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Environmental impacts characterization of packaging waste generated by urban food delivery services. A big-data analysis in Jing-Jin-Ji region (China)

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ABSTRACT

Controversies on food delivery services environmental impacts have been sparked due to the growth of this economic sector. This study focuses on the environmental impacts generated by packaging waste related to urban food delivery services. In particular, the Python based web-crawling and sample survey methods are used for big data mining, and LCA-based environmental impacts evaluation and Kernel density analysis methods are combined to determine the positioning trend of food delivery service providers and expansion direction of environmental pollution load in Jing-Jin-Ji region (North China). Results indicate that (1) food delivery service packages presently account for a very small proportion (<0.1%) of municipal solid waste (MSW). However, this study also evidences that food packaging accounts for 15.7% of the total MSW generated in this region. Even if this growing market sector might have a relatively low impact, households' lifestyle might affect the results. (2) In terms of consumption quantity, plastic bags are the most used packages, accounting for 35.08%; wooden chopsticks account for 32.21% and plastic boxes account for 27.43%. Among all environmental impact categories resulting from the process of production of packages, greenhouse effect is the most distinct one. Paper boxes generate the most serious environmental pollution. (3) The distribution of environmental pollution loads resulting from food delivery service packages positively correlates with the distribution of food delivery service providers in Jing-Jin-Ji. Shijiazhuang has the highest degree of pollution resulting from food delivery service packages with the interrupt value ratio of 80%, followed by Baoding City and Chengde City, which have the interrupt value ratios of 65.1% and 48.6%, respectively. Finally, as bridges between food delivery service providers and consumers, food delivery service platforms should improve their environmental protection mechanisms. Meanwhile, the government should define a standard concerning food delivery service packages to consolidate the concept of environmental protection in the society to change the ways people consume, in order to achieve a harmonious co-existence between resource utilization and environmental protection.

1. Introduction

Food delivery services, attracting many users, have become popular worldwide. In China, online food delivery platforms saw an increasing number of active users in 2017, when approximately 80% of the users ordered a delivery service at least once a week. Online-to-Offline (O2O), in a simple sense, refers to the integration of online services with offline ones, including sales, marketing, and customer relations management (data from: Chinese Local Life O2O Industrial Research Report (iResearch, 2018)). Ele.me, an online food delivery service platform, released huge amounts of data on Chinese food delivery service (~600 million users, whose

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63.3% consume more than 3 times per week, with annual transaction size close to 100 billion $).

Inevitably, controversies on the generated environmental impacts have been sparked (O'Mara, 2017). For example, considering food packaging, most food providers use durable plastic bags containing meal boxes to transport the food easily, due to the low cost of materials and functional advantages (such as thermosealability, microwavability, optical properties and unlimited sizes and shapes) over traditional materials such as glass and tinplate (Lopez-Rubio et al., 2004). Meal boxes too are usually made of disposable plastic or, alternatively, of paper. The excessive generation of waste, generated by the rise of food delivery services, is creating many concerns. Food packaging accounts for almost two-thirds of total packaging waste by volume (Hunt et al., 1990). In the case of China, a recent paper determined that, in year 2016, the waste generated by food-delivering sector reached 1.68 Mt, including 1.33 Mt of plastic waste (Jia et al., 2018). Another study detailed the approximate composition of solid waste generated by food delivery services, showing that polystyrene (PS) and polypropylene (PP) plastic containers constitute about 75% in weight of the total packaging waste (Song et al., 2018).

These numbers demonstrate that, even if a strict ban on plastic use by state council of China came into force in year 2008 to preserve resources and ease environmental pressures, the rapid evolution of the Internet and mobile networks has greatly weakened its binding effects. The reasons are manifold. With respect to food delivery services, consumers usually take the use of plastic boxes and bags for granted. Moreover, service providers, when packing food, assign top priority to safety, warm-keeping, convenience and reasonable price of their products. Thereafter, they consider both product outlook and brand promotion. Conversely, environmental protection seems to be the least priority. Moreover, it seems that the ban has no effect on the food delivery service industry, being converted, instead, into a promotion of plastics use. Besides, aluminum foil boxes, which are widely used in the aviation industry, have been suggested for use in the food delivery service industry for food sales, distribution, and pre-packaging or in households to replace plastic and paper boxes. Biomass packaging materials are also promising for a wide application in China. However, China hasn't yet implemented a special policy on food box recycling in the online food delivery service industry. Therefore, food boxes are usually treated as household waste. Thus, the entire food delivery service industry appears to underestimate the relevance of environmental protection.

Although the specific knowledge available has changed since publication of the 1st Scientific Status Summary on the relationship between packaging and municipal solid waste (MSW) (Institute of Food Technologists, 1991), this relation remains poorly understood, complicating efforts to address the environmental impacts of discarded packaging materials. In order to overcome these difficulties, many researches tried to gain a systemic view on related MSW management, e.g.: industrial plastic waste (Ayeleru et al., 2020; Gala et al., 2020), household waste (Finnveden et al., 1995; Eriksson et al., 2005; Casazza et al., 2019) developed different case studies, referred to Suzhou (Gu et al., 2014), Beijing (Qu et al., 2009), Jing-Jin-Ji (Chen et al., 2016), Huangzhou and Xiamen (Tai et al., 2011).

Packaging reduction and a shift to alternative materials and/or technologies should be especially addressed for products characterized by a high packaging relative impact. Vice versa, when packaging represents a low burden compared to other life cycle phases, the overall environmental performance will be improved with measures aimed at reducing food waste, which, in turn, could imply an affordable increase in the packaging impacts. For such a reason, a comprehensive analysis of the material from production to disposal is necessary to determine the environmental impacts of a packaging, since it incorporates a quantitative evaluation of environmental costs, considering issues such as material use, energy consumption and waste generation (Smith and White, 2000; Marsh and Bugusu, 2007).

This study aims to evaluate the impact of urban food delivery service packaging on the environment and to clarify the overall environmental burdens caused by the urban food delivery service sector in Jing-Jin-Ji region, in order to promote the reasonable utilization of resources. In particular, it intends to establish an approach for a comprehensive evaluation theory related to the impact of urban food delivery services packaging on the environment. Furthermore, it intends to obtain useful information including the distribution of environmental pollution density by processing data spatially.

Specifically, this evaluation is based on a new inventory generated by a big-data analysis of online food delivery network. This survey allowed to refine missing packaging data, improving a specific estimation method and uncertainty analysis. The Life Cycle Assessment (LCA) method is applied, together with the calculation of environmental footprint, derived from the new inventory, based on primary data. Secondary data came from the literature and Ecoinvent 3.1 database. The method proposed here is more consistent with the general attributional approach in LCA than the hitherto common practice of simply assuming a 1:1 substitution of primary material production. The sustainability goal builds on life cycle analysis to address material and energy recovery as well (McDonough and Braungart, 2002). Related results also provided some suggestion to the sustainable packaging and future consumption strategies for sustainability improvement. Finally, the obtained results can impact on a better planning and management of food delivery sector.

2. Methods

2.1. Python-based big data acquisition of urban food delivery service

The "Research Report on Chinese Third-Party Food Delivery Service Market 2017" shows that Ele.me accounts for a major share in the food delivery service market (51.5%), while Meituan Food delivery accounts for 40% of the market (Data from: BigData-Research data center). Ele.me merged with Baidu Food delivery in August 2017. Simultaneously, Ele.me formed an in-depth cooperative partnership with Alipay. The latter, then, provided an entrance icon to Ele.me on its homepage. As the only online food delivery service provider equipped with anti-crawling mechanism, Meituan Food delivery makes data captures from its web a difficult task. Thus, this study targets Ele.me. Python 3.10.0 for programming in Windows 10 (64 bit) is adopted for analyzing the collected data. The data collected from a crawling operation on Ele.me were listed in Appendix A.

2.2. Pre-treatment of urban food delivery service big data

Using a web crawling program, designed using Python, each valid food delivery service provider record was downloaded from the selected websites. Each record is composed by 22 items, including ID, name of food delivery restaurant, town/district, city, province, name, monthly sales, longitude, and latitude. This study screened and categorized the downloaded data through the steps, detailed in the following subsections.

2.2.1. Data screen

First of all, crawled data appeared to be characterized by some duplications, due to the crawling program script. Therefore, de-duplication is applied to obtain a unique id. In particular, this process includes: select "data tools" from "data" of Microsoft EXCEL and click "remove duplicates"; select "id" column and check "extend selection" to delete id duplicates for uniqueness. With such operations: 1,919 duplicate values were removed in Beijing, with 3,815 values remaining; 710 duplicate values were removed in Tianjin, with 3,400 values remaining; 983 duplicate values were removed in Hebei, with 7,803 values remaining. The resulting spreadsheet database is used for spatial analysis using geographic information system (GIS) software.

2.2.2. Data categorization based on food delivery service package types

(1) Pre-survey for food delivery service packaging and provider categorizations

As there are various types of food delivery service packages, this study pre-sets the direct link between package materials and the products carried by them. Accordingly, this study verifies whether the pre-setting is valid via a sample survey. This study targets more than 200 food delivery service providers in Ele.me within a radius of 2.5 km. Their package types and materials are analyzed, corresponding to the respective products. A field research, adopting both questionnaire and on-site visit surveys, was applied for such a purpose.

The survey result shows that packages having direct contact with food are all PP5 plastic cube or barrel boxes. Considering the crawled data and field surveys, urban food delivery service providers can be classified into the following five categories (Table 1): category A (i.e., fried or baked food providers), which use paper or plastic packages; category B (i.e., homely meal providers), which use plastic boxes or bags; category C (i.e., fruit providers), which use plastic bags only; category D (i.e., flower and green plant providers), which use packing papers only; category E (i.e., wine and other liquid providers), which use no additional packaging.

Taking advantage of the "flavors" label in Ele.me, packing categories are further categorized, based on the data collected from food delivery service providers after de-reduplication. In the screening data of Beijing region, category A mainly includes fried chicken and other meats, hamburgers, pizzas, and cakes; category B includes spicy hot pots, rice noodles, rice served with meat and vegetables on top, counter meals, Sichuan & Hunan meals, and other meals; category C includes convenience stores, large supermarkets, snacks, meats/poultries/eggs, fruits, and pharmacies; category D includes flowers and green plants; category E includes water supply stations and wine shops.

2.3. Life cycle impact assessment method

The environmental impacts evaluation is performed by means of the Life Cycle Assessment framework. LCA is a methodological framework, standardized by ISO and ILCD handbook (ISO 14040, 2006; ISO 14044, 2006; JRC, 2010), aiming at assessing the potential environmental impacts and the use of resources of the investigated products or services, throughout their entire life cycle. The results are provided as a set of environmental indicators such as climate change, stratospheric ozone depletion, depletion of resources, toxicological effects, among others (Pennington et al., 2004). This study employed the openLCA software v.1.9 (https://openlca.org) for both impacts and environmental footprint assessments, together with Ecoinvent database v.3.1 (Wernet et al., 2016). The 2016 ReCiPe Midpoint (H) v.1.1 impacts method, and a World ReCiPe (H), 2010 (year) normalization, has been used for impacts assessment (Goedkoop et al., 2009), while Ecological Footprint v.1.01 (Huijbregts et al., 2008) is used for the measurement of the amount of the Earth's regenerative capacity demanded by a given activity. The assessment was performed considering 100 tablesets as functional unit and a cradle-to-grave approach was developed, considering 100 produced, delivered and wasted tablesets.

Table 1
Packaging types and materials of urban food delivery.

Category	Packaging types	Materials
A: fried or baked food providers	Paper bags + Plastic bags + Plastic spoons and wooden chopsticks	Paper pulp + Polyethylene plastic bags
B: homely meal providers	Plastic boxes + Plastic bags + Plastic spoons and wooden chopsticks	Polypropylene plastic boxes + Polyethylene plastic bags
C: fruit providers	Plastic bags only	Polyethylene plastic bags
D: flower and green plant providers	Packing papers only	Paper pulp
E: wine and other liquid providers	No packing	None

As different dinnerware may adopt various materials, they can be summed up to calculate the representation coefficients of environmental impacts for packaging under different categories. If a food delivery service provider has a monthly sales volume of W, and each order requires a set of dinnerware, the calculation for the corresponding environmental impact assessment factor is given by the parameter in Table 2 multiplied by W/100.

For the environmental impacts of food delivery service packages under different categories, suppose the monthly sales volumes in categories A, B, C and D are WA, WM, WC, and WD. According to Table 2, categories A and D use paper boxes. Therefore, their paper box consumption quantity is WA + WD. Category B adopts plastic boxes. Categories A, B, and C use plastic bags. Thus, their plastic consumption quantity is WA + WM + WC. Categories A and B adopt spoons & chopsticks. Consequently, the consumption quantity of wooden chopsticks is WA + WM. The environmental impacts of different categories of food delivery service packages is determined accordingly.

Based on the acquired data, the tablesets were sorted according to the following categories:

A. (Fried or baked food providers): 13.5%
B. (Homely meal providers): 77.9%
C. (Fruit providers): 7.5%
D. (Flower and green plant providers): 0.8%
E. (Wine and other liquid providers): 0.2%

Delivery data, referred to 100 tablesets, were processed. A mean delivery time of 20 min was calculated, considering that only electric scooters are used for such a service. Data for electric scooters were derived from the database Ecoinvent 3.1. Considering an average speed of 40 km/h, the electric consumption is 0.03 kWh/km (1.2 kWh/40 km*h^{-1}). Thus, 20 min per delivery at 40 km/h corresponds to 13.3 km per delivery, with an electric consumption of 0.4 kWh per delivery. Then, for the 100 tablesets considered, the total electricity used by the scooter is 40 kWh, and the total distance covered is 1333. 3 km.

Data related to the waste generated by 100 tablesets, was accounted starting from the composition of each kind of tableset, as well as the assortment of the 100 tablesets. This corresponds to 0.29 kg of waste paperboard, 0.46 kg of waste chopsticks and 1.78 kg of waste mixed plastic. The disposal, considering the common waste treatment processes in the country and the treatments delivered in the database, has been modeled as incineration of paperboard and chopsticks and landfilling of plastics. A sensitivity analysis taking into account waste materials recovery and recycle

Table 2
The representation coefficients of environmental impacts for packages under different categories (per 100 sets of tableware).

	A PP box + PL bag + wooden chopstick	B PP box + PE bag + wooden chopstick	C PL bag	D Wooden box
Tableware weight (kg)	3.2	2.6	0.7	2
Energy consumption (MJ)	158.367	211.587	41.507	104.42
Material consumption (kg)	5.345	3.105	0.703	3.68

processes has been performed. It considered the recycle of plastic and paper into new plastic and paperboard and the anaerobic digestion of waste wood from chopsticks to produce biogas.

2.4. Spatial analysis

Kernel density analysis, also known as kernel density estimation, is a non-parametric way to estimate the probability density function of a random variable widely used for hotspots analysis and detection (e.g.: Schnabel and Tietje, 2003; Chu et al., 2012). It is a fundamental data smoothing approach, where inferences about the population are made based on a finite data sample. If no prior density hypothesis exists, a high-quality probability density can be achieved with a proper width. This method considers the location of the specific factor point as the center, distributing the properties of this point to the designated range of threshold (a circle with h as the radius). The density reaches its maximum at the center, attenuates with distance, and decreases to 0 at the threshold (Zhang et al., 2013). Kernel density analysis effectively illustrates the relative spatial concentration of data from food delivery service providers.

The unevenly distributed data of food delivery service providers are discrete, but the data take an unapparent spatial feature. This study applied the Spatial Analyst available ArcGIS software. Data were classified to display a discrete point interpolated density map. Through directional distribution method, the Standard Deviational Ellipse (SDE) of food delivery service providers is shaped. The output factors include CenterX, CenterY, XStdDist, YStdDist, and Rotation, indicating the coordinates of the mean center, the lengths of the long and short axes and the included angle shaped between the long axis and due north direction, respectively. The long axis reflects the direction of higher dispersion degree, and the short axis represents the direction of higher aggregation. With the positioning of food delivery service providers and the analysis of environmental pollution loads, the features of the positioning trend of food delivery service providers and expansion direction of environmental pollution load can be determined.

3. Results

3.1. Correlation analysis of food delivery service packages in the Jing-Jin-Ji region

3.1.1. Quantitative analysis of food delivery service providers

As a category focusing on fried meats and cakes, category A adopts, as packages, "paper boxes + chopsticks + plastic bags", accounting for 13% of the food delivery service providers in Beijing, 11% in Tianjin, and 13% in Heibei. Category B i.e., homely dishes, uses the packages "plastic boxes + chopsticks + plastic bags", accounting for 61%, 63%, and 72%, respectively, of the food delivery service providers in Beijing, Tianjin, and Heibei. Both categories A and B are dining service providers. Thus, they serve as the main force in the food delivery service market and also the major contributors to environmental impacts.

Category C includes supermarkets, fruit shops, and pharmacies. They use plastic bags, accounting for 14%, 18%, and 11% of the food delivery service providers in Beijing, Tianjin, and Heibei. Category D only includes flower and green plant providers, accounting for 11% of the food delivery service providers in Beijing, 7% in Tianjin, and 4% in Hebei.

In 2017, CBN data, in cooperation with Ele.me, released "Perspectives on 2016 Online Food Delivery Service Big Data" (onlne: cbndata.com/report/91?isReading = report&page=1), arguing that, besides providing dining service, online food delivery service has been expanding to various aspects of life to fully satisfy the instant demands of consumers. Fruits, flowers, and green plants have also been listed in food delivery services. Compared with Tianjin and Hebei, Beijing has a larger number of flower and green plant providers—i.e., non-dining food delivery service providers prioritize first-tier cities (Beijing, for example). Subsequently, they extend their businesses to second- and third-tier cities. In this study, non-dining food delivery service providers – i.e.: fruit shops – only adopt plastic bags for packaging.

Category E in this study mainly refers to water supply stations and wine shops, accounting for 1% of the food delivery service providers in both Beijing and Tianjin, and close to 0 in Heibei. As food delivery service providers of category E only account for a very small proportion with unclear package types, the environmental impact of this category is neglected in calculations. Moreover, category E includes a small number of fresh food shops. Hence, this study also omits the requirements of special packages in cold-chain logistics and cold storage.

3.1.2. Analysis of food delivery service package waste quantity

According to "dinnerware weight" data, the ratio of urban food delivery service package waste to total urban household waste can be computed. Thus, whether urban food delivery service package waste exert a relatively large impact on environment can be judged. Considering Beijing as an example, household waste weights in Beijing and its districts can be calculated from Beijing Statistical Year Book 2017[1], which is jointly compiled by Beijing Municipal Bureau of Statistics in Beijing.

Household waste refer to kitchen waste, plastic waste, paper waste, metal waste, glass waste, etc. (Marsh and Bugusu, 2007). Food delivery service packaging discussed in this study include paper boxes, plastic boxes, plastic bags, and wooden chopsticks. It is considered that the first two types of packages are plastic waste and the latter two are paper waste. To ensure that the calculation results are comparable, the known household waste structure is clarified (Table 3), so that the weights of plastic waste and paper waste can be obtained.

This study crawled and analyzed delivery data from Ele.me only, which accounts for a major share (52%) in the food delivery service market. If a proportional waste production with respect to the market share is hypothesized as a first approximation, with respect to the total food delivery packaging waste, the relative weight, Q, of Ele.me food delivery service packaging waste can be calculated using $Q_{total} = Q_{ele.me} \times 100/52$. Tables 3 and 4 summarize the details about food packaging sets, as combination of different

[1] online: tjj.beijing.gov.cn/nj/qxnj/2017/zk/indexch.htm.

Table 3
Basic data, differentiated on the basis of food packaging sets, in the Jing-Jin-Ji region (year 2017).

	A Fried or baked food providers			B Homely meal providers			C Fruit providers			D Flower and green plant providers			E Wine and other liquid providers			Sum
	Beijing	Tianjin	Hebei	Beijing	Tianjin	Hebei	Beijing	Tianjin	Hebei	Beijing	Tianjin	Hebei	Beijing	Tianjin	Hebei	
Number of stores	489	376	996	2310	2162	5641	554	603	853	413	235	287	47	24	26	*15,017*
Monthly sales	121,738	60,982	106,153	698,105	321,419	646,239	72,957	42,325	44,927	12,849	3,144	2177	4,416	596	309	*2,138,336*
Total weight (kg/a)	3.90×10^3	1.95×10^3	3.40×10^3	1.82×10^4	8.36×10^3	1.68×10^4	5.11×10^2	2.96×10^2	314.49	2.57×10^2	62.88	43.54	–	–	–	5.41×10^4
Total energy consumption (MJ/a)	1.93×10^5	9.66×10^4	1.68×10^5	1.48×10^6	6.80×10^5	1.37×10^6	3.03×10^4	1.76×10^4	1.86×10^4	1.34×10^4	3.28×10^3	2.27×10^3	–	–	–	4.07×10^6
Total material consumption (kg)	1.42×10^4	7.12×10^3	1.24×10^4	6.58×10^4	3.03×10^4	6.10×10^4	5.13×10^2	2.98×10^2	3.16×10^2	4.73×10^2	115.7	80.11	–	–	–	1.93×10^5

food packaging materials, and food packaging materials for the Jing-Jin-Ji region in year 2017.

The data available in the Beijing Statistical Year Book 2017 suggest that the annual household waste in Beijing, Tianjin and Hebei reached, respectively, 8.712 million ton/year, 2.533 million ton/year and 7.092 million ton/year. Paper and plastic waste accounted for 18.18% and 10.35% of the total household waste, respectively.

As indicated by Table 5, considering the annual food delivery service packaging waste quantities of Beijing, Tianjin and Hebei, the ratio of food delivery service packaging to total plastic and paper weight within the household waste of the Jing-Jin-Ji region can be computed. In particular, Beijing food delivery service packaging waste accounted for 0.021% of the total (plastic and paper) household waste in the city. Moreover, paper and plastic waste accounted for 0.010% and 0.041%. Tianjin food delivery service packaging waste accounted for 0.034% of the total (plastic and paper) household waste in the city, in which paper and plastic waste accounted for 0.016% and 0.066%. Hebei food delivery service packaging waste accounted for 0.023% of the total (plastic and paper) household waste in the province, in which paper and plastic waste accounted for 0.046% and 0.011%.

It is relevant to consider that kitchen waste accounted for the largest share of household waste, reaching 36%. Presently, during the treatment of food delivery service packaging waste, the dining boxes may become smudged with food residues, which are not easy to remove. Thus, such boxes are classified into the "kitchen waste" category without being differentiated. Urban household waste can be treated through land-filling, incineration, and biological treatment (Jiang et al., 2006). Kitchen waste is usually disposed through biological treatment, whereas plastic and paper waste are landfilled (Jiang et al., 2006). Accordingly, environment-friendly materials should be adopted for food delivery service packages. Starch-fiber sheets, for example, can be applied in degradable packaging.

In this study, it is hypothesized that each order is served with a set of dinnerware by default, in order to define a preliminary hypothesis for building a coherent inventory. However, calculated results might exceed from real ones. This choice is made with a cautionary approach, considering the worst possible scenario. To obtain values closer to actual ones, a field survey with a larger scope and more samples would be required, so that the statistical probability of an order with two or more sets of dinnerware is obtained, which is not explored in this study.

3.2. Life cycle impact assessment of food packaging in China

Table 6 reports the midpoint impacts with the related unit for all 2016 ReCiPe Midpoint (H) impact categories of the production, delivery and disposal of 100 tablesets. Fig. 1 shows the World ReCiPe H 2010 (year) normalized results. It is clear that the most impacted categories are METP, FETP, HCTP, HNCTP and TETP.

Considering the normalized values, being represented by the histogram in Fig. 1, major contributions are associated to Marine ecotoxicity potential (METP) and to Freshwater ecotoxicity potential (FETP). In particular, the highest contributions to METP derived from the electric scooter (55.47%), its battery (33.59%) and from the used electricity (7.77%). A very similar situation results for FETP. In particular, the electric scooter contributed for 57.43%, the battery contributed for 31.23% and the electricity contributed for 8.19%. The electric scooter was the major contributor (56.81%) to HCTP, followed by the battery (29.51%) and the electricity (10.24%). Within HNCTP the major contribution is from the Li-ion battery (53.71%), followed by the scooter (38.94%), while the electricity used contributes for the 4.05%.

Table 7 details the ecological footprint for 100 Tablesets. The major footprint was generated by carbon dioxide, with contribu-

Table 4
Main details about different food packaging types in Jing-Jin-Ji region (year 2017).

Packaging types	Woolen boxes			Polypropylene plastics boxes			Polyvinyl plastics bags			Wooden chopsticks		
	Beijing	*Tianjin*	*Hebei*	*Beijing*	*Tianjin*	*Hebei*	*Beijing*	*Tianjin*	*Hebei*	*Beijing*	*Tianjin*	*Hebei*
Total usage quantity	134,587	64,126	108,330	698,105	321,419	646,239	892,800	424,726	797,319	819,843	382,401	752,392
Total weight (kg/a)	2.69E+03	1.28E+03	2.17E+03	9.77E+03	4.50E+03	9.05E+03	6.25E+03	2.97E+03	5.58E+03	4.10E+03	1.91E+03	3.76E+03
Total energy consumption (MJ/a)	1.41E+05	6.70E+04	1.13E+05	1.10E+06	5.07E+05	1.02E+06	3.71E+05	1.76E+05	3.31E+05	1.02E+05	4.76E+04	9.36E+04
Total material consumption (kg)	4.95E+03	2.36E+03	3.99E+03	1.01E+04	4.63E+03	9.31E+03	6.28E+03	2.99E+03	5.61E+03	7.89E+03	3.68E+03	7.24E+03

Table 5
Food delivery service package waste quantity in Jing-Jin-Ji (2017).

	Paper						Plastic					
	Paper box	*Wooden chopsticks*	*Paper box*	*Wooden chopsticks*	*Paper box*	*Wooden chopsticks*	*PP box*	*PE bag*	*PP box*	*PE bag*	*PP box*	*PE bag*
	Beijing		*Tianjin*		*Hebei*		*Beijing*		*Tianjin*		*Hebei*	
Number (10^4)	310	1892	148	882	250	1736	1611	2060	742	980	1491	1840
Weight (t/a)	62.12	94.6	29.6	44.12	50	86.81	225.54	144.22	103.84	68.61	208.78	128.8
Delivery service package waste quantity (t/a)	156.71		73.72		136.81		369.76		172.45		337.58	
Urban domestic garbage (10^4 t/a)	158.4		46.05		128.93		90.12		26.22		73.4	
Proportion (%)	0.01%		0.02%		0.01%		0.04%		0.07%		0.05%	

Table 6
Recipe Midpoint (H) characterized results for 100 tablesets.

Impact Category		Result	Unit
FPMFP	Fine particulate matter formation potential	0.24	kg $PM_{2.5}$ eq
FRSP	Fossil resource scarcity potential	22.58	kg oil eq
FETP	Freshwater ecotoxicity potential	15.23	kg 1,4-DCB
FEP	Freshwater eutrophication potential	0.05	kg P eq
GWP	Global warming potential	93.82	kg CO_2 eq
HCTP	Human carcinogenic toxicity potential	6.14	kg 1,4-DCB
HNCTP	Human non-carcinogenic toxicity potential	301.82	kg 1,4-DCB
IRP	Ionizing radiation potential	5.12	kBq Co-60 eq
LUP	Land use potential	1.23	m^2a crop eq
METP	Marine ecotoxicity potential	20.21	kg 1,4-DCB
MEP	Marine eutrophication potential	0.02	kg N eq
MRSP	Mineral resource scarcity potential	1.36	kg Cu eq
HOFP	Ozone formation, Human health potential	0.26	kg NOx eq
TOFP	Ozone formation, Terrestrial ecosystems potential	0.27	kg NOx eq
SODP	Stratospheric ozone depletion potential	0.00	kg CFC11 eq
TAP	Terrestrial acidification potential	0.65	kg SO_2 eq
TETP	Terrestrial ecotoxicity potential	768.44	kg 1,4-DCB
WCP	Water consumption potential	0.90	m^3

Table 7
Ecological footprint for 100 tablesets.

Name	Impact result	Unit
Carbon dioxide	206.28102	m^2 a
Nuclear	14.71378	m^2 a
Land occupation	15.96151	m^2 a

tions from the electricity (50.07%), the electric scooter (production + maintenance) (30.98%) and from the battery production (11.44%). The land occupation footprint value mainly depended on the transportation process (52.63%), on the production of Tableset B (25.18%) and on the production of Tableset A (20.98%). The nuclear footprint depended on the transportation process (84.20%), on the production of Tableset B (13.22%) and on the production of Tableset A (1.85%).

3.2.1. Waste recycling scenario

An additional LCA has been performed to explore the effect of recycling of generated waste instead of the disposal methods taken

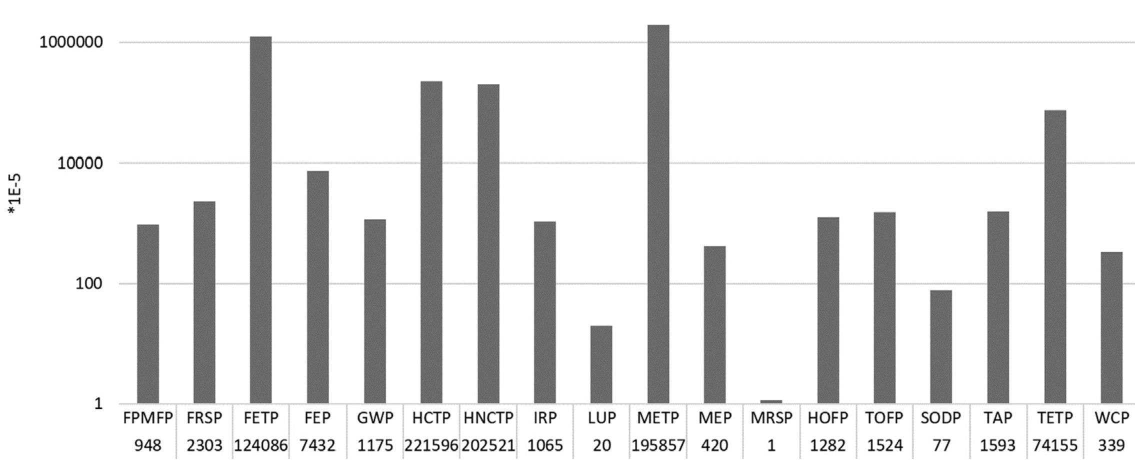


Fig. 1. ReCiPe (H) World 2010 normalized midpoint impacts, in logarithmic scale, for 100 tablesets.

Table 8
Recipe Midpoint (H) characterized results comparison of the disposal and recycling of the waste generated by the 100 tablesets.

Impact Category	Unit	Disposal	Recycle	Δ
FPMFP	kg $PM_{2.5}$ eq	2.42E-01	2.42E-01	−0.04%
FRSP	kg oil eq	2.26E+01	1.99E+01	−12.05%
FETP	kg 1,4-DCB	1.52E+01	1.50E+01	−1.52%
FEP	kg P eq	4.83E-02	4.83E-02	0.12%
GWP	kg CO_2 eq	9.38E+01	9.10E+01	−2.98%
HCTP	kg 1,4-DCB	6.14E+00	6.10E+00	−0.70%
HNCTP	kg 1,4-DCB	3.02E+02	2.95E+02	−2.13%
IRP	kBq Co-60 eq	5.12E+00	5.14E+00	0.37%
LUP	m^2a crop eq	1.23E+00	1.22E+00	−0.09%
METP	kg 1,4-DCB	2.02E+01	1.99E+01	−1.56%
MEP	kg N eq	1.94E-02	1.82E-02	−5.89%
MRSP	kg Cu eq	1.36E+00	1.37E+00	0.08%
HOFP	kg NOx eq	2.64E-01	2.59E-01	−1.88%
TOFP	kg NOx eq	2.71E-01	2.65E-01	−2.12%
SODP	kg CFC11 eq	4.61E-05	4.72E-05	2.41%
TAP	kg SO_2 eq	6.53E-01	6.52E-01	−0.13%
TETP	kg 1,4-DCB	7.68E+02	7.67E+02	−0.16%
WCP	m^3	9.04E-01	8.80E-01	−2.61%

into account in Table 6. The explored sensitivity analysis has been built based on the recovery of waste paper into paperboard and recovery and recycling of waste plastic, and the anaerobic digestion of the waste wooden chopsticks. The results are presented in Table 8. The Recycle scenario show a diminution of the generated burdens from a minimum of 0.04% within FPMFP to a significant diminution within FRSP of about 12%, mainly due to the plastic recycling operation. Table 8 also highlights slightly larger impacts within FEP (0.12%), IRP (0.37%), MRSP (0.08%) and SODP (2.41%). The average diminution of impacts throughout all investigated categories is equal to about 1.7%.

3.3. Pollution pattern analysis–Kernel density map

3.3.1. Distribution of food delivery services stores in Jing-Jin-Ji

The distribution of food delivery service providers in Beijing, Tianjin and Hebei is represented in Fig. 2.

In the case of Beijing (Fig. 2(a)), food delivery service providers for Ele.me are mainly located in downtown Beijing, Dongcheng District, Xicheng District, and Chaoyang District, being equally spread among these areas. In parallel, food providers are located in certain areas of Haidian District, Changping District and Fengtai District. These areas are also clustered with schools and office buildings. Conversely, Tongzhou District, Fangshan District and Mentougou District have relatively fewer food delivery service providers.

In the case of Tianjin and Hebei (Fig. 2(b) and (c)), similarly to Beijing, food delivery service providers are clustered in the downtown areas. In the case of Tianjin, specifically, Dongli District, Xiqing District, Beichen District and Jinnan District. In Hebei, food delivery service providers are mainly located in Shijiazhuang City and in the boundary area between Langfang and Beijing.

Adopting the Spatial Analyst–Density Analysis–Kernel Density Tool in ArcGis, a spatial distribution map of the environmental impact load for food delivery service packaging in the Jing-Jin-Ji region were obtained. Spatially, the environmental impact loads, caused by food delivery service packaging in the Jing-Jin-Ji region, were especially concentrated within Dongcheng District, Xicheng District, Haidian District, Chaoyang District, Changping District and Fengtai District in Beijing.

3.3.2. Spatial analysis of environmental impact load of food delivery service packages in the Jing-Jin-Ji region

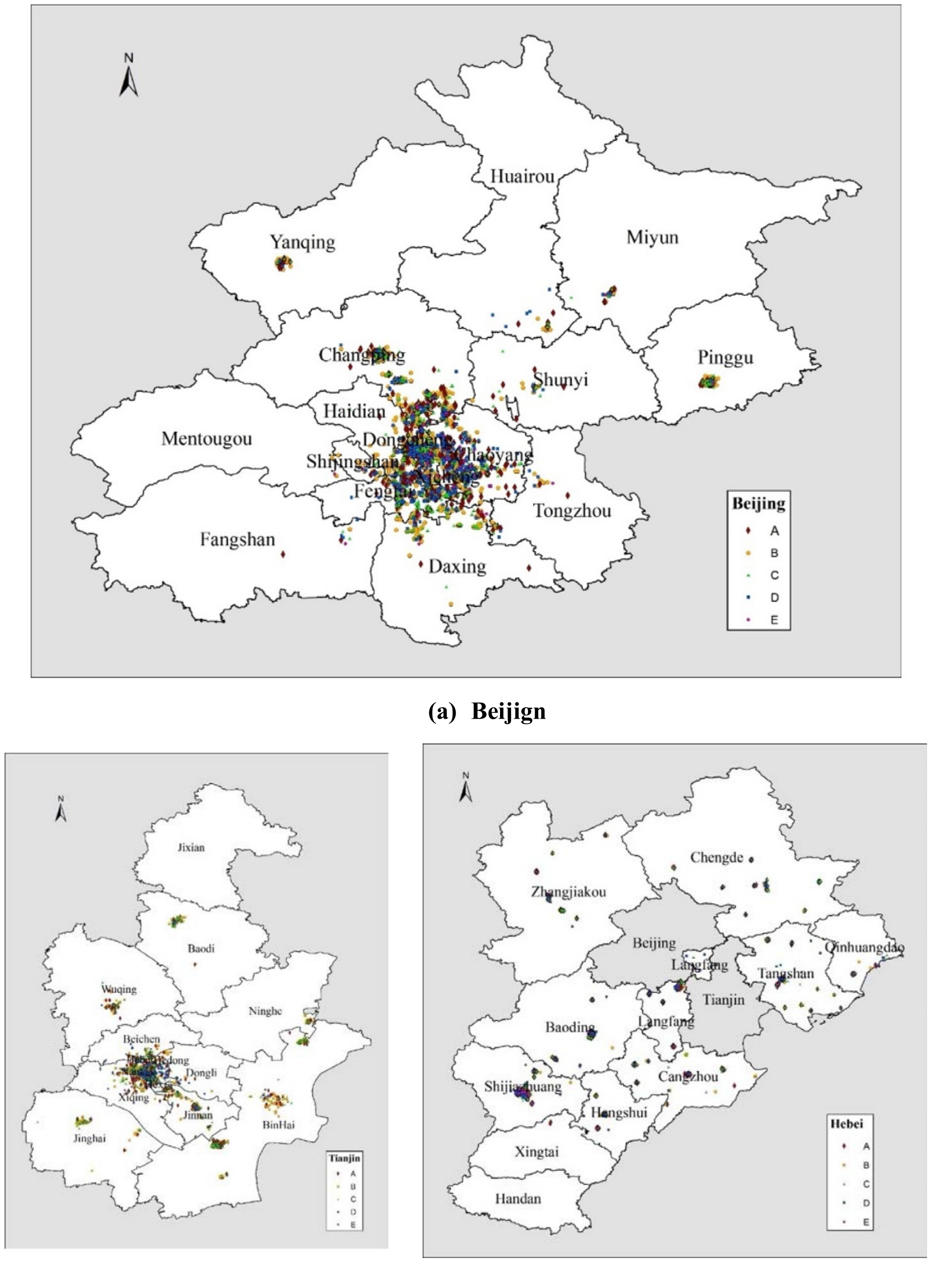
Fig. 3 shows the kernel density map of the environmental impact. The long axis reflects the direction of higher dispersion degree, and the short axis represents the direction of higher aggregation. With the positioning of food delivery service providers and the analysis of environmental pollution loads, the features of the location trend of food delivery service providers and expansion direction of environmental pollution load can be determined. Food delivery service providers are highly aggregated in downtown areas but are spread sparsely outside the central urban areas in the Jing-Jin-Ji region. The distribution of environmental pollution loads resulting from food delivery service packages positively correlates with the distribution of food delivery service providers in Beijing.

From Google Earth (GE), the spatial center of environmental pollution loads, resulting from food delivery service packages in Beijing, is located in Xicheng District (116.37, 39.98), creating an east–west distribution layout. In the kernel density map, each kernel corresponds to a relatively concentrated place of food delivery service providers. Besides the downtown area, another distinct kernel is located at Changping District, marked as dark red in the map. Yanqing District and Pinggu District are marked as light sapphire, whereas Huairou District is marked with yellow color in the map.

From GE, the spatial center of environmental pollution loads resulting from food delivery service packages in Tianjin is located in Hedong District (117.29, 39.09), creating an east–west distribution layout. The food delivery service providers are densely located in downtown areas, Dongli District, Xiqing District, Beicheng District and Jinnan District (the latter has the highest density). In the kernel density map, each kernel corresponds to a relatively concentrated place of food delivery service providers. The concentration degree of pollution resulting from food delivery service packages is higher in Tianjin than in Beijing. Besides the downtown area, another distinct kernel is located at Binhai New Area, marked as orange in the map.

Finally, the spatial center of environmental pollution loads resulting from food delivery service packages in Hebei is located in Langfang City (116.23, 39.27), creating a northeast–southwest distribution layout. In the kernel density map, each kernel corresponds to a relatively concentrated place of food delivery service provider. Different food delivery service providers (categories A–D) have similar spatial distributions of package pollution loads. Shijiazhuang has the highest degree of pollution resulting from food delivery service packages, marked as blue in the map with the interrupt value ratio of 80%, followed by Baoding City and Chengde City, which have the interrupt value ratios of 65.1% and 48.6%, respectively.

Considering the distributions of garbage harmless treatment plants and household waste compacting & transferring stations,



(a) Beijign

(b) Tianjin **(c) Hebei**

Fig. 2. Distribution of food delivery services stores in (a) Beijing (b) Tianjin and (c) Hebei in year 2017.

this study suggests that future studies may explore whether environmental pollution can be reduced by setting up food delivery service distribution or package recycling stations at places where food delivery service providers are densely located.

3.4. Spatial benefit and correlation analysis of environmental impact of food delivery service packaging during production

3.4.1. Comparative analysis of environmental impacts of different packaging categories in Beijing

For food delivery service data of Beijing, Table 9 summarizes the calculation results of monthly environmental impacts (energy flow, material flow, and environmental load) from various packaging categories.

From Table 9, the following assessments are made regarding the environmental pollution caused by food delivery service packages per month:

(1) In terms of consumption quantity, plastic bags are the most used packages, accounting for 35.08%; wooden chopsticks account for 32.21% and plastic boxes account for 27.43%. The weights of plastic bags and wooden chopsticks only account for 27.39% and 17.97% of the food delivery service products, respectively. Plastic boxes have the largest weight ratio, reaching 42.84%.

(2) Among all environmental impact categories resulting from the process of production of packages such as paper boxes, plastic boxes, plastic bags, and wooden chopsticks, greenhouse effect is the most distinct one.

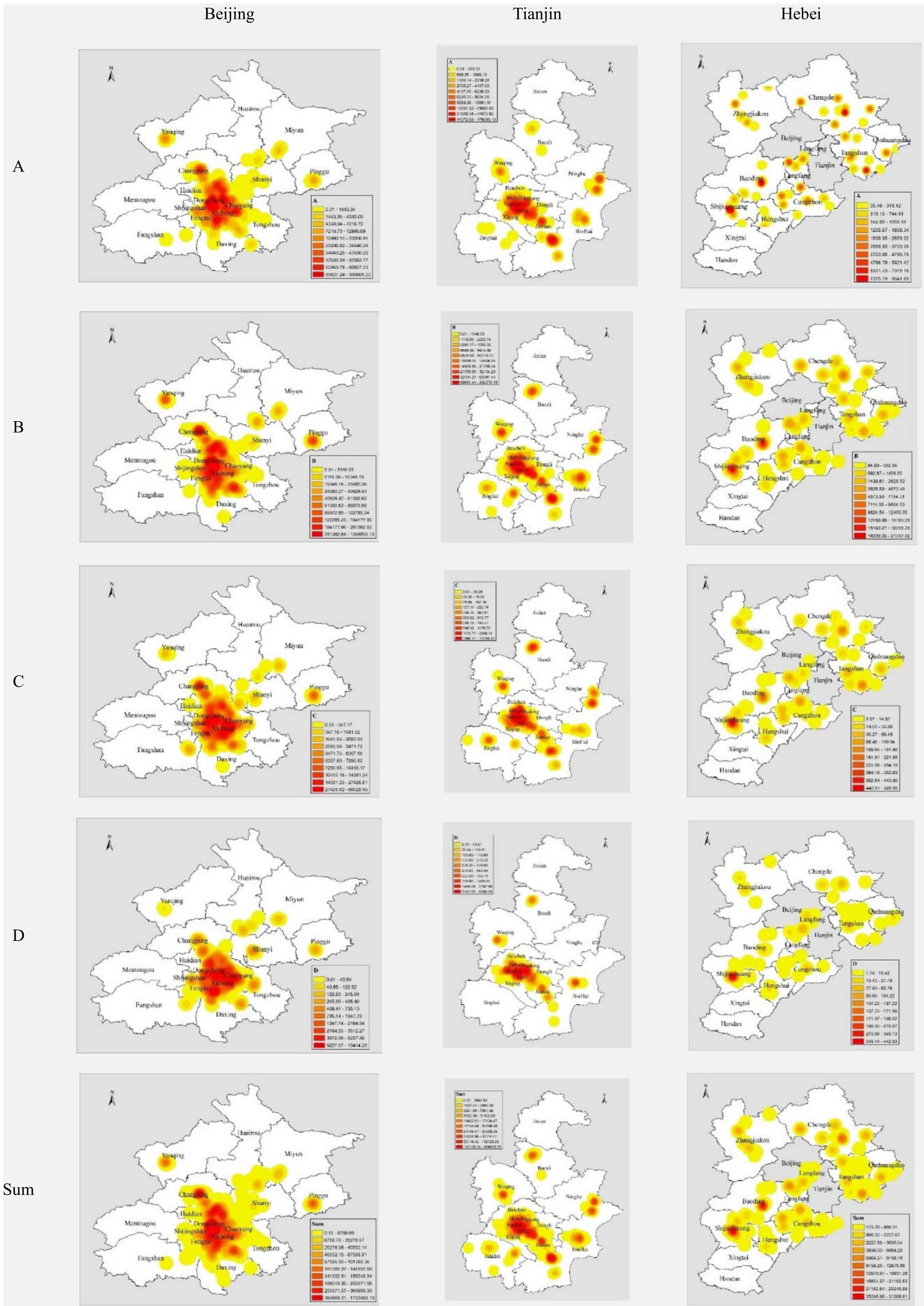


Fig. 3. Kernel density map of the environmental impact in Jing-Jin-Ji.

(3) Paper boxes generate the most serious environmental pollution. It can be observed from Table 9 that NO_X generated from the production of paper boxes has the largest environmental impact potential, exceeding that of CO_2. The results obtained from the quantitative analysis of paper and plastic boxes were unexpected. As major environmental impact occurs in material collection and processing, and the air pollutants produced will cause greenhouse effect, acidification, and eutrophication, PP boxes are more environment-friendly than paper boxes.

Generally, people criticize environmental pollution caused by urban food delivery service packages such as "plastic waste" or "white pollution," targeting plastic bags and boxes as culprits. This study, however, finds that more attention should be paid to paper boxes. As stated in 3.2.1, the gradual development of non-dining food delivery services may enable people to ask for better packages and to accept higher delivery charges (*Food delivery Service Big Data 2017*). In this situation, paper boxes, which are easier for color printing and are better-looking with customized logos, have better market

Table 9
Monthly environmental impact percentage of different packaging types in Beijing (2017).

Packaging types	Paper boxes	Polypropylene plastics boxes	Polyvinyl plastics bags	Wooden chopsticks
Usage quantity	5.29%	27.43%	35.08%	32.21%
Weight	11.80%	42.84%	27.39%	17.97%
Energy consumption	8.20%	64.22%	21.63%	5.95%
Material consumption	16.98%	34.46%	21.52%	27.04%
Environmental Impact Load	30.04%	34.48%	21.56%	13.92%
Greenhouse effect	25.14%	38.43%	24.05%	12.38%
Acidification	34.87%	28.04%	17.60%	19.49%
Eutrophication	65.49%	15.09%	9.65%	9.78%

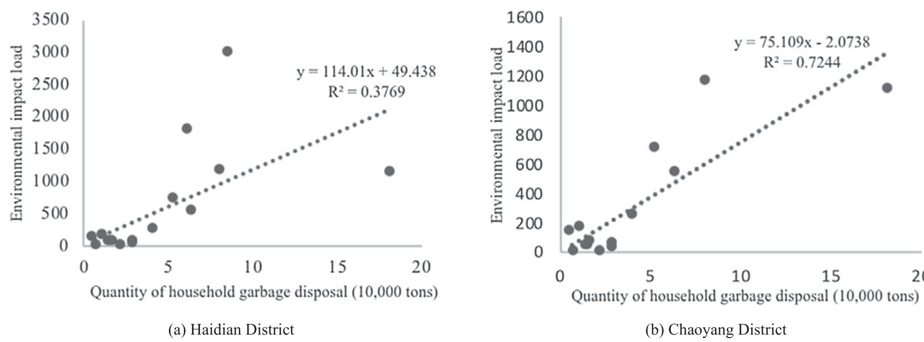


Fig. 4. The relationship between the environmental impact load and the amount of municipal solid waste.

potential; thus, paper packages may become a larger polluting source.

3.4.2. Correlation analysis

With "sum if" and "count if" in EXCEL, the environmental impact loads and numbers of food delivery service provider in the counties/districts of Beijing are calculated. When exploring the relevance between environmental impact load and household waste treatment quantity, as indicated in Fig. 4, Haidian District and Changping District have evident deviations. Excluding them, the study finds that, the environmental impact load of food delivery service packages has a certain degree of linear correlation with household waste treatment quantity (R^2 = 0.7244).

From Fig. 4 and *Beijing Statistical Year Book 2017*, this study performs a comparative analysis of Haidian District and Chaoyang District:

(1) Haidian District is located above the trend line, with a large proportion of food delivery service providers. Chaoyang District is located below the trend line with a small proportion of food delivery service providers.
(2) Haidian District treats 86,100 tons of household waste yearly, which is lower than that of Chaoyang District, the largest household waste handler with the annual waste treatment quantity of 182,100 tons.
(3) Chaoyang District has the largest permanent population in Beijing (3.856 million), followed by Haidian District, with 3.593 million. Haidian District has the largest household registered population in Beijing with 2.402 million, followed by Chaoyang District with 2.109 million. However, Chaoyang District has the largest number of registered households in Beijing with 828,000, followed by Haidian District with 733,000. Haidian District has an apparent population mechanical dynamics (incoming 76,497 and outgoing 65,984), followed by Chaoyang District (incoming 24,967 and outgoing 15,546).

In conclusion, Chaoyang District is a residential area with low job-housing ratio. There, more people end to cook for themselves, generating a low operativity of food delivery services. Haidian District, however, has a higher job–housing ratio, with a higher level of food delivery services too. Many students and young people work there for limited periods, contributing to a higher population dynamics in Haidian District.

4. Discussion

4.1. Enterprise environmental protection countermeasures

Major food delivery service platforms are now implementing countermeasures in order to respond to various criticisms related to food delivery service packaging impacts. Meituan Food delivery initiated Green Mountain Program, setting up the Green Mountain Fund and nominating a Chief Environmental Officer. This program encourages food delivery service users to prepare dinnerware themselves and assigning environmental protection labels to food delivery service providers, which promise to adopt "environment-friendly" packages. Furthermore, this platform added a "screen" menu in its app to facilitate users in selecting these providers. Ele.me launched the Blue Planet Program. It added a "need no dinnerware" menu in its app to encourage users to reduce the use of disposable dinnerware. Users, who follow the guide, are rewarded with scores as incentives. These scores, in turn, can be used to buy environment-friendly bags or claim public welfare forests. Moreover, Ele.me, using big data, upgraded plans for food delivery service providers, which consume dinnerware massively. In the long run, the cost of environment-friendly dinnerware should be reduced through these approaches. Baidu Food delivery generated the EP Movement. As a major food delivery service platform, it actively fills the regulation blanks in the environmental protection measures of the food delivery service industry by granting key supports to food delivery service providers adopting environment-friendly dinnerware and to suppliers providing environment-friendly dinnerware. The reduction of the use of "disposable dinnerware" is the first step for the food delivery service industry on the road to "green development", which is also a reason for the adoption of the choice of "need no dinnerware" by the above three major food delivery service platforms. Although contracting out local solid waste management service is assumed to deliver cost savings without sacrificing the service quality, privatization makes the municipal solid waste management system less reliable on investment for a long-time planned horizon (Zhu and Huang, 2017). To ensure cost savings while not degrading the service quality, attention needs to be given to the contract establishment between the government and the Food delivery enterprises.

This exploration, however, does not fully meet expectations. On the one hand, most consumers pay no attention to environmental protection while ordering food delivery service. On the other hand, food delivery service providers may neglect special requirements from consumers, when handling many orders simultaneously. This issue must be solved by further improving the "no dinnerware" food supply chain. Ele.me is already attempting to deepen the advantages of reform supply chain to force the upstream industries to reform. If the purpose can be fulfilled, the environmental protection mechanism of Ele.me will generate significant value.

4.2. Efforts from food delivery service stakeholders

The elimination of food delivery service packaging waste requires the joint efforts of food delivery service providers, consumers, package manufacturers, food delivery service platforms and the government.

Food delivery service providers should enhance awareness of environmental protection. While promoting their brands with customized product packages, they should attempt to produce packages for environmental protection rather than only focus on package outlook.

Consumers should emphasize environmental protection and cooperate with government or food delivery service platforms in adopting related strategies. Furthermore, they should actively take measures for environmental protection in a small scale; for example, they can reuse the food delivery service packages.

Package manufacturers should develop environment-friendly dinnerware with lower costs.

Food delivery service platforms, which bridge food delivery service providers, consumers, and manufacturers, should encourage consumers to make environment-friendly choices, guide food delivery service providers to use environment-friendly dinnerware, and promote the communication between package manufacturers and food delivery service providers, ensuring reasonable configuration of resources.

The government should define a standard concerning food delivery service packages, which is crucial at present. The ultimate goal of the government is to consolidate the concept of environmental protection in the society to change the ways people consume, in order to achieve a harmonious co-existence between resource utilization and environmental protection.

The fast-developing food delivery service industry is a new phenomenon in China and in the world. As it may pose environmental threats, the entire society, guided by the government, should make joint efforts to tackle problems that may occur.

4.3. Prospects of feasible measures

The term "green package" refers to proper packing, whose waste can be recycled, reused or degraded. Aluminum foil dish boxes and packages made from starch-fiber sheets, for example, have attracted attention in the market. Future follow-up studies may focus on the concept and connotation of green packing. With systematic analysis, that covers raw materials, recycling system, manufacturing techniques, processing technologies and legislations, studies could be conducted on proper packages, that best suit the food delivery service industry. Furthermore, related advice on policies can be proposed.

The approach of this study, with Python-based big-data, could be replicated to recognize the locations of food delivery service providers. Food delivery service platforms or the government can also conduct a thorough survey of all food delivery service platforms with big data. Thus, prominent food delivery service providers with high monthly sales volumes can be identified and advised to adopt environment-friendly packages, as food delivery service providers of high sales volumes use more packages and have heavier environmental impacts and larger social responsibility. These food delivery service providers should adopt at least one set of recyclable dinnerware in every 10 orders. In other words, the promotion and popularization of environment-friendly food delivery service packages must be initiated through consumption.

5. Conclusions

This study aims to evaluate the impact of urban food delivery service packaging on the environment and to clarify the overall environmental burdens caused by the urban food delivery service sector in Jing-Jin-Ji region, in order to promote the reasonable utilization of resources. This evaluation is based on a new inventory generated by a big-data analysis of online food delivery network. This survey allowed to refine missing packaging data, improving a specific estimation method and uncertainty analysis. Results indicated that, in the study area, food delivery service packages presently account for a very small proportion of household waste, smaller than 0.1%. However, this study also evidenced that food packaging account for 15.7% of the total urban waste generated in this region. Even if the growing market sector of food delivery services doesn't seem to generate new environmental concerns, households' habits dynamics should be deeper investigated. With this respect, it must be considered that China's average plastic recycling rate is 3%.

Adhering to the philosophy of "do not commit an evil act just because it is small in scale", food delivery service providers, which "pack a product with five or six boxes", should improve their way of packaging in order to limit their environmental impacts, as well as to avoid a further growth of households' urban waste. Moreover, food delivery service providers should assume responsibilities to reduce the consumption of plastic packages to a minimum for environmental protection. As bridges between food delivery service providers and consumers, food delivery service platforms should improve their environmental protection mechanisms.

Developing the advantages of big data mining, as shown in this work, and estimating the environmental impact of the whole industrial chain, further scientific solutions should be implemented.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

The data collected from a crawling operation on Ele.me were used in this study. The following are the specific steps followed in the crawling operation:

(1) Open Ele.me homepage in a PC, analyze it, and observe the hyperlink invocated from pull-to-refresh action. The website loads data dynamically when the mouse is slid. The URL of this web page serves as the main target for the crawling operation.

(2) A hyperlink is selected from Ele.me web to test data availability. This study considers h5.ele.me/restapi/shopping/v3/restaurants?latitude=31.23037&longitude=121.473701&offset=8&limit=8&extras[]=activities&extras[]=tags&extra_filters=home&rank_id=aa3f59810a6c4c9cab49b0865eeca487&terminal=h5 as the target. The following data are relevant: geographical frame of reference (latitude = 31.23037; longitude = 121.473701); paging parameter (offset = 8&limit = 8), in which "limit" refers to the number of records acquired and "offset" denotes the deviation value of the record (we set "limit" to 20 and "offset" to 0 (offset = 0&limit = 20), 20 (offset = 20&limit = 20), 40 (offset = 40&limit = 20), and so forth). The data returned from the corresponding links are in the required JSON format. The above analysis and operations lead to the conclusion that nearby restaurants can be searched by the geographical frame of reference. In detail, the current geographical location can be moved within an area to search for nearby restaurants. Then, all the information about restaurant in the selected area can be obtained through the deletion of duplicated data;

(3) Identifying current location scope and data acquisition precision. This study refers to the Beijing -Tianjin-Hebei region, also known as Jing-Jin-Ji region, going from the northwest (41.9, 114.5) to the southeast (36.7, 120.0) corners in the coordinate system via Amap (www.gpsspg.com/maps.htm). This study A 5 km diameter circular area is selected as a reference for the search. Thus, all food delivery service providers can be searched with the "current location" as the center and 2.5 km as the radius of the circle, ensuring that no food delivery service provider is missed. Moreover, this choice guarantees that the efficiency of data crawling can be improved with the max step size. The diametric distance of 5 km approximately equals 0.05° of longitude or latitude. In a given area, 105 × 11 current locations are set for acquiring information from the nearby restaurants, where 104 = (northwest latitude – southeast latitude)/0.05° = (41.9–36.7)/0.05 = 104, 110 = (southeast longitude –northwest longitude)/0.05° = (120–114.5)/0.05.

(4) Information on the province, city, and district can be obtained from the API of Amap, according the geographic coordinate system. Information on food flavors is directly collected from Unicode, which needs to be converted into Chinese. Therefore, we set "#coding: UTF-8" at the first line of the script and designate the file encoding type as UTF-8 to enable the Python source file to recognize Chinese.

(5) Data output can be multi-threading parallel processed or buffered written to enhance the crawling efficiency. Collected data are added to an EXCEL file. Each thread operates an EXCEL file. Thus, multiple threads yield many EXCEL files, which are merged at the end of the process.

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