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Food consumption and waste and the embedded carbon, water and ecological footprints of households in China

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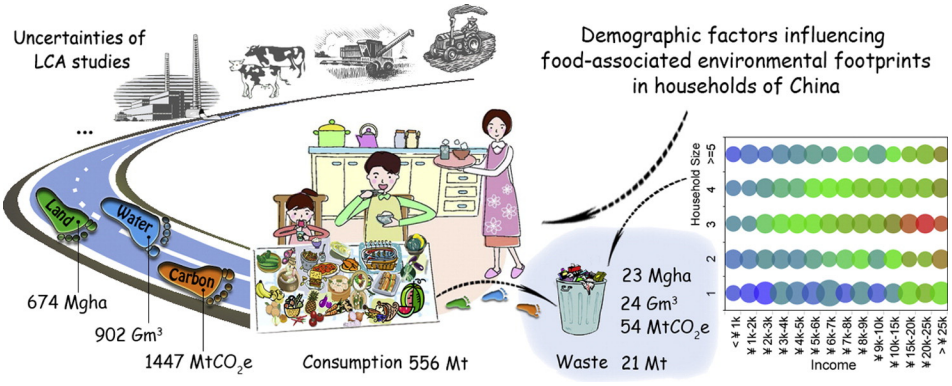
HIGHLIGHTS

- We calculate the carbon, water, and ecological footprints of food consumption and waste of household in China.
- Lower per capita food wastage and environmental footprints of household in China is offset by its large population.
- Rice, pork, and vegetables contribute most to overall environmental footprints of food consumption.
- Composition of food-waste and environmental footprints in China differs from that in developed countries.
- Demographic factors influence environmental footprints of dining behaviors greatly.

GRAPHICAL ABSTRACT



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ABSTRACT

Strategies for reducing food waste and developing sustainable diets require information about the impacts of consumption behavior and waste generation on climatic, water, and land resources. We quantified the carbon, water, and ecological footprints of 17,110 family members of Chinese households, covering 1935 types of foods, by combining survey data with available life-cycle assessment data sets. We also summarized the patterns of both food consumption and waste generation and analyzed the factors influencing the observed trends. The average person wasted (consumed) 16 (415) kg of food at home annually, equivalent to 40 (1080) kg CO_2e, 18 (673) m^3, and 173 (4956) gm^2 for the carbon, water and ecological footprints, respectively. The generation of food waste was highly correlated with consumption for various food groups. For example, vegetables, rice, and wheat were consumed the most and accounted for the most waste. In addition to the three plant-derived food groups, pork and aquatic products also contributed greatly to embedded footprints. The data obtained in this study could be used for assessing national food security or the carrying capacity of resources.

1. Introduction

Food systems driven by human patterns of consumption are responsible for 19–29% of the anthropogenic emission of greenhouse gases (GHGs) (Vermeulen et al., 2012), 70% of freshwater consumption (FAO, 1996) and 38% of terrestrial-surface occupation (Foley et al.,

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2011). These environmental impacts that are closely associated with the phases of food provision can be transferred to the phases of food consumption and disposal as the carbon footprint (CF), water footprint (WF), and ecological footprint (EF) (Galli et al., 2012). Policy makers can use these footprint tools to assess the external environmental impacts on other countries through international trade (Hoekstra and Mekonnen, 2012; Steen-Olsen et al., 2012), and companies and consumers can use them to find ways of abating their environmental impacts (Druckman and Jackson, 2009; Jones and Kammen, 2011; Ridoutt and Pfister, 2011).

Large amounts of food are lost and wasted between initial agricultural production and final household consumption, which has serious environmental consequences. One-third of global food production is lost or wasted, amounting to 1.18 billion tons (FAO, 2011) and implying that 24% of the freshwater, 23% of the agricultural land, 23% of the fertilizer and a large amount of the energy used to produce, process, store, and transport the food produced is wasted (Kummu et al., 2012). This effort to reduce food waste is especially meaningful for the people in China who are experiencing severe water shortages and land scarcity for arable agriculture. Climate change and the newly emerging problem of soil contamination are simultaneously worsening the predicament, putting China at a high risk of food self-insufficiency (Liu et al., 2013c). In addition to the severe challenge of food production, the country is plagued by progressively serious food loss and waste (Liu et al., 2013a; State Administration of Grain, 2013).

Understanding the pattern and scale of daily food waste is thus vital for each consumer in China, so that they can prioritize methods of reducing their food waste and the embedded footprints; however, doing so is hampered by fragmented and outdated data (Parfitt et al., 2010). Two reviews of tentative food loss and waste generation in the food-supply chains (FSC) in China have recently become available. Liu (2013) showed that the storage component of the FSC is the largest contributor to food loss, but its dominant role is expected to decline due to increasing consumer waste, especially in the catering and restaurant sector. Liu et al. (2013b) indicated that 19% of the food in China is lost and wasted, representing wastes of 135 billion m^3 for the WF and 26 million ha of agricultural land. This review also stated that consumer waste (7.3%) is the largest single contributor to food loss and waste along the entire Chinese FSC. Food wastage has been reviewed at the national level, but food wastage, consumption and the embedded CF, WF and EF of consumers at the household level have seldom been studied due to a lack of information.

Such analyses are now possible due to the large amount of data about food collected in the China Health and Nutrition Survey (CHNS, 2011a) and a footprint database for the Double Food — Environmental Pyramid model (DFEP, 2013a) that has reviewed several hundred life-cycle assessment (LCA) publications for various food systems. Our main objectives in this study were thus: i) to summarize the patterns of both food wastage and consumption in Chinese households, ii) to calculate the embedded environmental impacts characterized by CF, WF, and EF and iii) to analyze the factors influencing the behaviors of food consumption and waste generation within households.

2. Material and methods

2.1. Calculate food amount and footprints

Overall, 27 food groups (i.e. rice, wheat, legumes, maize, other cereals, potatoes, bread, snacks, biscuits, vegetables, fruits, dried fruits, pork, lamb, beef, poultry meat, aquatic products, other meats, eggs, milk, butter, yogurt, cheese, sugar, sweets, vegetable oils and others) were analyzed. We calculated the food consumed (discarded) and embedded CF, WF, and EF at both per capita level and household level, for the purpose of comparison with other studies. Eqs. (1)–(4) were used for per capita calculation, while Appendix Eqs. A1–A4 were used for household level calculation.

$$C_{\mathrm{I}} = \sum_{i=1}^{n}\sum_{j=1}^{p}\sum_{h=1}^{l} c_{i,j,h} / \sum_{i=1}^{n}\sum_{j=1}^{p} pd_{i,j} \tag{1}$$

$$W_{\mathrm{I}} = \sum_{i=1}^{n}\sum_{h=1}^{l} w_{i,h} / \sum_{i=1}^{n}\sum_{j=1}^{p} pd_{i,j} \tag{2}$$

$$FTC_{\mathrm{I}} = \sum_{i=1}^{n}\sum_{j=1}^{p}\sum_{k=1}^{26} c_{i,j,k} \times FT_k / \sum_{i=1}^{n}\sum_{j=1}^{p} pd_{i,j} \tag{3}$$

$$FTW_{\mathrm{I}} = \sum_{i=1}^{n}\sum_{k=1}^{26} w_{i,k} \times FT_k / \sum_{i=1}^{n}\sum_{j=1}^{p} pd_{i,j} \tag{4}$$

where C_H (W_H) represents per capita daily average grams of food consumed (wasted) with FTC_H (FTW_H) corresponding to CF, WF, and EF of food consumption (discards). A total of $n = 12{,}850$ households were surveyed and indexed by i; j indexes family members; p_i is all interviewed family members and is less than or equal to household size POP_i; h indexes food, with a maximum m equal to 1935; $c_{i,j,h}$ ($c_{i,j,k}$) is food h (food group k) consumed by individual j in household i; $w_{i,h}$ is food h discarded; $pd_{i,j}$ is a total of individual "person-days" during surveyed periods; k indexes food groups, with a maximum of 26, and $w_{i,k}$ is the total amount of discarded food group k. $FT_{k,}$ is the coefficient of CF, WF, and EF along the provision chains of food group k summarized from the DFEP database; while variables $c_{i,j,h}$, $c_{i,j,k}$, $w_{i,h}$, $w_{i,k}$, $pd_{i,j}$, and POP_i are from the CHNS database. Detailed information for the two databases is elaborated in Sections 2.2 and 2.3.

2.2. Food and demographic information from CHNS database

A survey was conducted to establish the CHNS (2011b)database. Grams of 1935 types of food consumed by each family member at each meal, along with the discarded food, were all recorded in detail following the China Food Composition code (Yang, 2004; Yang et al., 2009). Overall, about one million food records obtained from 17,110 family members in 2004, 2006, and 2009 were used. All foods were merged into the 26 food groups for further analysis. Along with the information about food consumption and discards, background demographic information about the household, including age, educational level, and physical activity level (PAL) for each interviewee, annual income, and household size were also recorded to reveal factors contributing to food consumption and waste.

2.3. Footprint coefficient from DFEP database

In terms of the footprint coefficient of food provision chains, literature data from LCA studies have been successfully used to quantity the environmental impacts of sustainable diets, though uncertainty is unavoidable (Stehfest, 2014; Tilman and Clark, 2014). In total, 658 LCA studies on the CF, WF, and EF of various foods were filtered from the reviewed studies using the DFEP (2013b)database , covering 154 food categories that belong to our 27 standardized food groups. Coefficients of CF, WF, and EF of each food group were summarized with a triangle probability distribution defined to further quantify uncertainty according to the IPCC (2006) recommendation. EF coefficients of maize and dried fruits were unavailable, although their CF and WF were available. We thus conducted a regression analysis to deduce the required