption, Δk_f is the ingredient temperature rise (100 K); α (0.75) is a correction factor accounting for heat loss from uncovered cookware surfaces in contact with food^[23].

(4) Deep-frying

The energy consumption of deep-frying E_f (J) includes oil heating E_{fo} (J) and ingredient heating E_{fh} (J), calculated using Equations (11-13)^[23]:

$$E_f = E_{fo} + E_{fh} \quad (11)$$

$$E_{fo} = \frac{m_o \times c_o \times \Delta k_o}{\eta h} \quad (12)$$

$$E_{fh} = \frac{\sum_k Q_k \times c_k \times \Delta k_d}{\eta h} \quad (13)$$

where m_o is the oil mass (g); c_o is the specific heat capacity of oil [2.0 J/(g·K)]; Δk_o is the oil heating differential (160 K, 20 °C to 180 °C); Δk_d is the ingredient temperature rise (130 K).

(5) Roasting

Energy consumption E_r for electric oven baking (Panasonic NB-HM3810 model) was calculated as Equation (14):

$$E_r = P_m \times \Delta T_m \quad (14)$$

where P_m is the oven power (1,800 W); ΔT_m is the baking duration (seconds).

Recipes nutrition estimation

Fifteen nutrients were quantified for each recipe: energy (kcal), macronutrients: carbohydrates (g), protein (g) and fat (g), vitamins: vitamin A (μg), vitamin C (mg), vitamin E (mg) and B vitamins (mg), mineral: calcium (mg), sodium (mg), iron (mg), and other nutrients: Dietary fiber (g), cholesterol (mg). We also assessed the contribution of each recipe to the recommended daily intake of that nutrient. The nutritional content of each recipe was calculated from the nutrient content of its ingredients and the nutrient retention rates specific to different food categories and cooking methods. The nutrient content N_{ijc} for nutrient c in recipe j of cuisine i was computed as Equation (15):

$$N_{ijc} = \sum_k \frac{W_{ijk} \times P_k \times O_{kc} \times R_{ijck}}{100} \quad (15)$$

where P_k is the edible portion coefficient (%) of ingredient k , and O_{kc} represents the content of nutrient c per 100 g of ingredient k . R_{kci} represents the percent retention of nutrient c for the food category to which ingredient k belongs under cooking method applied in recipe ij . Data on edible portions and nutrient compositions were sourced from the China Food Composition Table^[34]. Vitamin and mineral retention factors were obtained from United States Department of Agriculture (USDA) table of nutrient retention factors (Release 6)^[46]. For each food category and cooking method, the retention factors reported in the USDA table were averaged across the corresponding ingredients. For cooking methods not covered by the table, the mean retention value across all available cooking methods within the same food category was used as a proxy. The USDA table does not provide retention factors for macronutrients (energy, protein, fat, carbohydrates, dietary fiber, and cholesterol). Because these are thermally stable during cooking, their retention rates were assumed to be 100%.

The daily nutrition reference percentage DRP_{ijc} for nutrient c in recipe j of cuisine i was determined as Equation (16):

$$DRP_{ijc} = \frac{N_{ijc}}{NRV_c} \times 100\% \quad (16)$$

where NRV_c is the recommended daily intake for nutrient c , derived from the national standard Dietary Reference Intakes for Chinese Residents^[47].

Uncertainty and sensitivity analysis

To quantify the influence of parameter variations on the carbon footprint and nutritional content of recipes, the Monte Carlo simulation was performed. The parameters included cooking-stage assumptions (thermal efficiency, fuel mix, water use, *etc.*), GHG emission factors, nutrient contents, retention factors, and cooking time. Each parameter was independently perturbed using a normal distribution. For cooking-stage assumptions, GHG emission factors, nutrient contents, and retention factors, the variation coefficient (σ) was set to 10%^[48]. For cooking time, σ was set to 10%, 20%, and 30%. For all 320 recipes, 1,000 iterations were run in R to generate recipe-level distributions. The means and 95% confidence intervals of carbon footprint and nutritional values were then obtained from the simulated results. Throughout the manuscript, 95% confidence intervals are reported in parentheses alongside means; for example, 1,000 (95%CI: 900-1,100), or in abbreviated form as 1,000 (900-1,100).

The sensitivity ratio (SR) was then used to assess the effect of cooking stage assumptions on the carbon footprint of different cooking methods. The formula is given as Equation (17):

$$SR_{gq} = \frac{(\Delta R/R_0)_q}{(\Delta P/P_0)_g} \quad (17)$$

where SR_{gq} is the sensitivity ratio of parameter g with respect to cooking method q ; P_0 is the baseline value of parameter g ; ΔP is the change in parameter g ; R_0 is the baseline carbon footprint of cooking method q using the initial parameter values; and ΔR is the resulting change in carbon footprint caused by ΔP .

In the assessment of the cooking-stage carbon footprint, only the dominant cooking method that defines the dish flavor was quantified. Among the 320 recipes, 29 recipes reported two cooking methods without specifying the cooking time for each. To evaluate the potential error from this assumption, the total cooking time was equally split between the two methods, and a perturbation sensitivity analysis was performed. For each multi-method recipe, the baseline emission was set as the single-method case using only the dominant method. Then, the total cooking time was divided equally, and the time allocation was perturbed within $\pm 30\%$ of the equal share, normalized to keep the total cooking time unchanged. One thousand draws were generated for each multi-method recipe, and the relative difference between the perturbed carbon footprint of cooking stage and the baseline emission was calculated.

Correlation analysis

Spearman's rank correlation was employed to assess monotonic relationships between nutrient profiles and carbon footprints across all recipes. Analyses were conducted both within individual cuisines and for the aggregated dataset. Statistical significance was evaluated at $P < 0.05$, with correlation strength annotated alongside directionality (positive/negative). Asterisks (*) denote the significance level: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$. The non-parametric Spearman method was selected because of potential non-normal distributions in the relationship between nutrient profiles and carbon footprints and because of the sensitivity of parametric methods to outliers from high-emission cooking processes (e.g., deep-frying). This approach accommodates nonlinear yet monotonic trends, where increased use of carbon-intensive ingredients elevates footprints unevenly due to cooking method variability. The robustness of Spearman's method to distributional assumptions and its resilience to outliers ensures methodological validity under heterogeneous data conditions.

RESULTS

Carbon footprints of Chinese cuisines

Across the Chinese eight cuisines, as representative culinary systems of China, the average carbon footprint of Chinese eight cuisines was 1,337 g CO₂e (95%CI: 1,224-1,453). To illustrate the differences in carbon footprints resulting from varying food patterns and cooking methods across regions, we compared Chinese

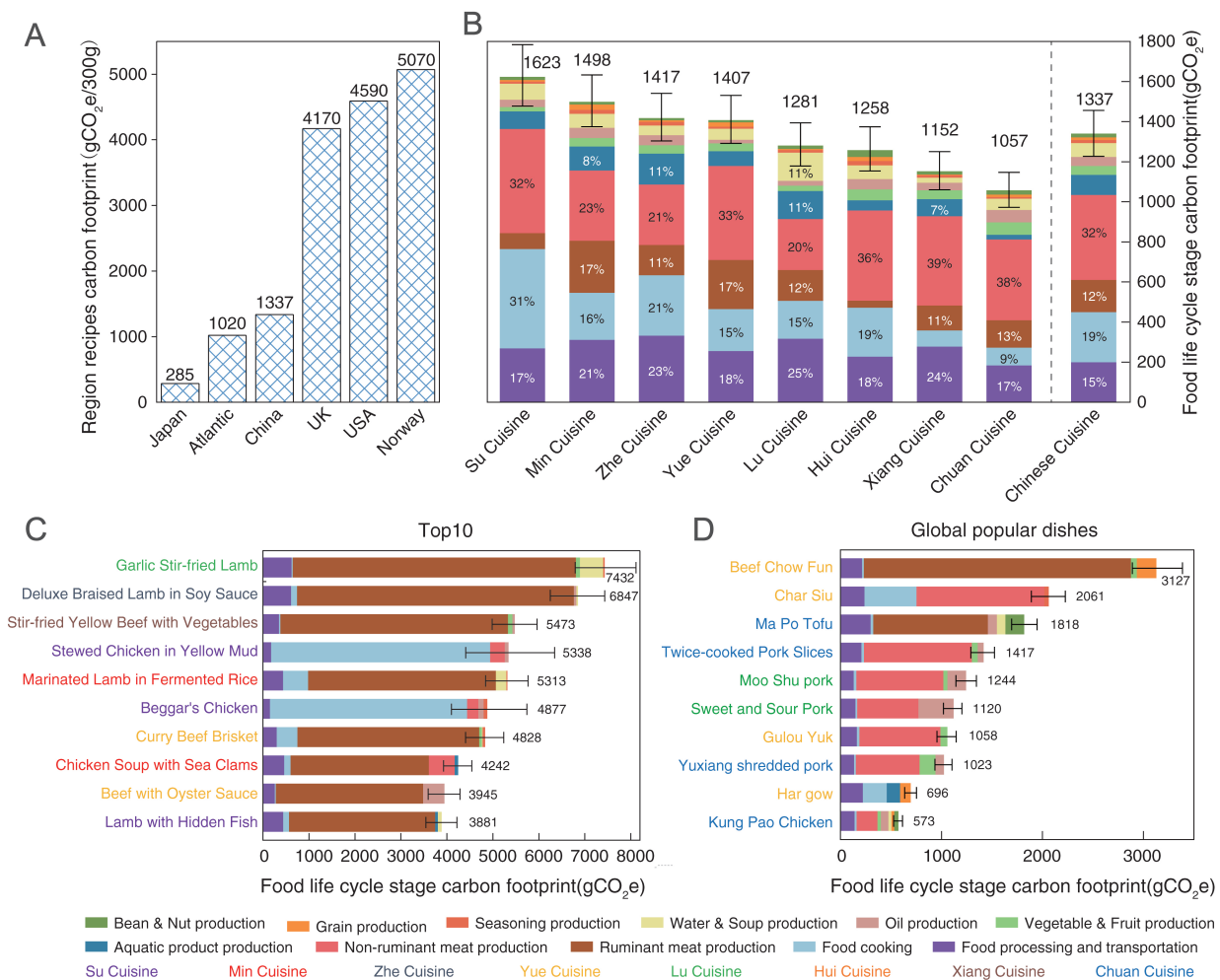


Figure 2. Carbon footprint of Chinese eight cuisines. (A) Comparison of recipe carbon footprint between China and other countries/regions; (B) Life-cycle carbon footprint of Chinese eight cuisines recipes; (C) Top 10 Chinese eight cuisines recipes in carbon footprint; (D) Carbon footprint of globally popular Chinese cuisine. Error bars represent the 95% confidence intervals of the carbon footprint.

cuisine with those of the United States (USA), the United Kingdom (UK), Norway, the Atlantic diet, and Japan (see Figure 2A). When standardized ingredient weight was 300 g under cradle-to-table system boundaries, the carbon footprint of Chinese cuisines was 4.7 times higher than that of Japanese recipes (285 g CO₂e)^[23] and 60%–73% lower than that of Western recipes (4,170–5,070 g CO₂e)^[4]. Japanese recipes predominantly use low-carbon ingredients (36.1% vegetables and mushrooms, 23% aquatic products) with streamlined cooking (17 min, 6% of total emissions), whereas Chinese cuisines frequently use meat (48% of total weight) and energy-intensive methods (36 min average cooking, 17% of total emissions)^[23]. In the Chinese eight cuisine, the non-ruminant meat production stage contributed the largest share of the carbon footprint (30%), followed by food post-farmgate stage (20%) and the cooking stage (17%). Although ruminant meat constituted only 1% of average dish weight, its production stage accounted for approximately 11% of the total carbon footprint. Chinese cuisine outperformed Western diets in sustainability largely because of its minimal reliance on ruminant meat^[4]. The Atlantic diet (1,020 g CO₂e) paralleled Chuan Cuisine, the lowest-emitting Chinese cuisine, with a high proportion of vegetables and fruits (36%) and water/soup (36%), a low proportion of meat (16%), and simplified cooking^[26]. These findings suggest that reducing the proportion of meat, optimizing protein sources, and adapting cooking methods could enhance dietary sustainability.

The average carbon footprint of the Chinese eight cuisines ranges from 1,057 g to 1,623 g CO₂e/per 300 g recipe, as shown in [Figure 2B](#). The cuisines showed a 54% difference in carbon footprint between the highest (Su Cuisine) and lowest (Chuan Cuisine) emitters, driven by differences in ingredient sourcing and cooking methods. Su Cuisine had the highest carbon footprint at 1,623 (1,474–1,780) g CO₂e, with the highest carbon footprint of both the cooking stage (332 g CO₂e, 274–402) and the non-ruminant meat production stage (519 g CO₂e), mainly because of the energy-intensive roasting technique characteristic of Su Cuisine. The preference for specific ingredients across cuisines is closely tied to geography. Min and Yue cuisines showed elevated ruminant meat emissions (259 and 245 g CO₂e respectively), while Zhe (from Zhejiang Province) and Lu (from Shandong Province) cuisines had substantial aquatic product emissions (154 and 139 g CO₂e respectively). Zhe, Lu, and Min cuisines feature numerous recipes centered on aquatic products. For example, Scallion-Braised Sea Cucumber (1,098 g CO₂e, 999–1,193) from Lu Cuisine has a lower carbon footprint than the Lu Cuisine average. In contrast, Fotiaoqiang (3,476 g CO₂e, 2,949–4,100) from Min Cuisine carries a high cooking stage carbon footprint (2,048 g CO₂e, 1,620–2,555) because of its long boiling time (360 min). Chuan Cuisine had the lowest carbon footprint for the aquatic product production phase (24 g CO₂e) and the highest for vegetable production (61 g CO₂e). Originating in the humid Sichuan Basin, where winters can be particularly cold, Chuan Cuisine frequently incorporates chili peppers to combat dampness and cold. It combines meat and vegetables in mixed cooking methods to enhance flavor complexity while balancing spiciness and strong seasonings. Chuan Cuisine used the highest amount of cooking oil among the Chinese eight cuisines, as oil serves as a carrier for various seasonings, effectively transferring flavors into the ingredients. Based on Monte Carlo simulations, applying a $\pm 10\%$ normal perturbation to emission factors at the production, postharvest handling, storage, and processing stages, and distribution and retailing stages resulted in coefficients of variation (CV) of 6.2%, 1.2%, and 0.5%, respectively, for the total recipe carbon footprint. Of the 320 recipes, 29 involved two cooking methods. The sensitivity analysis showed that using only the dominant method resulted in an average relative difference of 14.5% in cooking-stage emissions and 1.8% in the total carbon footprint for these recipes. These results demonstrate that the carbon footprint estimates were largely insensitive to the simplification of cooking methods.

[Figure 2C](#) presents the lifecycle carbon footprints of the top 10 recipes by emissions, with font colors indicating their respective cuisines. The carbon footprints of the top 10 recipes were predominantly driven by the ruminant meat production stage and the cooking stage. “Yellow Mud Chicken” and “Beggar’s Chicken” exhibited exceptionally high cooking stage carbon footprints because their roasting times exceeded 270 min. Prior research has shown that ovens are among the least sustainable cooking appliances because of their extended cooking durations and high energy demands^[27]. Beyond these two recipes, ruminant meat accounted for 25%–62% of the total weight in the remaining top 10 recipes. For instance, beef used in “Steamed Sea Clam with Chicken Soup” is primarily for broth preparation, while sea clams constitute the main ingredient. Traditional Chinese cuisines have spread throughout the world, and the carbon footprints of globally popular recipes are shown in [Figure 2D](#), drawn mainly from Yue Cuisine and Chuan Cuisine. MaPo Tofu and Kung Pao Chicken are representative dishes of Sichuan cuisine. The carbon footprint of the former is 3.2 times that of the latter, mainly because Mapo Tofu contains minced beef, whereas Kung Pao Chicken uses low-emission poultry combined with vegetables and beans. Char Siu and Har Gow (a type of dim sum) are representative of Yue cuisine dishes. The carbon footprint of the former is three times that of the latter because Char Siu is pork-based and requires prolonged roasting, whereas Har Gow consists mainly of shrimp and are briefly steamed.

This study analyzed 13 Chinese cooking methods, with an average cooking time of 36 min and an average cooking stage carbon footprint of 231 (188–280) g CO₂e for the Chinese cuisines. As shown in [Figure 3A](#) and [B](#), among the 13 cooking methods, roasting emerged as the most carbon-intensive technique (112 min,

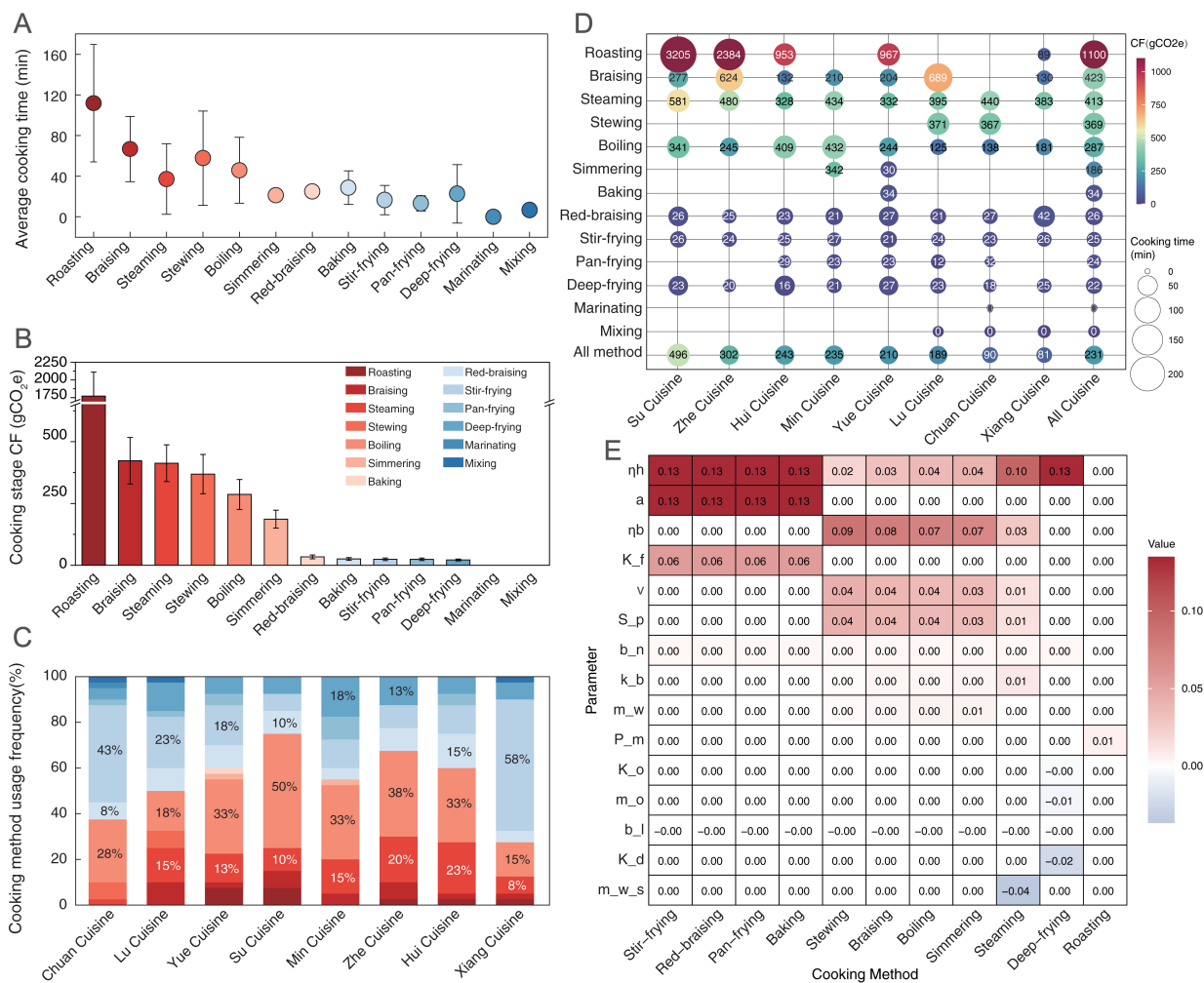


Figure 3. Carbon footprint, cooking times, and usage frequency of 13 cooking methods in Chinese eight cuisines. (A) Average cooking time, error bars represent the standard deviation (SD) of cooking time; (B) Average carbon footprint for various cooking methods, error bars represent the 95%CI of the carbon footprint; (C) Usage frequency of cooking methods in Chinese eight cuisines; (D) Average cooking time and carbon footprint of Chinese eight cuisines; (E) Sensitivity ratios of key parameters across 13 cooking methods.

1,771 g CO₂e, 1,447–2,127), taking seven times as long and emitting 70 times as much as stir-frying (16 min, 25 g CO₂e, 20–30). Boiling, stir-frying, steaming, and frying were the most commonly used methods in Chinese cuisine (see Figure 3C and D). While braising (67 min, 423 g CO₂e, 337–525) and boiling (46 min, 287 g CO₂e, 231–352) dominated water-based cooking, their carbon footprint per minute was about 4 times higher than oil-based stir-frying because of energy loss through steam. This loss does not occur when ingredients are heated directly.

Su Cuisine exhibited the most carbon-intensive cooking stage, with an average cooking duration of 63 min and a cooking-stage carbon footprint of 496 (404–600) g CO₂e per dish, 3.1 times longer and 6.1 times higher than Xiang Cuisine (20 min, 81 g CO₂e, 67–97). This disparity was particularly evident in Su Cuisine's roasting recipes, which required 202 min of cooking time (3,205 g CO₂e, 2,622–3,843), surpassing the mean cooking carbon footprint of all cuisines by a factor of 14. Su Cuisine, which originating from the lower reaches of the Yangtze River, a region abundant in freshwater aquatic products, predominantly uses boiling (50% of recipes) to preserve the original flavors of ingredients [Figure 3B and E], resulting in longer cooking times^[49]. In Xiang Cuisine, stir-frying was the most frequently used method, accounting for 58% of recipes, compared to 43% in Chuan Cuisine. Originating from the humid climate of Hunan Province, Xiang cuisine

relies on high-heat stir-frying to quickly cook ingredients and chili peppers, preserving their optimal texture and enhancing flavor while requiring minimal cooking time^[50]. As shown in Figure 3D, different cuisines exhibit distinct preferences for cooking methods and durations. For example, “baking” is unique to Yue cuisine, “stewing” is commonly used in Chuan and Lu cuisines, and “simmering” is characteristic of Yue and Min cuisines.

To evaluate the robustness of the carbon footprint estimates, sensitivity analyses were conducted on key modeling parameters, including cooking-stage parameters and cooking time. The resulting sensitivity ratios (SR) were below 0.1 for most parameters across all cooking methods; only the thermal efficiency and the correction factor for heat loss from uncovered cookware surfaces reached an SR of 0.13 for stir-frying, red-braising, pan-frying, baking, and deep-frying, as shown in Figure 3E. These low SR values indicate that the cooking-stage carbon footprint estimates are relatively robust to parameter variations. Cooking times were averaged from online recipe platforms. To evaluate the impact of this variability, the cooking time was perturbed by $\pm 10\%$, $\pm 20\%$, and $\pm 30\%$ in the Monte Carlo simulation. The resulting CVs for the cooking-stage carbon footprint were 6.5%, 13.0%, and 19.5%.

Nutrition content of Chinese cuisines

According to China’s dietary guidelines, the recommended daily food intake is approximately 1,622 g. In this study, the functional unit of the analyzed recipes is 300 g, representing about 18% of the daily recommended food intake. The nutritional composition of the Chinese eight cuisines by food category is shown in Figure 4. At the macronutrient level, the average energy content of the Chinese cuisines was 627.6 kcal (531.8–719.1), primarily derived from non-ruminant meats (35%), water & soups (23%), and oils (16%). Chuan Cuisine ranked highest in energy (695.7 kcal per dish), providing 34.7% of the daily recommended energy intake, largely because of its heavy reliance on oils (33%). Xiang Cuisine had the lowest energy content (526.4 kcal, 447.7–601.9), accounting for 26% of the daily recommendation. The average protein content of the Chinese cuisines was 24.6 g (19.7–29.4), with non-ruminant meat providing 35–59% and aquatic products contributing 8%–48%. Beans and nuts provide 4%–14% of the protein, with Chuan Cuisine deriving 14% of its protein from plant-based sources such as beans and nuts. Zhe Cuisine had the highest average protein content at 27.6 g (22.0–33.1), 46% of the daily recommended value, while Chuan Cuisine had the lowest at 19.8 g (33% of the recommended value). Chuan Cuisine features numerous dishes centered around bean products, such as the famous Mapo Tofu, and fermented bean paste is a commonly used seasoning. Together, these contribute to its relatively high plant-based protein content. The average fat content of the Chinese cuisines was 32.5 g, with non-ruminant meat contributing 52% and oils providing 35%. Chuan Cuisine had the highest average fat content at 45.2 g, accounting for 75% of the daily recommended value. The diverse flavor profiles of Chuan Cuisine rely on oil as a carrier for seasonings, enhancing flavor integration and balancing the spiciness while protecting the stomach from irritation^[51]. The average carbohydrate content of the Chinese cuisines was 55.6 (45.2–65.6) g, with soups contributing 60%, grains 16%, and seasonings 12%. Lu Cuisine had the highest carbohydrate content (85.8 g, 68.6–102.2), attributed to its soup-based dishes such as Thick Soup with Fish Maw and Milk Soup with Cattail. Xiang Cuisine predominantly consisted of stir-fried dishes with fewer soup-based recipes.

Turning to other nutritional components levels, the average cholesterol content of the Chinese cuisines was 185.8 mg (149.1–220.8), with non-ruminant meat contributing 65%. Xiang Cuisine had the highest cholesterol levels (254.5 mg, 200.1–306.5, 77% of daily intake), driven by recipes using organ meats such as pork liver, intestines, and tripe. Chuan Cuisine had the lowest (126.5 mg). Dietary fiber content in the Chinese cuisines ranged from 2% to 13% of the daily recommended value, with Chuan and Xiang cuisine having the highest fiber content (3.2 g, 2.6–3.7 and 2.1 g, 1.8–2.5, respectively), primarily from vegetables and fruits (66%), beans and nuts (20%). Vegetables and fruits are rich in dietary fiber, and the use of spicy

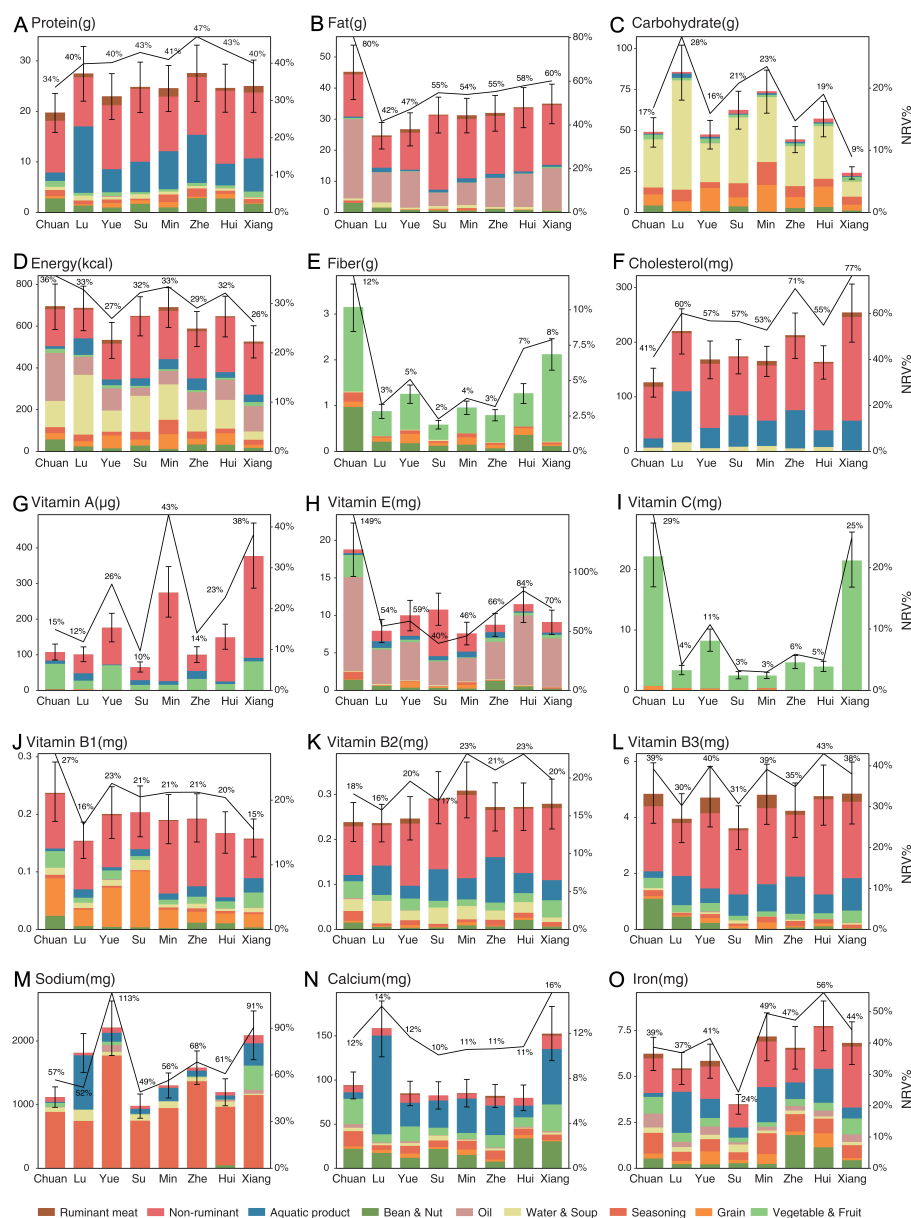


Figure 4. Nutritional composition of Chinese eight cuisines. The broken line indicates the percentage of the recommended daily value of nutrients provided per 300 g recipe. Error bars represent the 95% confidence intervals of the mean nutrient contents.

seasonings such as Sichuan pepper, black pepper, and dried chili peppers in Chuan and Xiang cuisine further increases fiber content.

At the micronutrients level, Chuan and Xiang cuisines led in ascorbic acid (vitamin C) content with 22.2 mg (17.2–27.7) and 21.5 mg (17.1–26.2), respectively, values 258% and 250% above the average of the Chinese cuisines. This elevation is directly correlated with their reliance on chili peppers dependency for signature pungent flavors. These values represented 22% of the daily recommended intake, in stark contrast to other cuisines' 2%–8% contributions. Chuan and Xiang Cuisines use a variety of vegetables, such as red peppers, bell peppers, and cabbage, which are rich in vitamin C. The average vitamin E content of the Chinese cuisines was 10.6 mg (8.5–12.6), primarily from oils. Chuan Cuisine had the highest vitamin E content at 18.8 mg (15.2–22.3), reflecting its diverse use of rich in vitamin E-rich oils such as Sichuan pepper oil, sesame oil, vegetable oil, and chili oil. Xiang and Min Cuisines had the highest vitamin A content at

377 µg (287.0–469.8) and 274.6 µg (205.7–347.7), respectively, likely because of their frequent use of eggs and animal livers, such as pork and chicken livers, which are rich in vitamin A.

Correlations between carbon footprint and nutritional quality of Chinese cuisines

To examine the relationship between nutritional composition and environmental impact of Chinese cuisines, this study conducted a quantitative correlation analysis between nutritional components and carbon footprints for the 320 representative dishes. Cholesterol, found exclusively in animal-derived foods, shows a positive correlation with carbon footprint. Protein, nicotinic acid, and fat, which are present in both animal and plant-based foods, also demonstrate positive correlations with carbon footprint. Nutrients exclusive to plant-based foods, such as dietary fiber and carbohydrates, exhibit weak negative correlations with carbon footprint. These correlations are primarily driven by the differing carbon intensities of animal-based versus plant-based ingredients rather than by direct causal relationships between individual nutrients and emissions.

The protein content of Zhe Cuisine ($r = 0.525^{***}$) and Min Cuisine ($r = 0.503^{***}$) exhibited strong positive correlations with carbon footprint, whereas Chuan Cuisine ($r = 0.238$) and Yue Cuisine ($r = 0.283$) cuisines showed weaker correlations, as shown in Figure 5. This divergence reflects differences in protein sources: Min Cuisine derived 7% of its protein from ruminant meats (highest among all cuisines), 31% from aquatic products, and 4% from beans & nuts, while Chuan Cuisine sourced 14% of protein from beans & nuts (highest among all cuisines) alongside minimal contributions from aquatic products (8%). Substituting meat with plant-derived proteins provides dual environmental and health benefits^[52]. Chinese cuisine features numerous bean-centric dishes, such as Boshan Tofu Pudding, Imperial Tofu, Wensi Tofu, and Mapo Tofu, alongside fermented soybean-based condiments such as bean paste, fermented tofu, and soy sauce. These are deeply embedded in Chinese culinary traditions^[53]. Protein from aquatic sources generally has a lower environmental impact than terrestrial animal protein^[54] and offers superior nutritional richness in micronutrients, vitamins, and unsaturated fatty acids^[55].

Strong positive correlations were found between cholesterol content and carbon footprint in Su Cuisine ($r = 0.568^{***}$) and Min Cuisine ($r = 0.527^{***}$). Reducing the intake of high-carbon-footprint and high-cholesterol dishes such as Crystal Pork Trotter (230 mg cholesterol, 3,426 g CO₂e) in Su Cuisine and Fotiaoqiang (278 mg cholesterol, 3,476 g CO₂e) in Min Cuisine can reduce health risks such as cardiovascular disease, type 2 diabetes, and obesity, thereby aligning with both health and environmental goals^[56]. Strong negative correlations were observed between dietary fiber and carbon footprint in Hu Cuisine ($r = -0.501^{***}$) and Yue Cuisine ($r = -0.362^*$). Dietary fiber in Hui Cuisine was derived 57% from vegetables and fruits, and 28% from beans and nuts, while Yue Cuisine's was 62% from vegetables and fruits, 14% from beans and nuts. Although dietary fiber cannot be digested by the human body, higher dietary fiber intake reduces the risk of various chronic diseases, including cardiovascular disease and type 2 diabetes, and is associated with lower body weight^[57]. Increasing the consumption of vegetables and fruits, which are key sources of dietary fiber, simultaneously lowers carbon footprints.

DISCUSSION

Low-carbon dietary transformation

Environmental and nutritional food labeling is essential for steering the global dietary transition towards low-carbon and healthy patterns. This study analyzed the carbon footprints and nutritional composition of 320 recipes from the Chinese eight cuisines, focusing on their food patterns and cooking methods. These results provide empirical support for developing carbon labeling systems on Chinese restaurant menus worldwide. Several strategies can help reduce the dietary carbon footprint: prioritizing foods with low environmental impact that meet human nutritional needs, adopting balanced food combinations, and

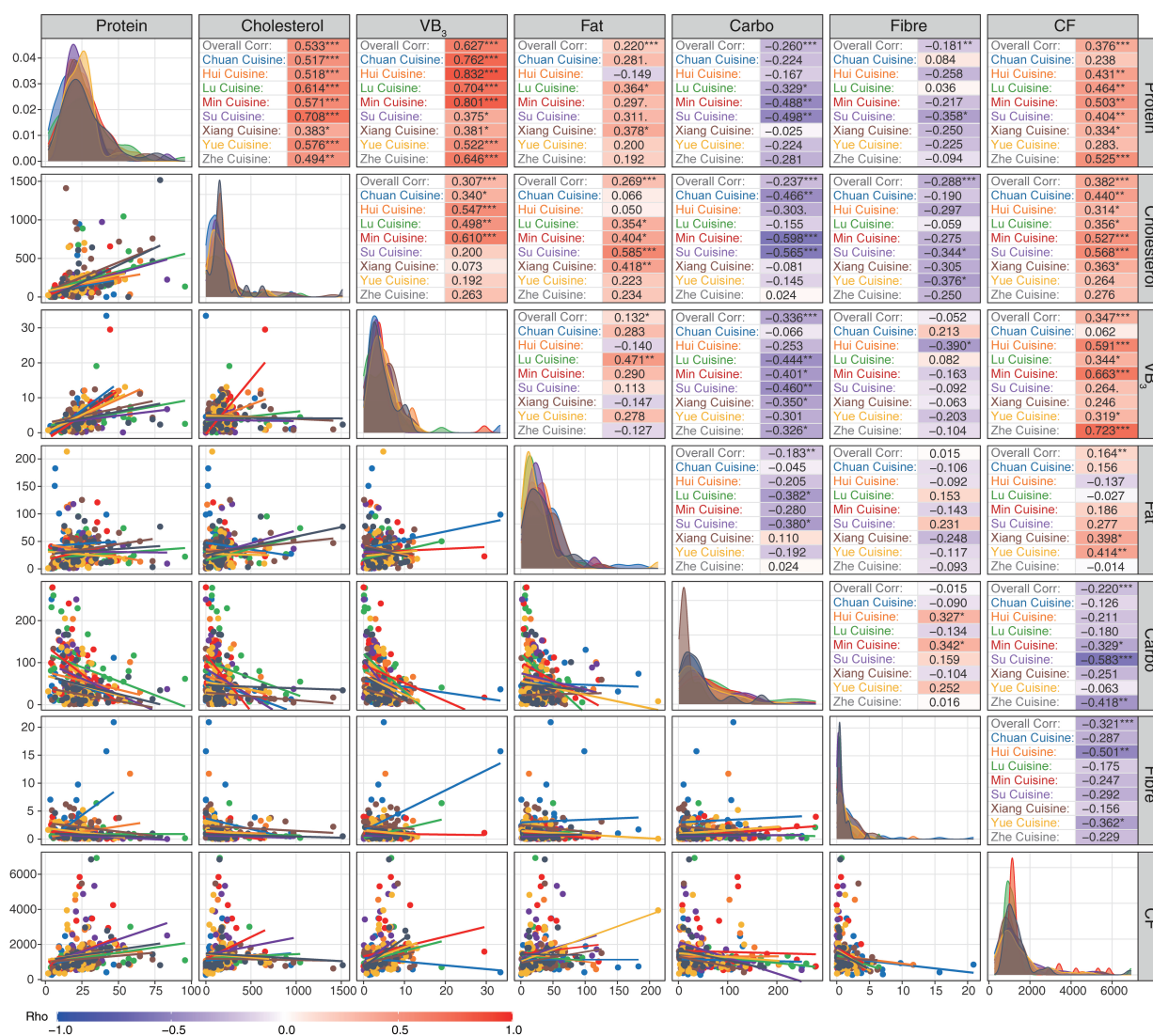


Figure 5. Correlation between the carbon footprint of recipes and nutrients. Spearman correlation coefficients between CF (g CO₂e/300 g) and nutrients. An asterisk indicates significance, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$. CF: Carbon footprint.

partially replacing ingredients in existing recipes can help reduce the carbon footprint of diets. Beans and aquatic products, as environmentally low-impact and healthy protein sources, are widely used in traditional Chinese cuisines. Chuan, Hui, and Xiang cuisines feature numerous bean-based recipes, while Zhe and Lu cuisines emphasize aquatic products. Bean-based foods, such as tofu, may offer superior environmental and nutritional benefits. Replacing animal-based foods with plant-based alternatives are effective for improving nutrient profiles, reduces premature mortality, and lowers some environmental impacts, particularly GHG emissions (reductions of up to 84%) [58,59]. Dried tofu contains approximately 50% protein, with a higher protein-to-fat ratio, fewer calories, no cholesterol or lactose, and lower saturated fat than meat or cheese [60]. Additionally, cuisines such as Chuan and Xiang reduce carbon footprints by blending meat with vegetables, thereby lowering overall meat content. Popular dishes like Mapo Tofu, which combine small amounts of beef with tofu, have gained global popularity. However, as shown in Figure 2d, the beef contributes 63% of the recipe's carbon footprint. Replacing it with lower-carbon pork would substantially reduce its environmental impact. While completely altering dietary habits proves challenging, implementing small changes through simple meal substitutions could serve as a valuable starting point for addressing both the environmental and health impacts of current food choices [61].

Adjustments in cooking practices can also significantly affect dietary sustainability. Su Cuisine, with a cooking time 77% longer than the average across all recipes, relies heavily on energy-intensive roasting and boiling. Research indicates that ovens are among the least sustainable appliances because of their prolonged cooking times and high energy demands, whereas microwaves offer a partial alternative with lower environmental impact^[27]. Similarly, extended boiling exacerbates stove energy loss, while pressure cooking can soften meats efficiently, reducing both cooking time and emissions. Avoiding overcooking and adopting energy-efficient appliances are therefore key strategies for lowering the carbon footprint of cooking.

Policy implications

This study provides a detailed analysis of the carbon footprint and nutrition of Chinese cuisines, equipping policymakers, restaurant operators, and consumers with the data support needed to drive a sustainable and healthy dietary transformation. For governments and policymakers, key priorities include encouraging restaurants to offer menus with environmental dish labels, developing culturally appropriate dietary guidelines, and proposing sustainable recipes that suit regional eating habits. Governments should encourage local restaurants to adopt “carbon footprint and health labels” on their menus to intervene in both offline and online dietary behaviors^[25] and promote the shift toward low-carbon and healthy consumer diets. By leveraging popular local recipes, governments can modify unsustainable practices (such as reducing excessive cooking times and replacing energy-inefficient appliances), decrease meat content by substituting plant-based ingredients, designing a series of improved recipes that align with local dietary cultures^[62], and popularizing the concept of low-carbon food consumption. Initiatives could begin in school cafeterias and communities, where public education campaigns raise awareness of topics such as the environmental impacts of cooking equipment, the carbon footprints of different food types, and balanced nutritional pairings.

Although the cooking-stage model in this study was parameterized for household cooking, the recipe-level ingredient carbon footprints and the relative differences among cuisines and cooking methods nonetheless provide a useful scientific basis for global Chinese restaurant operators. These data can inform the design of low-carbon menus and the optimization of cooking processes. By substituting commercial cooking and energy parameters into the proposed framework, restaurant operators can calculate the carbon footprints and nutritional profiles of their menu items and label them with “sustainable labels”, serve as an effective green marketing tool to facilitate sustainable dietary consumption^[63]. By adjusting food patterns and adopting energy-efficient cooking methods, such as using pressure cookers to reduce broth preparation times and pre-processing ingredients to minimize energy use, restaurants can lower their overall carbon emissions while enhancing the nutritional value of their recipes. This transformation not only promotes a shift in consumer diets towards sustainability but also strengthens restaurants’ competitive edge, achieving a win-win outcome for economic and environmental performance within the broader context of global dietary transitions.

For individual consumers, this study provides a practical set of dietary reference recipes that empower personal contributions to low-carbon food systems. By understanding the environmental and health impacts of their dietary choices, consumers can select recipes with lower carbon emissions and higher nutritional value, integrating them into their daily diets to collectively drive the global shift toward low-carbon eating. During daily cooking, choosing sustainable cooking methods, such as shortening cooking times, using clean energy^[64] and adopting low-oil techniques like stir-frying and steaming, can minimize energy consumption, reduce fat content, and improve overall health outcomes. These individual actions, when scaled, amplify the societal and planetary benefits of dietary low-carbon transitions, bridging personal well-being and global environmental stewardship.

Limitations and future works

There are limitations and assumptions in the research. The sample recipes were selected based on culinary white papers and online popularity. The reported carbon footprints and nutritional profiles reflect the popular restaurant-style recipes within each cuisine and may not fully capture the complete diversity of the Chinese eight cuisines. The results should be used as a benchmark for menu carbon labeling and consumer dietary guidance rather than as direct estimates of population-level dietary patterns or actual nutrient intakes. Future studies should incorporate recipes from diverse sources, such as restaurant point-of-sale data, to improve sample representativeness. The carbon footprint of spices and condiments, accounting for less than 5% of ingredient weight, was not considered, primarily because these ingredients constitute a small fraction of each recipe and because carbon emission factor data for them are lacking. Although nutrient retention factors from the USDA database were applied to account for cooking-induced losses of vitamins and minerals, these factors may not fully represent Chinese cooking conditions, potentially introducing uncertainty in micronutrient estimates. Future studies could incorporate localized retention data. Nutritional quality is multidimensional, but the correlation analysis in this study was conducted using individual nutrients. Future research should adopt a composite health score to more comprehensively evaluate the association between the nutritional quality of recipes and their environmental impacts. The correlations observed between carbon footprint and individual nutrients may partly reflect differences in ingredient composition rather than independent nutrient-emission relationships. For the cooking stage carbon footprint calculation, recipes were simplified to one dominant cooking method, which can impact the dish's flavor. While this simplification has only a limited impact on the total carbon footprint, future work should accurately quantify emissions from cooking processes involving multiple methods.

CONCLUSION

Recipe-level information can guide consumers toward sustainable dietary choices, an increasingly urgent priority as the global community seeks to address climate change through dietary reform. This study compiled a dataset on the carbon footprint and nutrition of 320 recipes from the Chinese eight cuisines. Recipes were standardized to 300 g of ingredients and categorized into nine food types and 13 cooking methods. Carbon footprints were assessed across the cradle-to-table boundary, which encompasses the production, post-farmgate, and cooking stages. The findings demonstrate that Chinese cuisines, characterized by lower ruminant meat use and a predominance of stir-frying and boiling methods, have substantially lower cradle-to-table carbon footprints than typical Western meals. Substantial variation exists in the carbon footprint across the eight cuisines, with Chuan Cuisine exhibiting the lowest emissions and Su Cuisine the highest. This is primarily driven by differences in cooking methods and the proportion of animal-based ingredients. The most common Chinese cooking methods are boiling and stir-frying, and roasting takes the longest on average and results in the highest cooking-stage emissions. In terms of nutrition, a 300 g portion of the eight cuisines supplies disproportionately high shares of the daily recommended intakes of energy, protein, fat, and cholesterol given its 18% weight share, while dietary fiber and vitamin C generally fall below the daily recommended levels. Correlation analysis indicates that protein, cholesterol, fat and niacin are positively associated with carbon footprint, while dietary fiber and carbohydrates show negative associations. These patterns are primarily driven by the differing carbon intensities of animal-based versus plant-based ingredients. This study provides recipe-level data for assessing the environmental and health impacts of Chinese cuisines, offering scientific evidence to support the formulation of carbon labeling and low-carbon dietary transition policies.

DECLARATIONS

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Authors' contributions

Methodology, formal analysis, investigation, data curation, validation, visualization, writing - original draft: Guan, A.

Formal analysis, investigation: Cai, Z.

Writing - review and editing, funding acquisition: Zhou, Y.

Writing - review and editing: Chen, M.

Conceptualization, methodology, validation, writing - review and editing, supervision, funding acquisition: Zhou, Y.

Availability of data and materials

The datasets generated and/or analyzed in the study are openly available in Figshare at <https://doi.org/10.6084/m9.figshare.29323547>. These data were derived from the following resources available in the public domain: nutritional composition data for the recipes were sourced from the China Food Composition Tables^[34], and nutrient retention factors accounting for cooking losses were obtained from the USDA Table of Nutrient Retention Factors (Release 6)^[46] (<https://www.ars.usda.gov/nutrientdata>).

AI and AI-assisted tools statement

During the preparation of this manuscript, the AI tool Doubao AI (version Seedream 5.0 Pro, released 2026-02-10) was used to generate the food-related icons in the Graphical Abstract, and ChatGPT (version GPT-4.1, released 2025-04-14) was used solely for language editing. The tools did not influence the study design, data collection, analysis, interpretation, or the scientific content of the work. All authors take full responsibility for the accuracy, integrity, and final content of the manuscript.

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Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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