CHEMICAL ENGINEERING TRANSACTIONS
VOL. 70, 2018
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Timothy G. Walmsley, Petar S. Varbanov, Rongxin Su, Jiří J. Klemeš

ISBN 978-88-95608-67-9; **ISSN** 2283-9216
DOI: 10.3303/CET1870111

Energy-Emission-Waste Nexus of Food Deliveries in China

Xuexiu Jia[a,*], Jiří J. Klemeš[a], Petar S. Varbanov[a], Sharifah R. Wan Alwi[b]

[a]Sustainable Process Integration Laboratory – SPIL, NETME Centre, Faculty of Mechanical Engineering, Brno University of Technology - VUT Brno, Technická 2896/2, 616 69 Brno, Czech Republic
[b]Process Systems Engineering Centre (PROSPECT), Research Institute for Sustainable Environment, Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bahru, Johor, Malaysia
jia@fme.vutbr.cz

Door-to-door cooked food deliveries are booming in China, so are the food packaging waste and the related environmental issues. This paper aims to overview the waste flows generated from the food delivery processes – including food packaging and delivery, which is followed by an analysis of the energy consumption and emissions of the waste treatment and the delivery. Based on the overview, this paper provides benchmarking of the energy consumption and emissions within the food delivery in China, which can be helpful for further studies regarding the energy minimisation and environmental impact mitigation in the food delivery supply chain. The results showed that in 2016, the waste generation of door-to-door cooked food deliveries in China was 1.68 Mt, including 1.33 Mt plastic waste and 0.35 Mt of wooden chopsticks, which has not been properly recycled and/or reused. In 2016, the energy consumption for treating the food package waste is 58.89 GWh_e, and the electricity needed for charging the electric bikes is 14.93 GWh_e. The number of spent batteries from the delivery processes, deposited to waste, was 19,507, including 17,285 lead-acid batteries. The estimated GHG emission of energy consumption is 73.89 Gt CO_{2eq}. The conclusions are that the amount of waste from food deliveries is remarkable and still increasing. Encouraging the use of biodegradable food packaging can be helpful for reducing energy consumption and emissions of waste treatment. The energy consumption and GHG emissions covering the whole supply chain of food deliveries should be further discussed.

1. Introduction

The fast urbanisation of cities has changed the human lifestyle and started causing new environmental issues in the city, and one is the steep increase of municipal solid waste (MSW). MSW includes both organic and inorganic fractions such as kitchen refuse, cloth, bottles, paper, batteries, etc., produced by a society, which do not generally carry any value to the first user (Ramachandra et al., 2018). The global waste generation has raised to 1.3 Gt/y since 2012 and is projected to be more than 2.2 Gt/y in 2050 (Hoornweg et al., 2012). Considering ten countries with largest MSW generation (Waste atlas, 2017), China is leading the top of total annual MSW generation with a share of 27.4 % in 2017 (Figure 1), while the MSW generation per capita is much less than other countries with the large population. As an important part of the MSW, waste generated during the food services and use has been claimed to have an increasing environmental impact. This waste mainly includes raw material residual, food waste as well as the food packaging. Raw material residual and food waste are mostly organic kind and easier for further treatment (Bang et al., 2017). Various methods have been developed to utilise the bio-waste and mitigate its environmental impacts, e.g. composting, anaerobic digestion, pyrolysis, incineration and landfill (Lee et al., 2018). The food packaging is used to contain the food for food safety and reduce food waste (Poyatos-Racionero et al., 2017). On the other hand, the food packaging is leading to environmental issues due to the rapid increase of its amount as well as the lack of sufficient management. Efforts have been made to reduce the generation of food packaging waste from food industries and retailers. For example, China has launched the policy to limit the production, selling and use of plastic bags in supermarkets (GOSC, 2007), the “Packaging and Packaging Waste” (PPW) Directive came to force in EU to reduce the generation of packaging waste (European Commission, 2004). Hahladakis et al. (2018) assessed the yield of multiple collection-recycling schemes of food packaging in England and found that only a small percentage (16 %) of the total amount of post-consumer plastics collected in the examined period was finally

Please cite this article as: Jia X., Klemes J.J., Varbanov P.S., Alwi S.R.W., 2018, Energy-emission-waste nexus of food deliveries in china , Chemical Engineering Transactions, 70, 661-666 DOI:10.3303/CET1870111

sent to re-processors (22 kt) in 2014. The food package waste generated by the users becomes more difficult to manage due to the lack of proper collection and sorting in China. Especially in large cities, with the fast development of e-commerce and fast-paced lifestyle, the door-to-door food deliveries have become increasingly popular. The huge increase of food delivery packages is becoming one of the top new challenges of MSW management.

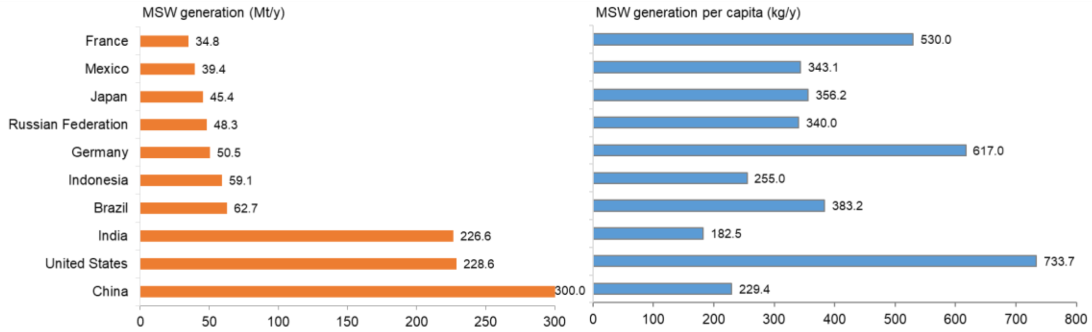

Figure 1. Top ten countries with the largest amount of MSW and their MSW per capita in 2017 (Derived from Waste Atlas, 2017)

The market for online food ordering reached 162.2×10^9 CNY in 2016, and increased to 204.6×10^9 CNY, with an increased rate of 23.1 % in 2017 (iiMedia, 2017). The number of registered users in the food delivery apps has risen to 295 M until June of 2017, which is about 19 % of China's population (iiMedia, 2017). The online food delivery is becoming increasingly popular because of its convenience and the lower food price than in the restaurant. Studies show that 13.4 % of the customers are ordering food with the price less than 15 CNY, and 37.3 % ordering food with the price of 16 - 25 CNY (about 2.6-3.2 Euro), and only 10.1 % customer order food with price higher than 45 CNY, which is similar to the price of having the meal in the restaurant (iiMedia, 2017). More than 80 % of the users surveyed use food delivery apps once a week in the first half of 2017, and more than 10 % of users order delivery once a day (iiMedia, 2017). With the increase of orders, the increase of the amount of waste from the delivered food is remarkable. Song et al. (2017) estimated that the total amount of packaging waste from door-to-door food delivery surged in China from 0.2 Mt in 2015 to1.5 Mt in 2017. While the food delivery packaging waste only accounts for approximately 1 % of the annual municipal solid waste (MSW) generated in China, it concentrates in a few megacities and is comparable to the annual MSW generated in many second-tier cities such as Taiyuan, and Dalian etc. Obviously, the rapid increase of door-to-door cooked food deliveries have been resulting in environmental issues concerning the waste and related environmental impacts, but the data and studies towards these issues still deserve further investigation. This paper aims to identify the waste generation and energy consumptions of the increasing door-to-door food deliveries and provides the background data for further studies to mitigate the issue.

Table 1: Food ordering, delivery processes and system boundaries

Processes	System boundaries	
	Waste Generation	Energy Consumption & Emissions
1. Users ordering food via Third-party Online Platform (TOP), and the TOP send the order to the delivery person	N/A	
2. Delivery from TOP to the food supplier (shop/restaurant, etc.) 3. Delivery from food producer to the customer 4. Delivery from the user back to the TOP	Waste from end-of-life vehicles (batteries)	Energy consumption of charging the e-bikes GHG emissions of the end-of-life batteries
5. Users consume the food	Waste from packaging and food waste (plastic bag/cutlery; wooden chopsticks, etc.)	Energy consumption and GHG emissions from waste treatment

2. Food Deliveries and System Boundary of the Study

Food deliveries are usually made via third-party platforms. The ordering information is received by the third-party platform, which is usually online food ordering Applications (APPs), and then transferred to the delivery staff. They deliver the food to the users. At last, the delivery person still needs to go back to a certain place and wait for another order. The food ordering and delivery processes, as well as the system boundaries of this study are shown in Table 1. This is used as the basis of the evaluation of energy consumption and emissions.
The waste generated during food deliveries includes the food package waste and the waste from end-of-life batteries. The energy consumption and emissions of the waste treatment and the e-bike direct charging have been considered as well. The food producing stages are not considered in the system boundary. The data are mainly based on the national statistical data of China in 2016, due to data availability reason, Tainwan, Hongkong and Macao are not discussed in this study.

3. Estimations of Waste Generations, Energy Consumption and Emissions

The online food delivery data applied in this study are mainly from the research report of iiMedia (2017) and Song et al. (2017). It has been assumed that all delivering vehicle are electric bikes (e-bike). China's e-bike committee (2015) claimed that lead-acid batteries (LABs) and lithium-ion batteries (LIBs) are the most used batteries for e-bikes, and in the year 2015, 95 % of the e-bikes on-road use LABs due to cost considerations. Considering the advance and promotion of technology, it is assumed the proportion of LABs is 70 % and LIBs is 30 % in 2016. The data and data source are listed in Table 2.

Table 2: Food delivery and intensity data of 2016

Data Item	Amount	References
Number of active users	179.2 M	Estimated based on the report by iiMedia (2017)
The average ordering frequency	2 times/week	
The average distance per order	25 km (3 orders/delivery)	
Number the e-bikes	491,400	
Electricity used per km	0.05 kWh/km	
Lifetime of the e-bike batteries	2 y for LABs 4 y for LIBs	Estimated based on Liu et al. (2015) and Liang et al. (2017)
Average waste generation per order	1 plastic bag 3 plastic boxes 2 plastic forks 2 plastic spoons 2 pairs of wooden chopsticks	GVLC, 2017

Other data for end-of-life vehicles, energy consumptions, and emission factors etc. are from literature (listed where mentioned). Considering data availability, this study mainly focuses on the year of 2016.

3.1 Waste Generation

Based on the listed data, the waste generation, energy consumption and emissions are analysed. In this study, the average weight of 1 food delivery plastic bag is 0.003 kg, 1 plastic box is 0.01 kg, 1 plastic fork/spoon is 0.001 kg, 1 pair of wooden chopsticks is 0.005 kg. The annual food package waste can be calculated using Eq(1):

$$W_{pw} = N_o \times W_{po} \tag{1}$$

Where the W_{pw} is the weight of package waste per year, Mt/y; N_o is the number of orders per year, W_{po} is the weight of the food package per order, kg/order.
Besides the waste from food packaging, the waste generation due to the huge number of electric bikes used during food delivery should also be considered. The major waste generated is the end-of-life batteries. The number of annual end-of-life bikes (batteries) can be calculated in Eq(2):

$$W_{mb} = N_{mb} \times P_c \times D_e \tag{2}$$

Where W_{mb} is the number of end-of-life batteries per year, N_{mb} is the number of e-bikes used for food delivery, P_c is the percentage of spent batteries, and D_e is the percentage of spent batteries that are disposed into the environment. Based on the lifespan of the batteries, it is assumed that for LABs, the percentage of spent batteries is 50 %, which means 50 % of the e-bike LAB batteries reach to the end-of-life stage every year. For LIBs the percentage is assumed as 25 %. Among these end-of-life batteries, about 20.1 % of spent batteries are discarded by consumers directly into the environment (Chen et al., 2017). For both types of batteries, D_e is 20.1 %. The results of waste generation are shown in Table 3.

Table 3: Estimation of waste generated during food delivery system in 2016

Waste generation source	Amount
Waste from food delivery packages-total	1.68 Mt
Waste from food delivery packages-plastic	1.33 Mt
Waste from food delivery package-wood	0.35 Mt
Spent batteries disposed into the environment	19,507
LABs	17,285
LIBs	2,222

It showed that in 2016, the total package waste from food delivery in China is 1.68 Mt, including 1.33 Mt plastic waste and 0.35 Mt wood waste. The estimated waste generation in this study is larger than the estimation of Song et al. (2017) (0.61 Mt/y), one possible reason is that the cutlery was not considered in their studies. The total number of spent batteries entering the environment in 2016 is 19,507, of which 88.6 % is LABs. Liu et al. (2015) analysed the life cycle assessment of LABs (1 kWh capacity) used in e-bikes in China and found that the spent batteries are contributing 91 % of the human toxicity potential (HTP), which reflects the potential harm of a unit of chemical released for human health. Even during the using stage, LABs has a considerable contribution to many environmental impacts. For example, the use stage results in 86 % of global warming potential (GWP), 78 % of eutrophication potential (EP) and 69 % of acidification potential (AP), within the overall battery life cycle. The collecting and managing of the used e-bike and the spent batteries entering the environment have been proved to cause environmental issues (Boyden, et al., 2016).

3.2 Estimation of Energy Consumption and Emissions

Except for direct waste generation, the food delivery processes also have embodied energy consumption and emissions. The energy consumptions and emissions during the food delivering and waste treatment are estimated. The indicators used for calculating energy consumption and emissions of waste treatment are listed in Table 4.

Table 4: Consumption and emission factors

Factors	Value	References
Energy Consumption factor of waste treatment (f_{eclf})	26.37 kWh_e/t	Calculated based on Sisani et al. (2016), and BMAQTS (2015)
Lifecycle Greenhouse gas (GHG) emissions of electricity (with coal as electricity source)	1.0 kg CO_2/kWh_e	Moonmaw et al., 2011

The energy consumption depends on the way of waste treatment and the specific situation of the treatment plant. According to the statistical data from National Statistical Bureau of China (2017), in 2016, 37.5 % of the MSW is treated by landfill, and 60.3 % are sent to incineration. As the rest counts for 2.2 % only landfill and incineration are considered.
Based on the waste generation, the energy consumption can be calculated in Eq(3):

$$E_{wt} = W_{wt} \times f_{ec} \tag{3}$$

Where E_{wt} is the total energy consumption of food delivery waste treatment GWh_e/y; W_{wt} is the amount of food package waste; f_{ec} is the energy consumption factors for waste treatment.
The charging of the delivery e-bikes can be calculated based on the numbers of orders and the electricity consumption of per km, as shown in Eq(4):

$$E_c = N_t \times T_n \times f_c \tag{4}$$

Where E_c is the electricity needed for the vehicle charging, kWh_e/y, N_t is the number of trips, T_n is the distance per trip, km, and f_c is the energy efficiency of e-bikes, kWh_e/km.
Based on the results of electricity consumption of the vehicle charging and waste treatment, the indirect GHG emission of the electricity consumption is also determined. The results of the are shown in Table 5.

Table 5: Estimation of Energy consumption and GHG emissions in 2016

Energy consumption and GHG emissions	Amount
Electricity used for waste treatment	58.89 GWh_e
Electricity used for charging	14.93 GWh_e
GHG emissions of electricity consumption (with coal as electricity source)	73.89 Gt CO_{2eq}

It showed that in 2016, the major energy consumption of the food delivery system is the electricity for package waste treatment, with a ratio of 79.8 %. The total GHG emission of the electricity consumption is 73.89 Gt CO_2.

4. Discussion

The online food ordering and deliveries are increasing considerably, these growths are resulting in the increase of waste generation and the related resources consumption and environmental issues. The average weight of the food packages for one order is about 0.047 kg. However, with a large number of users and orders, the total amount of food packages waste is remarkable. Most of the food package is made of polypropylene (PP) and polystyrene (PS), which are hard for biodegradation. The food packages including the cutleries are mostly used once and then dumped into bins mixing with other municipal waste. Together with the MSW, these waste materials are sent to landfill or incineration. However, it is claimed that PP/PS should be incinerated in higher temperature (above 1000 °C), incinerated in a lower temperature would lead to the generation of toxic chemicals. In addition, a considerable proportion of the waste is disposed of improperly and enters the rivers or lakes and causing serious environmental issues. The plastic can remain in the soil for a considerable long time, which could lead to soil pollution, and by rain wash, these wastes enter the water bodies and result in groundwater pollution. All these solid waste discharges would lead to the increase of economic and environmental cost.
This study only considered the waste generated during food delivery processes, but the better management of food delivery waste should also consider the reduction of waste generation. One is to use biodegradable cutlery instead of plastic ones. As the food delivery market is expanding and the increasing of the orders, most of the take-out lunch boxes are made of non-degradable materials, which increases the cost of garbage disposal. As packages and cutlery are usually offered by the food ordering platforms, encouraging the use of biodegradative packages and cutlery is critical for decreasing the generation of food package waste. Another option is to improve the parameters of the e-bike batteries. The future works should cover the life cycle of food deliveries, and investigate the further environmental footrpints of the packaging waste. Promosing technologies, such as the reclying of PP and waste-to-energy from PP/PS incineration should also be discussed, in order to search for more possibilities of reducing the environmental impact of food delivery waste.

5. Conclusions

This paper investigated the waste, energy and emission issues raised by the increasing of online food deliveries in China, aiming to provide the background data and suggestions for reducing the environmental impact of food delivery processes. The results showed that in 2016, the door-to-door food deliveries generated food packaging waste is 1.68 Mt, including 1.33 Mt plastic waste and 0.35 Mt wooden waste. The number of spent e-bikes batteries was estimated as 19,507, including 17,285 LABs and 2,222 LIBs. The energy consumed during the treatment of the food package waste was 58.89 GWh_e, the charging batteries electricity 14.93 GWh_e, and the GHG emission during the waste treatment processes was estimated as 73.89 Gt CO_{2eq}. Encouraging the use and promotion of biodegradable food packages, improvement of battery lifespan and improving the supply chain management can effectively reduce the discharge of the toxic materials and improve the energy efficiency.

Acknowledgements

The EU supported project Sustainable Process Integration Laboratory – SPIL funded as project No. CZ.02.1.01/0.0/0.0/15_003/0000456, by Czech Republic Operational Programme Research and Development, Education, Priority 1: Strengthening capacity for quality research in the collaboration agreement with the Universiti Teknologi Malaysia (UTM) based on the SPIL project have been gratefully acknowledged.

References

Beijing Municipal Administration of Quality and Technology Supervision (BMAQTS), 2015. The norm energy consumption per unit incineration treatment of municipal solid waste, <bjmac.gov.cn/hjwsbz/hjwsbzbzgf/201604/P020160623361896425100.pdf> assessed 16.03.2018.

Bong C.P.C., Lim L.Y., Lee C.T., Ho W.S., Klemeš J.J., 2017. The Kinetics for Mathematical Modelling on the Anaerobic Digestion of Organic Waste- A Review, Chemical Engineering Transactions, 2017, 61:1669-1674.

Boyden, A., Soo, V.K., Doolan, M., 2016. The environmental impacts of recycling portable lithium-ion batteries. Procedia CIRP, The 23rd CIRP Conference on Life Cycle Engineering, 48, 188–193.

Chen, F., Yang, B., Zhang, W., Ma, J., Lv, J., Yang, Y., 2017. Enhanced recycling network for spent e-bicycle batteries: A case study in Xuzhou, China. Waste Management, Special Thematic Issue: Urban Mining and Circular Economy 60, 660–665.

China's e-bike Committee, 2015, China's e-bikes increases tenfold in ten years up to 200 million, (2015). <com/news/html/201501/2015011910382241.htm> accessed 20.03.2018.

European Commission, 2004. Directive 2004/12/EC of the European parliament and of the council of 11 February 2004 amending Directive 94/62/EC on packaging and packaging waste - Statement by the Council, the Commission and the European Parliament (Official Journal of the European Union L047 of 18.02.2004).

General Office of the State Council (GOSC) of the People's Republic of China, 2007, Notice of restricting the production, sale and use of plastic shopping bags. <gov.cn/zwgk/2008-01/08/content_852879.htm> accessed 18.03.2018

Green Volunteer League of Chongqing (GVLC), 2017, The focus on food delivery wastes, <greenu.org.cn/b_29_177_7_news.aspx> assessed 16.3.2018.

Hahladakis, J.N., Purnell, P., Iacovidou, E., Velis, C.A., Atseyinku, M., 2018. Post-consumer plastic packaging waste in England: Assessing the yield of multiple collection-recycling schemes. Waste Management. DOI: 10.1016/j.wasman.2018.02.009.

Hoornweg, D.; Bhada-Tata, P., 2012. What a waste: a global review of solid waste management. Urban development series; knowledge papers no. 15. World Bank, Washington, DC, USA.

iiMedia Research Group, 2017, 2016-2017 China Online Take-out Market Research Report, <iimedia.cn/14890266658597444l.pdf> assessed 12.3.2018.

Lee, C.T., Rozali, N.E.M., Fan, Y.V., Klemeš, J.J., Towprayoon, S., 2018. Low-carbon emission development in Asia: energy sector, waste management and environmental management system. Clean Technologies and Environmental Policy, 20, 443-449.

Liang, Y., Su, J., Xi, B., Yu, Y., Ji, D., Sun, Y., Cui, C. ,Zhu, J., 2017. Life cycle assessment of lithium-ion batteries for greenhouse gas emissions. Resources, Conservation and Recycling, 117, 285-293.

Liu, W., Sang, J., Chen, L., Tian, J., Zhang, H., Olvera Palma, G., 2015. Life cycle assessment of lead-acid batteries used in electric bicycles in China. Journal of Cleaner Production 108, 1149–1156.

Marcinkowski, A., Kowalski, A.M., 2012. The problem of preparation the food packaging waste for recycling in Poland. Resources, Conservation and Recycling, 69, 10–16.

Moomaw, W., Burgherr P., Heath G., Lenzen M., Nyboer J., Verbruggen A., 2011: Annex II: Methodology. In IPCC special report on renewable energy sources and climate change mitigation (Edenhofer O., Pichs-Madruga R., Sokona Y., Seyboth K., Matschoss P., Kadner S., Zwickel T., Eickemeier P., Hansen G., Schlömer S., von Stechow C. (eds)), Cambridge University Press, Cambridge, UK and New York, NY, USA.

National Bureau of Statistics of China, 2017, Annual data-Environment and Resources, <data.stats.gov.cn/easyquery.htm?cn=C01> assessed 16.03.2018

National Bureau of Statistics of China, 2017, National data, <data.stats.gov.cn/easyquery.htm? cn=C01> assessed 18.03.2018.

Poyatos-Racionero, E., Ros-Lis, J.V., Vivancos, J.L., Martínez-Máñez, R., 2018. Recent advances on intelligent packaging as tools to reduce food waste. Journal of Cleaner Production 172, 3398–3409.

Ramachandra, T.V., Bharath, H.A., Kulkarni, G., Han, S.S., 2018. Municipal solid waste: generation, composition and GHG emissions in Bangalore, India. Renewable and Sustainable Energy Reviews 82, 1122–1136.

Romare M., Dahllöf L., 2017, The life cycle energy consumption and greenhouse gas emissions from lithium-ion batteries, IVL Swedish Environmental Research Institute, Stockholm, Sweden.

Sisani, F., Contini, S., Di Maria, F., 2016. Energetic efficiency of landfill: an italian case study. energy procedia, ATI 2016 - 71st Conference of the Italian Thermal Machines Engineering Association 101, 66–73.

Song, G., Zhang, H., Duan, H., Xu, M., 2018. Packaging waste from food delivery in China’s megacities. Resources, Conservation and Recycling 130, 226–227, doi: 10.1016/j.resconrec.2017.12.007.

Waste Atlas, 2017. Municipal solid waste generation, <atlas.d-waste.com/> assessed 16.03.2018.