Environmental impact of express food delivery in China: the role of personal consumption choice

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Abstract

The online food ordering business in China is developing rapidly in recent years with considerable environmental impacts. However, the impacts caused by the express food delivery and the differences between the regions with different economic levels have seldom been quantified. Changing personal consumption behavior might help to reduce such impacts. But to what extent personal consumption changing could alter the environmental impacts caused by express food delivery remained uncertain. Thus, we have conducted a quantitative study based on the data collected from a 45-persons survey to determine the environmental impacts caused by the express food delivery in the different regions of China. Additionally, the reducible environmental impacts were estimated by establishing a scenario of personal consumption behavior changing. The results showed that each express food delivery order would generate 111.80 g CO₂ emission equivalent on average. Most (86%) of the CO₂ equivalent of the express food delivery came from the food packages. Compared to the orders in the second-class and third-class cities, the orders in the first-class cities had a significantly higher CO₂ equivalent due to the greater use of food packages. The results also demonstrated that by walking to take the food in the restaurants nearby (< 1 km), 68% of the CO₂ equivalent derived from the express food delivery could be reduced. People's willingness to change consumption behavior plays an important role to achieve the environmental impact reduction.

Keywords Food delivery transport · Food package · CO₂ equivalent · Consumption behavior · Happiness

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1 Introduction

In the year of 2011, the environmental writer Colin Beavan has published his book “No Impact Man” in which the author has shared the experience of how his family passed one-year eco-friendly living. One of their efforts was to consume locally on foot for food products in order to reduce the environment impact caused by the transportation and packages of goods. However, after eight years it has been difficult to achieve buying locally on foot in China. Global and regional food trade has made our markets full of unlocal foods. According to the data of 2017 from WITS (World Integrated Trade Solution), China spent 265 million, 79 million, and 44 million dollars for the global trade for food products, animals, and vegetables, respectively. Thus, a great amount of food in our markets comes from the import with long-distance transportation. In addition, the client’s demand for food inside country also requires a number of logistics transportation. Based on the Chinese National Logistics Operation Report for 2018, the total expenditure of agricultural product logistics was 3900 billion Yuan, viz. 567 billion dollars. Even so, clients could still go to markets or groceries and choose to buy the foods produced in the regions closed to their cities and counties. But with e-commerce development soaring by the days, it seems clients in China are also losing their “mobility” on foot to consume foods. Instead, people prefer to order express food delivery using some apps (e.g., Meituan and Eleme) on the cell phones (Liu & Chen 2019). The results of Daxue Consulting on the Chinese market in 2019 have demonstrated that the worth of China’s delivery food market was estimated to be over 37 billion dollars with a quarter of Chinese clients (355 million) ordering food on the cell phones.

The huge economic benefits in the food transportation and the delivery market would lead to considerable environmental impacts (EIs). Distant food transport is a major contributor to fuel using pollution and greenhouse gas emission (Norberghodge et al. 2002). In the USA, transporting food within the nation’s borders accounts for over 20% of all commodity transport, and results in at least 120 million tonnes of CO₂ emissions every year (Norberghodge et al. 2002). Considering the greater population in China, the amounts of CO₂ emissions caused by distant food transport could reasonably be greater than that of the USA. In addition to fuel using pollution, food delivery is also proved to have other huge environmental costs, like package material cost. In 2015, the Chinese express delivery industry, including food delivery, accomplished a total of 20.70 billion express delivery orders and consumed approximately 9.92 billion package boxes, 8.27 billion plastic bags, 3.10 billion woven bags, 1.11 billion envelopes, and 16.69 billion meters of tape accounting for 1.17×10^9 kg CO₂ emission with other pollutants (Fan et al. 2017). It was reported that takeaway food consumption can generate tonnes of food wastes and approximately 0.3 billion wasted meal boxes and plastic bags per day in China (Liu & Chen 2019). Moreover, Gallego-Schmid et al. (2019) mentioned that the single-use food containers are quite environment influencing, by considering 12 environmental impacts, including element cycles, fossil resources, global warming, human toxicity, ecotoxicity, etc.

Many technical strategies are being taken to reduce the EIs of global and regional food transport, such as the optimization of food logistics (Guo et al. 2017). The efforts are also made in management strategies, such as the implementation of Green Supply Chain Management (Wang et al. 2016) and Sustainable Supply Chain Management (Rajesh 2020a). Those technical and management strategies would confront several barriers to overcome, including the lack of adequate training and progress monitoring,

poor customer awareness, and lack of pressure for widespread adoption. Therefore, those approaches would take a long time to have considerable effects on the reduction in EIs caused by global food trade and transport and would not be a personal work.

On the other hand, individual efforts should not be ignored in reducing the EIs of food transportation and delivery. Urien and Kilbourne (2011) mentioned that consumption in industrial countries is the main cause of environmental problems. Thus, a change in consumption behaviors in our daily life might be possible to create sustainability of the food market, especially when ordering express food delivery is now becoming the lifestyle of Chinese people. If they reduce the frequency of ordering express food, it will definitely have a positive effect on reducing the EIs caused by food delivery and packages. The willingness to change personal consumption would be the key to accomplish such an effort. Prothero et al. (2011) mentioned that only 10% of consumers who said they were willing to consume greenly would actually fulfill their willingness. In that case, understanding the potential of reducing the EIs of express food delivery via changing personal consumption and whether it is worthy to conduct the consumption behavior changing might help people to fulfill their willingness of consuming greenly. Therefore, this study aims firstly to conduct a quantitative analysis to show the magnitude of EIs of express food delivery could be reduced by changing consumption behavior. The data for the quantitative analysis were collected by a 45-persons survey on the information in their cell phone food ordering apps. Then, whether the scenario of consumption behavior changing and the reduction in EIs are possible and worth being conducted is discussed by considering people's preference over environment quality and other material welfares.

2 Material and methods

At the macro-scale, the EIs of consumption and production could be assessed by the methodologies of environmentally extended input–output tables, process-based life cycle assessment, and hybrid methods (Lorenzo et al. 2015). Those methods have been successfully applied to estimate the different categories of EIs of consumption and production in multi-regions. For example, Ivanova et al. (2016) had used the EXIOBASE 2.2 multiregional input–output database to estimated four EIs of carbon footprint, land footprint, material footprint, and water footprint for 43 countries in the world. While Beylot et al. (2019) added the elementary flow to the EXIOBASE to estimate 14 EIs of consumption in countries of EU, including acidification, terrestrial eutrophication, marine eutrophication, freshwater eutrophication, land use, water use, non-cancer human toxicity, cancer human toxicity, freshwater ecotoxicity, particulate matter, photochemical ozone formation, climate change, fossil resource use, mineral and metal resource use. However, the EI estimation of the express food delivery could be simplified. The local express food delivery does not need to take the multi-region effects into consideration. In addition, there is no need to consider the various categories of environmental impacts for the express food delivery. It is because that the only input–output flows of materials for the consumption demand of express food delivery are the energy used for delivery transport and the materials for food containers, while both of them could be easily converted into carbon footprint or material footprint. The details of the methods are described in the following sections.

2.1 Data collection

The data collection was conducted via an enquiry invitation on the social software WeChat during a period of two weeks from 27 June to 11 July, 2019. In total, 45 persons from 23 Chinese cities (Tianjin, Haikou, Xiaogan, Wuhan, Hangzhou, Beijing, Changsha, Ningbo, Shanghai, Shenzhen, Zhuhai, Nanjing, Fuzhou, Yanglin, Xi'an, Suizhong, Ha'erbin, Qingdao, Huhehaote, Taiyuan, Guilin, Lipu, Zhenjiang) have responded to the enquire. The participants were asked to provide their express food delivery data by sending us the captured figures of food orders from the food ordering apps (Ele.Me and Meituan) containing the information of restaurant location, delivery destination, and order contents. At most ten recent express food orders were collected from each person, and in total 398 sets of data were recorded.

For each data set, the delivery distance between the restaurant location and the delivery destination was deemed on the site of AMAP (<https://www.amap.com>). The information of food package materials and amounts was figured out via the food order contents and the description of the participants.

2.2 Environmental impact calculation

The EIs of express food delivery mainly consists of fuel consumption during delivery and the usage of food packages (Fan et al. 2017). The fuel consumption is calculated from a delivery distance. The usage of food packages is first figured out by the order contents, and the EIs of each sort of material is calculated separately. To facilitate the calculation, the environmental impact equivalent used in this study was the CO₂ emissions equivalent (CO₂-eq).

2.2.1 Fuel consumption of delivery

The express food is mainly delivered by electric motorcycles. The common bands of electric motorcycles in China are Tailing (<https://www.tailg.com.cn/>), Yadea (<https://www.yadea.com.cn/>), and Aima (<https://www.imatech.com/>). According to the parameters of electric motorcycles on their sites, most motorcycles equipped with the 48V12Ah battery (total power about 0.6 kWh). In general, the travel distance for those motorcycles is 40–60 km. Therefore, the electric motorcycle would consume 0.01–0.015 kWh of electricity per kilometer. Although electric motorcycle may not generate CO₂ emission by not using mineral fuel as power, the generation of electricity could cause CO₂ emission. According to Ang and Su (2016), the average CO₂ emission of electricity production over the world in 2013 was 520 g CO₂ per kWh. The electricity production from coal power plants would cause a great proportion of CO₂ emission. In 2013, about 65% of total electricity was produced by thermal power generation over the world (Ang & Su 2016). They had a low generation efficiency of 20% and a high CO₂ emission of 1700 g per kWh. Several technologies have been applied to reduce the CO₂ emission for electricity generated from coal. For instance, the approaches of pulverized fuel combined with flue gas desulphurization and integrated gasification combined cycle could reduce the CO₂ emission of coal-generated electricity to 229 g and 190 g CO₂ per kWh (Sims et al. 2003). Those technologies as well as the other electricity sources of nuclear power, hydropower, eolien power, and solar energy contributed to reducing the average CO₂ emission to 520 g

CO₂ per kWh. Since in 2018, 70.4% of total electricity was produced by thermal power generation in China (data from China Electricity Council), which was similar to the global situation in 2013. So, in this study, the CO₂ emission per kWh could be deemed at 520 g for the electricity consumption impact calculation of the food delivery.

In terms of the transport distance, it firstly depends on the delivery distance, viz. the distance between the restaurant and the delivery destination. In general, the delivery rider would stay close to the commercial center where the restaurants located. So, for a single order, the transport distance could be simply calculated as twice as the delivery distance. However, several orders could share the same routing due to the uncertainty of the coming orders, which could decrease or increase the transport distance. According to the survey of 110 delivery riders conducted by Liu et al. (2019a, b), 56.25% of the total orders could share delivery and 43.75% of the total orders would need a single delivery. In general, there might be 2–5 orders for sharing. Thus, the transport distance for each order could be estimated as follows:

$$D = 2d * (\alpha/n + \beta)$$

where D is the transport distance; d is the delivery distance; α is the proportion of orders sharing a delivery; β is the proportion of orders taking a single delivery; n is the average number of orders sharing a delivery. In this study, α , β , and n are deemed at 56.25%, 43.75%, and 3.5%, respectively.

Hence, the environmental impact (CO₂-eq) caused by fuel consumption of delivery is calculated as follows:

$$E_{\text{delivery}} = D * e * C_{\text{electricity}}$$

where E_{delivery} is the environmental impact caused by fuel consumption of delivery; D is the delivery distance; e is the electricity used by electric motorcycle per km; $C_{\text{electricity}}$ is the CO₂ emission caused by electricity generation of 1 kWh. In this study, e and $C_{\text{electricity}}$ are deemed at 0.01 kWh km⁻¹ and 520 g CO₂ kWh⁻¹, respectively.

2.2.2 Food packages

Another part of the EIs caused by express food delivery come from the food packages. Those impacts were generated by raw material fabrication, package production, transportation, and use (Fan et al. 2017). During the life time of food packages, a lot of harmful compounds, such as heavy metals, CO₂, fluoride, NO₂, SO₂, methane, PM_{2.5}, and radioactive emission, will be emitted to the environment. Among these harmful compounds, the amount of CO₂ is at least two magnitudes higher than any of the other compounds (Fan et al. 2017). Therefore, the CO₂ emission could approximately represent the EIs of the express food packaging. In order to deliver the food steadily, the restaurants usually chose plastic bags, plastic boxes/bowls, paper bags, and paper boxes as food containers. Barrett et al. (2002) have listed the carbon footprint for the consumption of different types of plastics by considering its production and transportation: 6.96 kg CO₂ per kg plastic film, 6.75 kg CO₂ per kg plastic drink bottles (PET), 7.08 kg CO₂ per kg food packaging (LDPE), and 6.43 kg CO₂ per kg dense plastic (HDPE). The CO₂-eq of plastic usage has been reduced in recent years. According to the study of Muthu et al. (2011) in China, the CO₂-eq of plastic bags is 1.95 kg CO₂ per kg plastic. Whereas, the CO₂-eq of paper bags is 0.53 kg CO₂ per kg paper. Those values were used for the calculation of food package EIs in this study. The total amounts of plastics and papers used for each order were first

figured out based on the order contents, and then, their CO₂-eqs were calculated. The average weights of the plastic bag, plastic box/bowl/cup, paper bag, and paper box/bowl are deemed at 5 g, 20 g, 50 g, and 50 g per each, respectively, according to the data offered by the merchants on Alibaba (<https://www.alibaba.com>). Besides food packaging, disposable chopsticks should be taken into account to calculate the EIs of the express food packages. China's annual consumption of disposable chopsticks is 80 billion pairs, which brings carbon emissions for 36.8 million kg (Chen 2011), viz. 0.46 g CO₂ per pair of disposable chopsticks.

In addition, a part of the packages could be recycled. For instance, in the European Union, 11% of the express food containers made of PP were recycled, while 44% went to incineration and 45% went to landfilling (Gallego-Schmid et al. 2019). The recycling rate of papers could be higher than that of plastics. The recycling process could contribute to reducing the EIs caused by the raw materials of plastics and papers, such as oil extracts for plastic production. However, the recycling of plastics and papers also generates CO₂ emission. So, it is difficult to quantify precisely the effects of recycling on the EIs of plastic and paper food packages. Thus, in this study, we did not take the recycling of plastics and papers into account. The environmental impact of the food package was calculated as follows:

$$E_{\text{package}} = m_{\text{plastic}} * C_{\text{plastic}} + m_{\text{paper}} * C_{\text{paper}} + p * C_{\text{chopsticks}}$$

where E_{package} is the environmental impacts caused by food package; m_{plastic} and m_{paper} are the amounts of plastics and papers used for one order on gram; C_{plastic} and C_{paper} are the CO₂-eqs caused by production, transportation, and use of plastics and papers; p is the pairs of disposable chopsticks used in one order; $C_{\text{chopsticks}}$ is the CO₂-eq caused by production, transportation, and use of chopsticks. In this study, C_{plastic} , C_{paper} and $C_{\text{chopsticks}}$ are deemed at 1.95 g CO₂ g⁻¹ plastic, 0.53 g CO₂ g⁻¹ paper, and 0.46 g CO₂ per pair of chopsticks, respectively.

2.3 Consumption changing scenario: replacement of express food delivery

In this study, we shall not discuss thoroughly replacing the express food delivery by home-made dishes for the sake of reducing its EIs, since it is difficult to fulfill. We considered that the food delivery activity could be replaced by walking to the restaurant to have the same or similar food in place. In that case, the EIs of food delivery and food packages might be reduced.

In terms of consumers' willingness to walk for consumption, Yang and Diez-Roux (2012) have conducted a study showing that 16% of clients willed to a walking trip of 0.7 miles (1.12 km), 65% of walking trips were more than 0.25 miles (0.40 km), and 18% of walking trips were more than 1 mile (1.60 km). On average, the distance of walking trips for consumption might be at least 0.73 km. We assumed that the walking trips for the restaurant could probably not be stout of line compared to other purposes. Accordingly, in this study, we have created a scenario that the consumers are willing to walk about 1 km to have the food rather than ordering express food delivery. For each order, we searched the area within 1 km away from the delivery destination in Gaode Map (<https://ditu.amap.com>) to find whether there was a restaurant offering the similar foods as the order. If there was such a restaurant, the environmental impact caused by food delivering and packaging could be reduced via walking to have food in place. But

for the fast foods, the environmental impacts from packages cannot be reduced even when eating in place. The reduction in EIs was calculated by the methods mentioned in Sect. 2.2.

2.4 Statistical analysis

The average values of delivery distance, plastic package amount, paper package amount, disposable chopstick pairs, CO₂-eqs of express food delivery order (including those of food delivery, food package, and the total value), and possibly reducible CO₂-eqs (including those of food delivery, food package, and the total value) by walking to restaurant and having food in place were calculated for all the orders. Additionally, in order to compare the different situations of express food ordering in the areas with different economic development levels, the data were categorized into three groups, which were the orders from first-class cities (Beijing, Shanghai, and Shenzhen as the new first-tier cities in China), second-class cities (Tianjin, Wuhan, Hangzhou, Changsha, Ningbo, Nanjing, Xi'an, Qingdao as the new first-tier cities), and third-class cities (Haikou, Xiaogan, Changsha, Zhuhai, Fuzhou, Yanglin, Suizhong, Ha'erbin, Huhehaote, Taiyuan, Guilin, Lipu, Zhenjiang as other cities), respectively. The ANOVA was conducted using the MIXED procedure in SAS 9.4 (SAS Institute Inc., USA) to study the effects of city groups on the variables of express food delivery EIs. The effects of city groups were the fixed effects, and the effects of survey participants were considered as the random effects. City groups' effects were deemed significant when $P < 0.05$. Differences of each variable among the city groups were identified by multiple comparisons with test Tukey using the LSMEANS statement in SAS 9.4. The differences between variables of different city groups were significant when $P < 0.05$.

3 Results

3.1 Food delivery costs

According to the results, one express food delivery order on average required a delivery distance of 2.51 km and generated 15.60 g CO₂-eq for the food delivery (Table 1). Taking different classes of cities into consideration, there was no significant difference between the average delivery distances for first-class cities (2.23 km), second-class cities (2.83 km), and third-class cities (2.14 km) (Table 1). Thus, CO₂-eqs for the food delivery between three city groups shared similar patterns with no significant difference observed.

Overall, 25.7% of the orders had a delivery distance shorter than 1 km, while 22.7%, 18.4%, 14.6%, 9.8%, and 8.8% of the orders had a delivery distance of 1–2 km, 2–3 km, 3–4 km, 4–5 km, and over 5 km, respectively (Fig. 1). It should be noted that even having the smallest average delivery distance, third-class cities had a smaller proportion (17.8%) of orders with delivery distance inferior to 1 km in contrast with those of first-class cities (30.5%) and second-class cities (31.1%). Whereas for second-class cities, there was a higher proportion of orders with delivery distance over 5 km (13.5%) than those of first-class cities and third-class cities (3.4% and 5.2%, respectively).

Table 1 Average values of delivery distance, plastic package amount, paper package amount, disposable chopstick pairs, CO₂ equivalents of express food delivery order (including those of food delivery, food package, and the total value), and possibly reducible CO₂ equivalents (including those of food delivery, food package, and the total value) by walking to restaurant and having food in place for all the orders, and the orders from first-class cities, second-class cities, and third-class cities

	Delivery distance (km)	Plastic package amount (g)	Paper package amount (g)	Disposable chopstick pairs	CO ₂ equivalent of food delivery (g)	CO ₂ equivalent of food package (g)	Total CO ₂ equivalent (g)	Possibly reducible CO ₂ equivalent of food delivery (g)	Possibly reducible CO ₂ equivalent of food package (g)	Possibly reducible CO ₂ equivalent (g)
All	2.51 ± 0.10*	43.36 ± 1.97	21.16 ± 2.51	0.93 ± 0.04	15.60 ± 0.61	96.20 ± 3.72	111.80 ± 3.74	11.96 ± 0.62	64.01 ± 3.81	75.97 ± 3.97
First-class cities	2.23 ± 0.22	67.12 ± 8.38a	29.66 ± 8.81a	1.20 ± 0.13	13.87 ± 1.35	147.16 ± 15.63a	161.03 ± 15.35a	11.63 ± 1.44	116.11 ± 17.67a	127.74 ± 17.68a
Second-class cities	2.83 ± 0.15	39.14 ± 2.31b	23.89 ± 3.65ab	0.80 ± 0.05	17.62 ± 0.94	89.35 ± 4.33b	106.97 ± 4.46b	12.64 ± 0.93	49.55 ± 3.54b	62.19 ± 4.03b
Third-class cities	2.14 ± 0.15	39.33 ± 2.46b	13.33 ± 3.03b	0.99 ± 0.08	13.33 ± 0.91	84.22 ± 4.64b	97.55 ± 4.74b	11.08 ± 0.96	62.99 ± 5.22ab	74.07 ± 5.52b

*The value after ± is the standard error

Different letters after the values indicate the significant difference ($P < 0.05$) between the different classes of cities

Fig. 1 Proportions of orders with the delivery distances of <1 km, 1–2 km, 2–3 km, 3–4 km, 4–5 km, and >5 km for all the food orders, and the orders in the first-class, second-class, and third-class cities

3.2 Food package costs

In terms of food package, each order costed 43.36 g of the plastic package, 21.16 g of the paper package, and 0.93 pairs of chopsticks (Table 1). The usage of those packages could generate 96.20 g CO₂-eq per order. The orders in the first-class cities used significantly higher amounts of plastic and paper packages (67.12 g and 29.66 g per order, respectively) than those in second-class cities and third-class cities (Table 1). In addition, 30.6% and 37.9% of the express food packages were made of paper in the first-class cities and the second-class cities, respectively, and the value of the third-class cities was only 25.3% (Fig. 2). But there was no significant difference observed on the use of disposable chopsticks, although orders in first-class cities also tended to use relatively more chopsticks per order (Table 1). Because of using a greater amount of food packages, express food delivery orders in the first-class cities had significantly greater the CO₂-eq caused by food package (147.16 g per order) than those of the second-class and third-class cities (89.35 and 84.22 g per order, respectively) (Table 1).

Fig. 2 Average proportions of paper package and plastic package usages for all the food orders, and the orders in the first-class, second-class, and third-class cities

3.3 Environmental impacts of express food delivery

Accordingly, each delivery order could generate 111.80 g CO₂-eq (Table 1). The orders in the first-class cities had significantly greater total CO₂-Eq. (161.03 g per order) than those of the second-class and third-class cities (106.97 and 97.55 g per order, respectively). On average, 14.0% of total CO₂-eq came from food delivery and 86.0% of total CO₂-eq came from food packages (Fig. 3). Different cities had a similar pattern with 91.3%, 83.5%, and 86.3% of total CO₂-eq were caused by food packages for the orders in first-class cities, second-class cities, and third-class cities, respectively.

3.4 Possibly reducible environmental impact

Based on our assumption, by walking to the restaurant within 1 km away and taking the similar food in place, 75.97 g CO₂-eq could be reduced per order (Table 1), taking up 68.0% of the total CO₂-eq (Fig. 4). Significantly more reducible CO₂-Eq. (127.74 g) was found for the orders in the first-class cities. While the orders in the second-class cities had the smallest possibly reducible CO₂-Eq. (62.19 g) (Table 1). It was because the orders in the first-class cities had significantly more reducible CO₂-eq caused by food package

Fig. 3 Average proportions of CO₂ equivalents caused by food delivery and food package for all the food orders, and the orders in the first-class, second-class, and third-class cities

(116.11 g), whereas the second-class cities had the smallest possibly reducible CO₂-eq caused by food package (49.55 g).

In terms of the proportion for reducible CO₂-eq, orders in the first-class cities had the highest proportion of 79.3% followed by 75.9% in the third-class cities and only 58.1% in the second-class cities (Fig. 4). Moreover, as shown in Fig. 5, across all the orders 84.3% of the possibly reducible CO₂-eq came from the food package. The proportion of reducible CO₂-eq of food package was highest for the orders in first-class cities (90.9%) followed by those of the third-class cities (85.0%) and the second-class cities (79.7%).

4 Discussion

4.1 To what extent the EIs of express food delivery could be reduced?

The results showed that on average an express food delivery order would generate 111.8 g CO₂-eq. This amount is about half of the CO₂ emission caused by 1-km driving of internal combustion vehicles (Onat et al. 2015). Considering that there will be more than 10 million express food orders per day (iiMedia Report: 2018–2019 China online take-out industry analysis report), the amount of CO₂-eq caused by express food delivery is considerable.

Fig. 4 Average proportions of possibly reducible and non-reducible CO₂ equivalents for all the food orders, and the orders in the first-class, second-class, and third-class cities

But it was assumed that 68.0% of the EIs could be reduced by taking the foods in the restaurant nearby (< 1 km).

Firstly, walking to restaurants to have food will certainly contribute to reducing the CO₂-eq caused by food delivery. For each order, 11.96 g CO₂-eq of food delivery could be possibly reduced. Different economic development levels of cities did not bring significant difference to the food delivery distance and the food delivery derived CO₂-eq. However, the clients in the first-class and second-class cities seemed to be “lazier” than the clients in the third-class cities with more orders within 1 km away (Fig. 1). Thus, the clients in the first-class and second-class cities have more potential to conduct the efforts to reduce food delivery derived CO₂-eq. In addition, other efforts, such as optimizing the delivery routing to shorten delivery distance and time (Zhao 2018; Liu et al. 2019a, b), could also contribute to mitigating the CO₂ emission caused by food delivery. However, it should be pointed out that the food delivery derived CO₂-eq only possessed a small part of the total CO₂-eq of express food delivery. The CO₂-eq of food delivery only took up 14.0% of the total CO₂-eq (Fig. 3), and the possibly reducible CO₂-eq of food delivery took up 15.7% of the total possibly reducible CO₂-eq (Fig. 5). Thus, reducing food delivery transportation would have limited effects on EI reduction. More attention should be paid on the CO₂-eq derived from food package.

According to Song et al. (2018), the waste food packages from food delivery surged from 0.2 million tons in 2015 to 1.5 million tons in 2017. The authors pointed out that

Fig. 5 Average proportions of possibly reducible CO₂ equivalents caused by food delivery and food package for all the food orders, and the orders in the first-class, second-class, and third-class cities

because of the food residues the food delivery packages had low recycling value with 62% disposed by sanitary landfilling, 32% for incineration and 6% treated by illegal dumping and open burning. Our results demonstrated that the CO₂-eq derived from food package occupied 86% of the total CO₂-eq, which was more than six times of the food delivery derived CO₂-eq. The usage of food packages per order was site-specific. The orders in the first-class cities had the highest proportion of food package-derived CO₂-eq with significantly higher use of food packages per order (Table 1). This might be first due to that clients in the first-class cities tended to order food together, especially the company staff. It was proved by the use of disposable chopsticks as clients in first-class cities used more pairs of chopsticks per order (Table 1). Another likely reason could be that in the high economic development areas, clients are more willing to consume the food with nicer packages as described by Silayoi and Speece (2007) and Chandon (2012). Hence, the restaurants tended to use more and nicer food packages to improve their sales. This theory was partly confirmed by the use of package materials. The food orders in the first-class and second-class cities would use more paper for food packages compared to those in the third-class cities (Fig. 2) since the paper packages would feel more textured and comfortable than plastic packages. It should also be mentioned that although paper had a smaller carbon footprint than plastic for the same weight, the packages made of paper would be heavier than the same-size plastic packages. Thus, using paper food packages instead of

plastic packages would not help to reduce the EIs (Muthu et al. 2012; Roach 2003), which is shown in our results.

On the other hand, the orders in the second-class cities had the smallest proportion of possibly reducible CO₂-eq (Fig. 4). It could be strongly related to the orders of fast foods including chips, hamburgers, fried chicken, milk tea, and other soft serves. According to the data, 22.7% of the total orders in the second-class cities were the fast food, while there were only 15.3% and 12.6% for the first-class cities and third-class cities, respectively (data not shown as results). Since most of the fast-food packages are made of paper, that is why the orders in the second-class cities had a higher proportion of paper package use than the others (Fig. 2). In our assumption, fast food packages could not be replaced and their EIs could not be reduced even when eating in the restaurants. In China, most private restaurants use non-disposable dishes for the clients eating in place or accept clients to take away their foods even with the clients' own containers. However, in terms of the fast-food restaurants which are generally managed in a chain store mode, the use of the disposable dishes is strictly demanded for the sake of food security. We had tried to use our own containers to take away foods from McDonald's and KFC in China, and HFC in France, but were refused for food security reasons. Therefore, if clients are willing to order fast foods by cellphones, its environmental impact caused by food packages will be the least reducible.

In short, on average 68.0% of the EIs of express food delivery could be reduced by walking to take food in the restaurant nearby (< 1 km). Compared to shortening the food delivery, more EIs could be potentially reduced by saving food packages. It would be easier for the clients in the first-class and second-class cities to reduce the food delivery derived CO₂-eq as they ordered more foods from the restaurants nearby (< 1 km). Moreover, it will be difficult for the clients in the second-class cities to reduce the CO₂-eq caused by food packages since the CO₂-eq caused by the food packages for fast foods can seldomly be reduced.

4.2 Is it possible to achieve a reduction?

Ideally, more than half of the EIs of express food delivery could be mitigated by walking to have similar food in the restaurants within 1 km. However, whether it is possible in practice to achieve such a reduction is questionable. Firstly, although we have created the scenario that people are willing to walk 1 km to have food according to the study of Yang and Diez-Roux (2012), many other factors would influence the willingness to walk. In the study of Sumalee et al. (2011) on people's transport under adverse weather, they have pointed out that people are less willing to travel by public transport or walk under adverse weather. It is a similar case for people's willingness to walk for food. In general, the peak seasons of food ordering in China are the months of July to September (summer) and December to February (winter) (<https://www.can-dao.com/news/2206.html> & <https://www.waimaiwanjia.com/?p=20461>). Because during those seasons, the weather is either too hot or too cold so that more people are willing to order foods on the cellphones rather than walking out for foods.

The second factor influencing the willingness to walk could be the time. A round walking trip of 1 km commonly requires about 30–40 min, and taking food in place takes 25–30 min including the waiting time. In total, it might take more than one hour to have food in the restaurant nearby. It would be a little urgent for some people to do so. For instance, the staff in Chinese enterprises usually have 1–1.5 h of resting time at noon. As most staff will choose to take a nap of 30–45 min to keep energetic in the afternoon, using

more than one hour to take food could be a luxury for them. In contrast, ordering food online beforehand could be a better choice for them to save time.

Whereas, Agrawal et al. (2008) reported that the density, diversity, and design of the route will also influence people's decision to walk. We shall not discuss much on the esthetics of urbanization, but it will be commonly accepted that people prefer to walk with the presence of greenery, attractive buildings, smooth, and wide sidewalks compared to the presence of heavy traffic (Agrawal et al. 2008).

In addition to the walking willingness, people's compromise to take similar foods in the restaurants nearby is also questionable. Cho et al. (2019) have conducted a survey of people's perceptions about food delivery apps. The results showed that among five-dimensional attributes of food delivery app quality: convenience, design, trustworthiness, price, and various food choices, the trustworthiness were the most significant attribute for the implementation of the online food delivery business. Even though similar foods might be found in the restaurants nearby, people still tend to order the foods from the restaurants with high trustworthiness, viz. high reputation, more sales, or high purchase frequency in the restaurants.

On the other hand, in this study, the environmental impacts of express food delivery were estimated for the delivery transport and food packages. But, Liu and Chen (2019) mentioned that the food waste and the overconsumption should also be taken into account for the EIs. The food practice recognizes both material and social contexts, especially in the *mianzi* culture of China. When several people eating in the restaurant in China, the hosts would order more dishes than they need to show their kind hospitality. It would lead to either food wastes or extra food packages for the dishes left. Whereas, the surveys conducted by Liu and Chen (2019) showed that the express food delivery also caused the problem of food wastes when some light eaters complained that usually, they could not eat up the foods they ordered. Thus, more information on food waste is necessary in order to estimate the EIs of express food delivery.

Therefore, although 68% of the total environmental impact of express food delivery orders could be potentially reducible, we have to make a discount for the reduction as it is questionable in practice to fulfill the reduction potential. People's awareness of the environmental problem and willingness to behave is indispensable to conduct the reduction.

4.3 Is it worthy to conduct the reduction?

In terms of environment protection, it is no doubt that people should sacrifice some convenience and comfort to reduce the EIs of express food delivery orders. However, in environmental economics, there exists a preference function over environment quality and other valued goods, which captures the trade-off people are willing to make between material well-being and the quality of the natural environment (Welsch 2002). Thus, it is clear that we should protect a good environment for a comfortable life, not use a comfortable life to trade for a good environment unless it could bring us a better life. Welsch (2002) mentioned that it is possible to identify appropriate levels of environmental protection only when we could quantify the trade-off of happiness and comfort of life. For example, Levinson (2012) has shown that people were willing to sacrifice about \$40 for a one-standard-deviation improvement in air quality, like $14.4 \mu\text{g m}^{-3}$ of PM10, with a happiness model. Hofstetter et al. (2004) also suggested happiness as a unit to quantify sustainable consumption. They use the indicator CHap to describe the relationship between happiness and CO₂ emission, as follows:

$$\text{CHap}_i = \frac{\Delta \text{Happiness}_i}{\Delta \text{CO}_{2,i}}$$

where $\Delta \text{Happiness}_i$ is the increase/decrease in happiness due to consumption activity i ; and $\Delta \text{CO}_{2,i}$ is the increase/decrease in CO₂-emissions due to activity i .

Taking the express food delivery order for the case, the convenient food ordering could contribute to save time and avoid adverse weather, whereas walking to have food in place could contribute to do sports and perhaps enhance the social relationships. The difference between happiness and the difference of CO₂ emission between the two activity choices could both be figured out with some measurements. Thus, once there is a standard CHap adapted to the current era, national circumstances, environmental requirements, and, etc., we could simply tell whether it is worthy to change the consumption behavior to reduce the environmental impacts.

The CHap calculation would help people to make consumption decision at a personal level, there is also the indicator calculation considering EIs for the organization. For instance, Rajesh and Rajendran (2020) induced the Environmental, Social, and Governance (ESG) scores as an indicator for the sustainability performance of organizations. It contributed to investigating the potential negative impacts of economic activities on environments. They also mentioned that good performance on ESG of firms could improve their financial performances and hence be beneficial to investors, managers, and decision-makers. Additionally, Rajesh (2020b) reported that the Resource use, the Environmental innovation, and the Corporate Social Responsibility emerge as the most important indicators contributing to ESG scores indicating the great attention on environmental impacts in the economic activities. If there are more enterprises with good environmental performance, it will be easier for clients to make the decision to consume greenly.

Moreover, the choice over environment quality and material welfare should have a low priority in some emergencies. During the explosion of coronavirus (COVID-19) pandemic in the city of Wuhan from January to April 2020, the citizens were confined at home, while the foods were only supplied by the express food delivery organized by the government. According to our study that activity would no doubt lead to more environmental impacts and less feeling of happiness, but it effectively ensured the control of the epidemic. Therefore, the conclusions of our research should only apply to daily life conditions and not to social emergencies.

5 Conclusion

In this study, we have shown how much environmental impact would be produced for each express food delivery order in China, and how much of the impact could be potentially reducible. We also found that the potential reduction in express food delivery environmental impacts are site-specific. More impacts are potentially reducible in the first-class cities. As we know that from the beginning of 2020, the food ordering Apps (Ele.me and Meituan) started to make efforts to reduce express food delivery environmental impacts by rewarding the consumers who do not command tablewares in their orders. However, only a part of disposable chopsticks, forks, spoons, and napkins could be saved in that way while most food packaging would be still needed. According to the results in the study, even more than half of the environmental impacts could be reduced by changing the consumption behavior of express food delivery, in practice, it is difficult to conduct the ideal reduction because of

various reasons such as people's work patterns, food quality, and weather condition. Thus, more efforts might be made to help people to enjoy taking food on foot. Right now many grand companies in China have their own canteens to provide high-quality foods for their staffs instead of making them ordering express foods. In addition, the enterprises could also change their time-table to give people more flexible time for taking meal comfortably. Of course, the government could use regulations to guide people's consumption. For example, according to the new regulation of Ministry of Ecology and Environment, China, by the end of 2020, the use of non-degradable disposable plastic straws are prohibited in the catering industry. But after all, people's willing to alter the consumption choice is the key to reduce the environmental impacts. In addition, before changing consumption behavior people should understand if it is worthy to reduce the environmental impact. A quantifying function for the trade-off between environmental quality and material well-being could be defined based on the collection of more data in the express food delivery business to help people make the choice of consumption. However, it should be noted that this approach should only apply to daily life conditions and not to social emergencies.

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