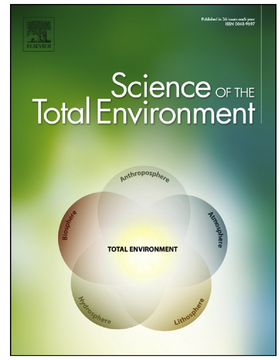
Journal Pre-proof



Potential climate benefits of reusable packaging in food delivery services. A Chinese case study

Laia Camps-Posino, Laura Batlle-Bayer, Alba Bala, Guobao Song, Huimin Qian, Rubén Aldaco, Ramón Xifré, Pere Fullana-i-Palmer

PII: S0048-9697(21)03642-1

DOI: https://doi.org/10.1016/j.scitotenv.2021.148570

Reference: STOTEN 148570

To appear in: *Science of the Total Environment*

Received date: 15 December 2020

Revised date: 16 June 2021

Accepted date: 16 June 2021

Please cite this article as: L. Camps-Posino, L. Batlle-Bayer, A. Bala, et al., Potential climate benefits of reusable packaging in food delivery services. A Chinese case study, *Science of the Total Environment* (2018), https://doi.org/10.1016/j.scitotenv.2021.148570

Potential climate benefits of reusable packaging in food delivery services. A Chinese case study

Laia Camps-Posino[1], Laura Batlle-Bayer[1], Alba Bala[1], Guobao Song[2], Huimin Qian[2], Rubén Aldaco[3], Ramón Xifré[1,4,5], Pere Fullana-i-Palmer[1].

[1]UNESCO Chair in Life Cycle and Climate Change ESCI-UPF, Universitat Pompeu Fabra. Passeig Pujades 1, 08003 Barcelona, Spain

[2]Key Laboratory of Industrial Ecology and Environmental Engineering (MOE), School of Environmental Science and Technology, Dalian University of Technology. Dalian 116024, China.

[3]Department of Chemical and Biomolecular Engineering, University of Cantabria. Avda. De los Castros, s.n., 39005 Santander, Spain

[4] UPF Barcelona School of Management, Barcelona, Balmes 132-134, 08008 Barcelona, Spain.

[5] Public-Private Sector Research Center (PPSRC), IESE Business School. Arnús I Garí, 3-7, 08034 Barcelona, Spain.

Corresponding author: Pere Fullana-i-Palmer pere.fullana@esci.upf.edu Permanent address

Highlights

- The impact of single-use food delivery packaging on climate change is assessed.
- The manufacture of the packaging contributes to 63% of current emissions
- End-of-life waste management is responsible of 35% of the emissions
- Introducing reusable packaging reduces 54% of current emissions
- Higher recycling rates and recycled content are also key to reduce emissions.

Abstract

In China, the food delivery packaging waste is increasing due to the rapid growth of the sector and the use of single-use packaging to transport the meals. In addition, the recycling rates of current municipal waste management are low. In this regard, this study aims at estimating the climate change impact of current food delivery packaging and its waste treatment, by performing a Life Cycle Assessment with a cradle-to-grave approach. In addition, this article explores the potential benefits of increasing the current recycling rates, the recycled content of the packaging as well as the use of reusable packaging. For this study, the food packaging of a typical dumpling-based meal of the popular Chinese restaurant Xijiade was selected. Based on this menu and the current Chinese consumption patterns, the food delivery packaging in China would have emitted about 13 million tons of CO_2eq. Increasing current recycling rates to 35% would reduce 16% the emissions of single-use packaging, and further decrease (60%) could be found if half of the packaging was made of recycled material. In addition, if single-use packaging was replaced by reusable PP-based packaging (food container and carrier bag), the emissions would potentially be 63% lower than the current situation. In this case, doubling the recycling rates and the recycled content of the reusable food packaging would represent an extra 6 and 17% reduction of emissions, respectively.

Keywords: Climate change, reusable food container, recycling rate, recycled content, life cycle assessment

ABBREVIATIONS:

CC_{RMtoF}: climate change impact of producing plastic film
CC_{GtoF}: Climate change impact of manufacturing PP film from PP granulates
CC_p: Climate change impact of producing propylene (PP) at plant
CC_{PP}: Climate change impact of the whole process of producing PP granulates
CC_{polim}: Climate change impact of the propylene polymerization
CC_{prop_p}: Climate Change impact of producing propylene at the plant
CC_{prop_r}: Climate Change impact of producing propylene at the refinery
CN: China
DE: Germany
EF: Efficient Factor
EoL: End of Life
EPS: Expanded polystyrene
G: Amount of granulates
G_c: Amount of virgin material to be credited
HDPE: High-density polyethylene
HSW: Household Solid Waste
LCA: Life Cycle Assessment
MHURD: Ministry of Housing and Urban-Rural Development of the People's Republic of China
MSW: Municipal Solid Waste
PE: Polyethylene
PET: Polyethylene terephthalate
PLA: Polylactic acid
PP: Polypropylene
RPCs: reusable plastic crates
Q_r: quality of the secondary (recycled) granulate at the point of substitution
Q_v: quality of the virgin material
S-CRec: Scenario of single-use food packaging with current recycling rate
S-35Rec: Scenario of single-use food packaging with the targeted 35% recycling rate

S-35Rec-50RC: Scenario of single-use food packaging with the targeted 35% recycling rate and 50% recycled content
RC: percentage of recycled content
R-CRec: Scenario of Reusable food packaging with current recycling rates
R-35Rec: Scenario of Reusable food packaging with the targeted 35% recycling rate
R-35Rec-50RC: Scenario of Reusable food packaging with the targeted 35% recycling rate and 50% recycled content

1. Introduction

Since the 1980s, the rapid economic growth of China (with an average annual GDP growth of 10%; Chen et al., 2020) has transformed the country into the second-largest economy in the world. This economic development has been linked to a fast urbanization growth. About 61% of the Chinese population live in cities (NBSC, 2020). Extensive cultivated land has been converted to urban areas (Zhou et al., 2020) and energy consumption has increased (Ji and Zhou, 2020). In addition to that, China is the largest Municipal Solid Waste (MSW) producer worldwide (Chen et al., 2010). It produces 10% of global MSW (Ding et al., 2021) and no decrease in the short term is expected due to the population and urbanization growth (Cheng et al., 2020).

The two main waste treatments are incineration (52.5%) and landfilling (47.5%) (NBSC, 2020), but new sorting municipal regulations are encouraging the increase of recycling. In 2017, the government launched the Plan on the Household Solid Waste (HSW) Classification System in order to adopt mandatory waste sorting in 46 Chinese cities to increase the recycling rate of HSW to 35% by 2020 (Ye et al., 2020). The Guangdong Provincial Urban and Rural HSW Management Regulation was the first pilot plan in September 2017, followed by other cities such as, Guangzhou (April, 2018), Shanghai (July, 2019) or Fuzhou (September 2019) (Wang & Jiang, 2020). The Shanghai HSW system has been considered as the strictest and the most complex one in China, without public involvement and the application of fines for individuals and businesses that do not follow the rules (Wang and Jiang, 2020). In this regard, Ye et al. (2020) emphasize the need of a more citizen-based approach to accomplish satisfactory results. In addition, they suggest to perform a long-term behavioral change of citizens regarding waste sorting, since current public awareness on HSW and recycling knowledge is low and differs among sociodemographic groups (Wang et al., 2020). In November 2020, the Ministry of Housing and Urban-Rural Development of the People's Republic of China (MHURD) and twelve ministries and departments published the "Views on Further Promoting the Housing Waste Classification", which established three targets for the next five-years: (1) to establish a comprehensive law system to regulate waste classification; (2) to establish the waste classification, transport, and treatment system, and guide the public to classify waste; and (3) to increase China's urban recycling rate of HSW to at least 35% (Wang et al., 2020).

About 11% of the collected MSW in China is plastic (Xu et al., 2020). While there are many sources of plastic waste, this study focuses on the plastic waste generated by the food packaging used for delivery service. The food delivery service sector in China is one of the most rapidly-growing sectors, especially in megacities, with a revenue of $37 billion in 2018 (Statista, 2019). The revenue per consumer is lower than in the US and European food delivery sectors; but the large population of China (1,441 million inhabitants in 2019) has turned this sector into the biggest eService market worldwide (Statista, 2019). The increasing popularity of food delivery services (283.1 million users in 2019; Liu et al., 2020) has increased the use of single use food packaging and, in consequence, the generation of waste (6.5-fold increase from 2015 to 2017; Song et al., 2018). This packaging waste ends up in landfills and incineration plants, but illegal dumping still occurs (6%), with the related pollution that can cause to the environment and human health (NBSC, 2020).

Hence, with the current on-growing use of single-use packaging for food delivery and the low rates of recycling in China, this study aims to assess the climate change impact of this current systems by selecting a common menu served by a Chinese food delivery restaurant. Second, this study estimates the climate benefits of increasing the recycling rates to 35%, as targeted by the Chinese regulations, and the potential benefits of two other hypothetical actions: the increase of the recycled content of the packaging and the introduction of a reusable food packaging. To do so, this study applies the widely accepted methodology of Life Cycle Assessment (LCA), following the ISO 14040 and 14044 standards (ISO, 2006). While several studies have assessed the impact of food packaging in China (Liu et al., 2020; Xie et al., 2020), this study is the first one assessing the potential impacts, in terms of climate change, of the current strategies to recycle and two other hypothetical circular strategies.

2. Review of food packaging LCAs

Previous comparative LCA studies of single-use versus reusable food packaging have usually focused on secondary (i.e., crates) and primary (those with direct contact with foods) packaging. Concerning secondary packaging, several studies (Abejón et al., 2020; Albrecht et al., 2013; Levi et al., 2011; Tua et al., 2019) have assessed the environmental impact of reusable plastic crates (RPCs) versus single-use corrugated boxes to transport fresh foods, especially fruits and vegetables. In this respect, Abejón et al. (2020) reported the environmental benefits of RPCs within the Spanish market, and Levi et al. (2011) highlighted the travel distance as a key factor; RPCs were more environmentally beneficial than corrugated boxes for distances below 1,200km. Accorsi et al. (2014) evaluated both the environmental impact and the cost of different secondary packaging of fresh organic fruit and vegetables within a catering supply chain. RPCs performed better, and they highlighted the key role of disposal treatment, network distribution and packaging lifespan when doing an LCA.

Large amount of LCA studies have assessed the environmental impacts of the primary packaging of beverages (as reviewed by Sazdovski et al., 2021) as well as of foods sold at retailers (i.e., Siracusa et al. 2014), and some LCA studies have examined legislation, such as Navarro et al. (2018), who assessed the impact of the Spanish legislative initiative that promoted the replacement of current reusable primary packaging to single-use ones. In the past years, more LCAs on packaging used for food delivery services have been published (Table 1), since consumption of takeaway food is growing worldwide. As summarized in Table 1, several studies analyzed some components of take-away food services (i.e. tableware, cups), others assessed all the packaging items of a certain meal (i.e, Blanca-Alcubilla et al., 2020), and some examine all types of packaging used in the food delivery system, such as the case of Arunan and Crawford (2021) for Australia. While, in most of the cases, reusable food packaging performed environmentally better, a key aspect was the number of reuses needed to outweigh the impact of single-use packaging, the so-called transition point (Lighthart and Ansems, 2007). For instance, an stainless steel beverage cup should be used at least 140 times in the case study of Changwichan and Gheewala (2020); and for a Tupperware, different reuses were reported by Gallego-schmid et al. (2020), depending on the environmental impact that was considered (i.e., 18 reuses to balance out the CO_2 emissions of Expanded polystyrene (EPS) food containers, 24 times to outweigh half of the analyzed environmental impacts, and 208 times to equal the impact category of abiotic depletion potential). Nevertheless, no transition point was found for steel tableware used for flight meals due to its heavier weight than the disposable ones (Blanca-Alcubilla et al., 2020).

Table 1. Summary of the LCA studies on food packaging for food delivery services.

Reference	Country	Type of packaging	Packaging component	System boundaries	GHG emissions of single-use packaging per meal [kg CO_2 eq / serving]
(Arunan and Crawford, 2021)	AU	Single-use	Boxes, bags, straw and cups	Cradle-to-grave	0.15 – 0.29
(Changwichan and Gheewala, 2020)	TH	Single-use (bio-based, PP and PET) and reusable (stainless steel)	Beverage cups	Cradle-to-grave	0.07 – 0.12 [PET] 0-04 – 0.08 [PP] 0.04 [PLA] 0.01 - 0.03 [Stainless steel]
(Gallego-schmid et al., 2020)	EU	Single-use (Aluminum, EPS and PP) vs reusable (PP)	Food containers	Cradle-to-grave	0.08 [single-use Aluminum] 0.05 [single-use EPS] 0.15 [single-use PP]
(Foteinis, 2020)	UK	Single-use (paper) vs reusable (PP)	Coffee cups	Cradle-to-grave	0.03 [disposable paper cup] 0.01 [reusable PP]
(Blanca-Alcubilla et al., 2020)	Iberia Flights	Single-use and reusable	All packaging items for a flight menu	Cradle-to-grave	0.12 [Reusable Steel cutlery] 0.08 [Single-use Al food container] 0,01 [Coffee paper cup]
(Gallego-schmid et al., 2018)	EU	Reusable (plastic and glass)	Tupperware	Cradle-to-grave	0.05 [plastic] 0.05 [glass]
(Fieschi and Pretato, 2018)	EU28	Single-use (biodegradable-compostable and fossil-based plastics)	Tableware	Cradle-to-grave	0.22 [Fossil-based] 0.11 [Biodegradable, compostable]

3. Methodology

3.1. Goal and scope of the study

The goal of this study is to assess the environmental impact of current single-use food packaging for delivery service and compare it to alternative scenarios in packaging and waste treatments. A cradle-to-grave approach is considered (Fig.1). Hence, this study considered the life-cycle stages of material extraction, packaging production, transport of the food packaging from the manufacture to the restaurant, transport from the restaurant to the consumer (and the way back, for reusable containers), the washing process (for the reusable food containers), and the waste management.

For the reusable food container, a life span of 50 uses is assumed. Hence, to compare the single-use and reusable packaging systems, the functional unit is defined as the packaging used to provide 50 standard menus in their takeaway delivery service. This study focuses on the delivery-service meal orders in the Chinese restaurant Xijiade. It is a popular Chinese restaurant brand that can be found in the main food delivery service platforms (Ele.me, Meituan and Waimai). It is highly popular in Beijing, and it is representative of the Chinese culture because of its standard menu based on Jiaozi (dumplings) and its standard price (approximately 30 yuans) (Statista, 2019).

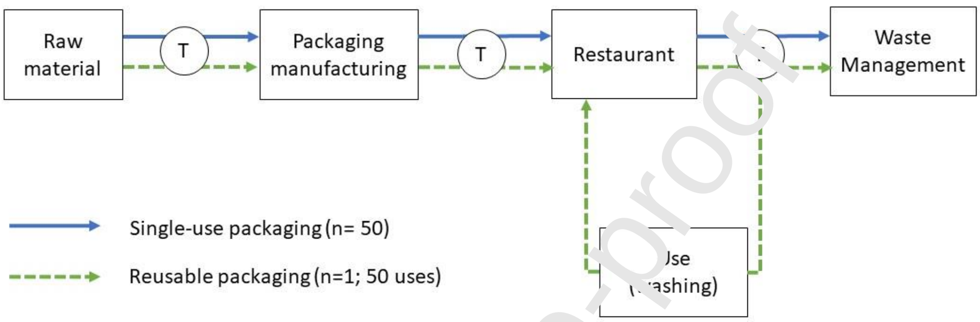


Figure 1. System boundaries of the study

3.2. Inventory analysis

GaBi Professional software (Sphera, 2020) has been used to model the life cycle of the packaging systems, and the latest Environmental Footprint impact assessment method (EF 3.0; Fazio et al., 2018) was used to assess the impact of Climate Change (kg CO_2 eq).

3.2.1. Food packaging material

Figure 2 and Table 2 summarize the composition of the single-use food packaging used for a food delivery at a Xijiade restaurant. Concerning the reusable packaging scenario, it was assumed to be composed of two items: a polypropylene (PP)-based reusable food container (132.8 gr PP and 8.5 gr Silicone; based on Gallego-schmid et al., 2020) and a reusable plastic bag (100 g) made of PP. Tableware and extra sauces containers were excluded in this alternative scenario, consistently with the more environmentally-friendly initiative.

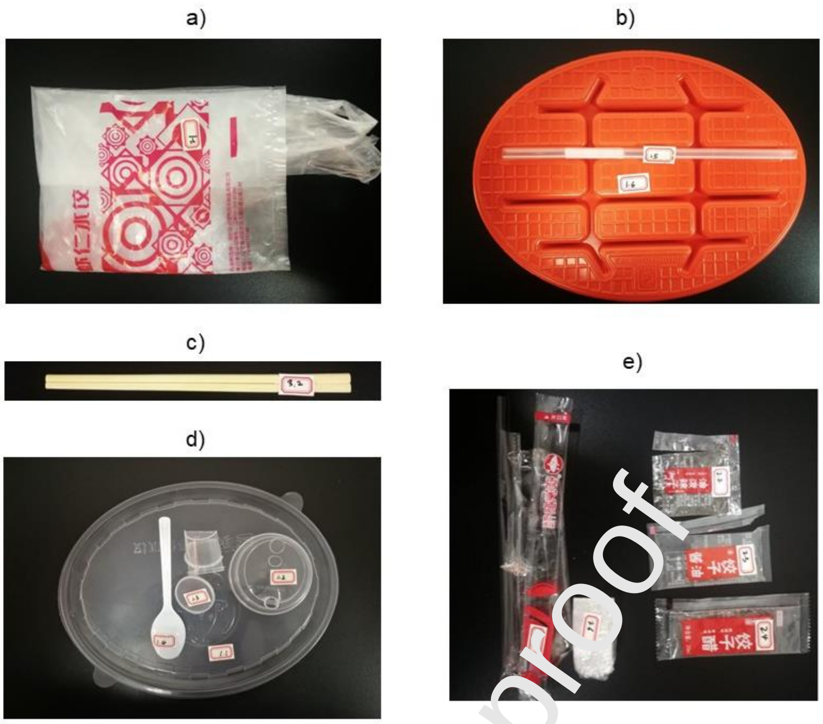


Figure 2. Food delivery service packaging of the studied menu at Xijiade restaurant: a) HDPE plastic bag; b) PP straw and PP dumplings container base; c) Bamboo chopsticks; d) PP spoon, PP sauces pots and PP dumplings container top; e) PP packaging for sauces, PP Packaging bag for the spoon, Cellophane chopsticks packaging and PE packaging for the rest of items.

Table 2: Composition of the current food packaging at Xijiade restaurant

Type of packaging	Weight (g)	Material
Top	20.1	PP
Base of the container	37.3	PP
Sauce pot	2.4	PP
Spoon	3.3	PP
Straw	1.2	PP
Packaging for sauces	1.7	PP
Packaging of the spoon	0.9	PP
Plastic bag	8.0	HDPE
Chopsticks' packaging	0.8	Cellophane
Packaging for all the items	1.5	PE
Disposable chopsticks	5.8	Bamboo

To model the manufacture of PP-based packaging to the Chinese context and assess its impact on climate change, assumptions were needed due to the lack of data in the GaBi database (SP40). The only available data for China was the production of propylene at the refinery level (CN-Propylene at refinery). Since propylene is the material to produce PP via polymerization, this process was used as a starting point. However, manufacturing propylene at the production plant is less efficient than in a refinery. Hence, to account for this lower efficiency at the plant level, an efficient factor (EF) was defined (Equation 1):

$$EF = \frac{CC_{prop_r}}{CC_{prop_p}} \qquad (Eq. 1)$$

Where,

CC_{prop_r}: Climate Change impact of producing propylene at the refinery (kgCO_2 eq / kg propylene)

CC_{prop_p}: Climate Change impact of producing propylene at the plant (kgCO_2 eq / kg propylene)

To calculate the EF, the European processes (EU-28 propylene at refinery and EU-28 Propylene (production mix at plant)) were used as proxies. The EF was estimated to be 2.85.

Next, since no specific data on the polymerization of propylene was available, the climate change impact of the propylene polymerization (CC_{polim}) was calculated as the subtraction of the emissions of producing propylene at plant (CC_p) from the climate change of the whole process of producing PP granulates (CC_{PP}; kg CO_2eq / kg PP granulates) (Equation 2). To estimate this value, the European processes of the Gabi database (EU-28 Polypropylene, PP, granulate and EU-28 Propylene (production mix at plant) were used as proxies:. This resulted in 0.18 kg CO_2eq per kilogram.

$$CC_{polim} = CC_{PP} - CC_{prop_p} \qquad (Eq. 2)$$

Finally, the emissions of producing PP granulates in China were calculated as defined in equation 3; and resulted in 1.90 kg CO_2eq per 1 kg of PP granulates.

$$CC_{PP_{CN}} = CC_{prop_r} * EF + CC_{polim} \qquad (Eq. 3)$$

The next step was to assess the climate change impact of manufacturing PP film from PP granulates (CC_{GtoF}). Since no specific data was available on this process, it was calculated as the subtraction of the climate change of granulates manufacture (CC_{PP}) from the climate change impact of producing film (which consider the extraction of raw material to the extrusion of the film; CC_{RMtoF}) (Equation 4). In this case, German data were available (two processes: DE- Polypropylene Film (PP) without additives and DE-Polypropylene granulate (PP)), which were used as proxies. The climate change impact of the process of producing the film from PP granulates was 0.39 kg CO_2eq. Adding these emissions to the ones of producing 1kg of PP granulates, the climate change impact of manufacturing PP Film within the Chinese context was estimated to be 2.29 kg CO_2 eq per kg of PP film.

$$CC_{GtoF} = CC_{RMtoF} - CC_{PP} \qquad (Eq. 4)$$

Regarding the processes used to model the polyethylene-based packaging and the bamboo chopticks, they are listed in table 3. Table 4 shows the energy consumption to produce the different packaging items, and their reference.

Table 3: GaBi Processes used for food packaging materials

Material	**GaBi Process**
PE film	RER: Polyethylene film (PE-LD) PlasticsEurope
HDPE granulates	EU-28: Polyethylene, HDPE, granulate PlasticsEurope
Bamboo	CN: Natural bamboo fibres ts
Silicone	EU-28: Silicone sealing compound (EN15804 A1-A3)
Electricity	CN: Electricity grid mix ts
Heat	CN: Thermal energy from natural gas

Table 4: Energy consumption to produce the plastic items for the studied Chinese delivery meal

Packaging component	**Energy use packaging component [J / g]**	**Reference**
Single-use PP food container	5.43 (electricity) and 0.002 (heat)	Gallego-schmid et al. (2019)
Reusable PP food container	5.86 (electricity) and 0.002 (heat)	Gallego-Schmid et al. (2019)
HDPE carrier bag	0.03 (electricity)	Civancik-Uslu et al. (2019)
Reusable PP carrier bag	0.08 (electricity)	MEFD, 2018
Bamboo chopsticks	0.26 (heat)	Wang (2012)

3.2.2. Transport

Once the packaging is produced, it is assumed to be transported 400km to the restaurant by a 10t diesel-truck (Table 5). To deliver the food menu to the consumer, an electric motorbike was assumed, as reported by Maimati et al. (2018). Due to the lack of data on this type of transport in the GaBi database, this study considered the use of 2.1 kWh per 100 km (Cherry et al., 2010) to transport five meals. It is assumed that the electric motorbike is powered by the electricity grid mix.

Table 5: Data to model the type of transport and distances to distribute the food packaging to the restaurant and for the delivery

Transport	Distance (km)	Data
From factory to restaurant	400	Process of GaBi database: GLO: Truck, Euro 0 - 6 mix, 12 - 14t gross weight / 9,3t payload capacity ts <u-so>
From restaurant to home	2.5	Electric bike (2.1kWh/100km; Cherry et al., 2010)

3.2.3. Reuse

This stage was only considered for the three scenarios of reusable packaging. For these cases, a hypothetical take-back system was designed, which was based on the placement of collection points within the area where the delivery platforms operate. The delivery drivers' workforce of the food delivery platform were in charge of collecting and transporting the reusable packaging back to the restaurants. Moreover, the same distance and type of transport as for the transport for the food delivery meal (from the restaurant to the consumer) was considered. Restaurants are in charge of cleaning and stocking the reusable items.

This study assumes that the reusable food container has a lifespan of 50 uses, as reported by Accorsi et al. (2014), and that they are automatically washed. To estimate the energy consumption for washing, data from Arendorf et al, (2014) was used. Assuming that 25 food containers fit in a dishwasher for 12 place settings, this study estimated an energy consumption of 0.204 MJ per container. Data on the use of detergent, rinsing agent and water were based on Gallego-schmid et al. (2018). Concerning the reusable bag, it is assumed a lifespan of 20 uses, as reported by Civancik-Uslu et al. (2019), and 18.14 liters of water, 0.03 MJ and 4.2 g of detergent was considered to be used to wash one kg of reusable bags (Yuan et al., 2016).

3.2.4. End-of-Life scenarios

This study considers three disposal scenarios for both, the single-use (S-) and the alternative reusable (R-) packaging systems for food delivery service (Table 6). The first type of scenarios (-CRec) represent the current percentage of waste management (landfilling, recycling and incineration) of plastics in China (NBSC, 2020); and no recycled content was considered in the packaging components production. For the second type of scenarios (-35Rec), a policy target in recycling rates of municipal waste was applied. In this regard, the minimum target of increasing the recycling rate to at least 35% (MHURD, 2020) was considered. For the third type of scenarios (-35Rec-50RC), in addition to the recycling target, it is assumed that half of the weight of all the packaging components were produced with recycled material.

Table 6: Distances and transport used in this study

	Scenarios	MSW treatment (%)			Recycled content
		Recycling	Landfill	Incineration	
Single-use packaging	S-CRec	0%	47.5%	52.5%	0%
	S-35Rec	35%	31%	34%	0%
	S-35Rec-50RC	35%	31%	34%	50%
Reusable packaging	R-CRec	0%	47.5%	52.5%	0%
	R-35Rec	35%	31%	34%	0%
	R-35Rec-50RC	35%	31%	34%	50%

Besides crediting the energy production from incineration, this study also credits the climate benefits of recycling. In the case of the recycling target scenarios (S-35Rec and R–35Rec), they were credited by the total amount of granulates that resulted from the recycling process. For the scenarios with recycling targets and recycled material (-35Rec-50RC), the credit was calculated as the percentage of material being recycled that corresponds to the virgin proportion of the packaging. Thus, no credits for the recycled materials used in the production of the items were considered. To estimate the amount of material to be credited, the loss of quality of the recycled granulates was considered, which is defined as:

$$G_c = G * (1 - RC) * \frac{Q_r}{Q_v} \qquad (Eq.\ 1)$$

Where,

G_c: amount of virgin material to be credited

G: amount of granulates

RC: percentage of recycled content

$\frac{Q_r}{Q_v}$: quality ratio between the quality of the secondary (recycled) granulate at the point of substitution (Q_r) and quality of the primary (virgin) granulate (Q_v). Values for this ratio were retrieved from Nessi (2018): 0.9 for PP and HDPE; and 0.75 for LDPE film.

Table 7 summarizes all the processes used to model the different waste management treatments within the Chinese context.

Table 7. Sources of the data used to model the waste treatments of the different packaging items

Type of material	Waste treatment	Reference or GaBi process
PE and PP	Landfill	Chen et al. (2019)
	Incineration	Chen et al. (2019)
	Recycling	Chen et al. (2019)
Chopsticks to landfill	Landfill	CN: Landfill (Municipal household waste)
	Incineration	CN: Landfill (Municipal household waste)
	Composting	Hong and Zhaojie, 2010

3.4. Sensitivity analysis of the reusable packaging system

Due to the importance of the weight of packaging when assessing their environmental performance (Blanca-Alcubilla et al., 2020), and the high weight assumed in this study for the reusable food packaging items, this study performed a sensitivity analysis by reducing 20% the reusable packaging weight. Moreover, two other sensitivity analyses were done; one considering the lifespan of the food container (reducing it by 20%) and the other one considering the energy consumed to wash the reusable packaging items (halving the energy consumption).

4. Results & discussion

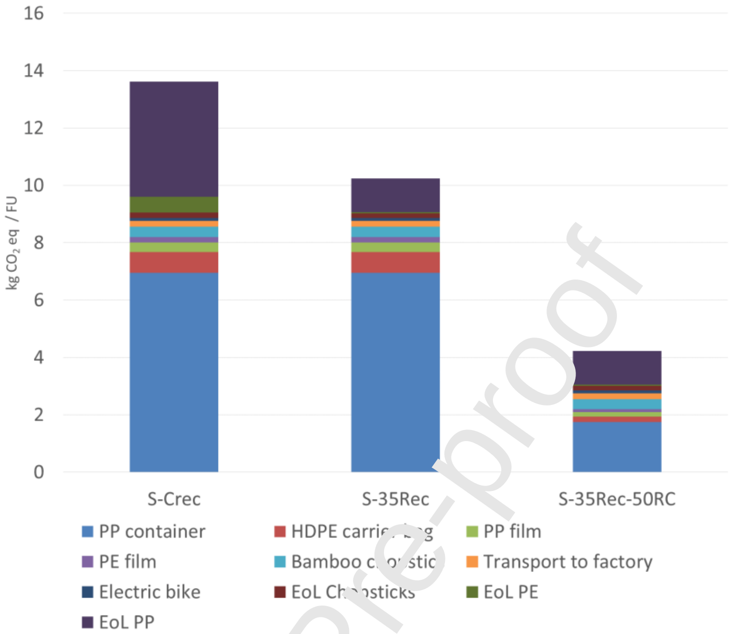
The food packaging for 50 current standard delivery menus of a Xijiade restaurant emit 13.61 kg CO_2eq (S-CRec: Fig.3a). The manufacture of the packaging is the process with the largest contribution (63%), followed by the end-of-life (EoL; 35%). Among the packaging components, the single-use food containers are the largest emitters (6.11 kg CO_2eq per functional unit (FU)), followed by the other PP-based packaging (0.84 kg CO_2eq per FU) and the HDPE single-use carrier bags (0.73 kg CO_2eq per FU). When the recycling rates are raised to 35% (S-35Rec), the CO_2eq emissions of the food delivery packaging are reduced by 16%, due to the production of recycled granulates. In addition, if the recycled content of the packaging components increases up to 50% (S-35Rec-50RC), the overall impact is reduced by 60%, since the production of all the packaging components is lower.

The reusable food packaging with current recycling rates (R-CRec; Fig.3b), for the studied functional unit, emits 5.05 kg CO_2eq; 54% less than the current situation (S-CRec). In this case, the use stage is the largest contributor (63%) to climate change, due to the energy consumed for washing the reusable packaging. The manufacture of the food packaging contributes 28%. Hence, when the recycling rates and/or the recycled content in the packaging are increased, no large climate benefits are observed for R-35Rec and R-35Rec-50RC. Instead, strategies that aim to increase the energy efficiency of the use stage may have larger benefits. This was studied within the sensitivity analysis. By halving the energy consumption (50EN) for washing the reusable food container, the emissions would be cut by 24% (Fig.4).

The two types of packaging system significantly differ in weight: 86.4 g of single-use food packaging *vs* 241.3 g of reusable food packaging. In this regard, performing a sensitivity analysis based on the weight of the reusable food packaging was essential to evaluate the potential improvements. The results show that total emissions decrease by 18% with 20% less weight of the reusable food packaging (20PW in Fig. 4). In addition, lowering the lifespan (20LS) of the food container by 30% would increase the emissions by 14%.

This article is the first one assessing the climate change impact of food delivery waste packaging in China with a cradle-to-grave approach. Xie et al. (2020) reported the emissions of this type of packaging (about 150 g CO_2 per food order in first-class cities, such as Beijing), but they did not consider the end of life treatments, which is an important life cycle stage as shown here as well as by Gallego-schmid et al.(2020), who concluded the important contribution of the end of life stage as well as of the raw materials extraction and the manufacture to the environmental impacts. Moreover, the packaging items considered within the current study are the most common ones: plastic bags, wooden chopsticks and plastic boxes (Liu et al., 2020). Concerning the reusable food container and the carrier bag, further investigation is needed since the present study used standard ones based on previous research. In particular, the design of lighter reusable packaging items seems crucial to reduce even further the climate change impact. Moreover, the size of the food container can influence the food being wasted. Xu et al. (2020) found that bigger food portions in food-away-from-home consumption increases the food waste. Finally, the use of recycled material can play a crucial role to reduce environmental impacts (as also found by Arunan and Crawford (2021) and Gallego-schmid et al. (2020)). Nevertheless, this is an on-going debate since post-consumer recycled plastic cannot be used to produce primary food packaging due to safety reasons for food contact (Matthews et al., 2021), and no definition of food grade post-consumer plastics has been yet defined in China (Hui, 2020).

(a)



(b)

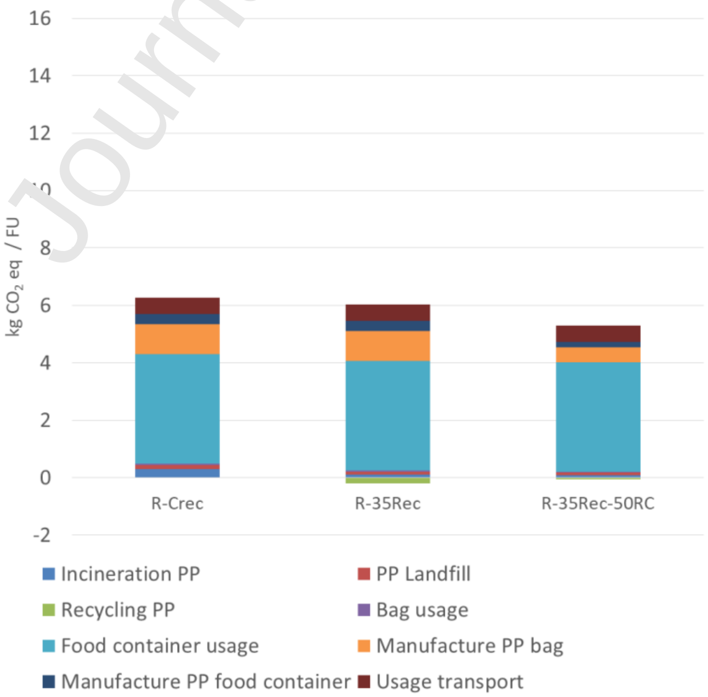


Figure 3: Climate Change impact (kg CO_2 eq) per functional unit of the study for a) the single-use and (b) the reusable food packaging scenarios

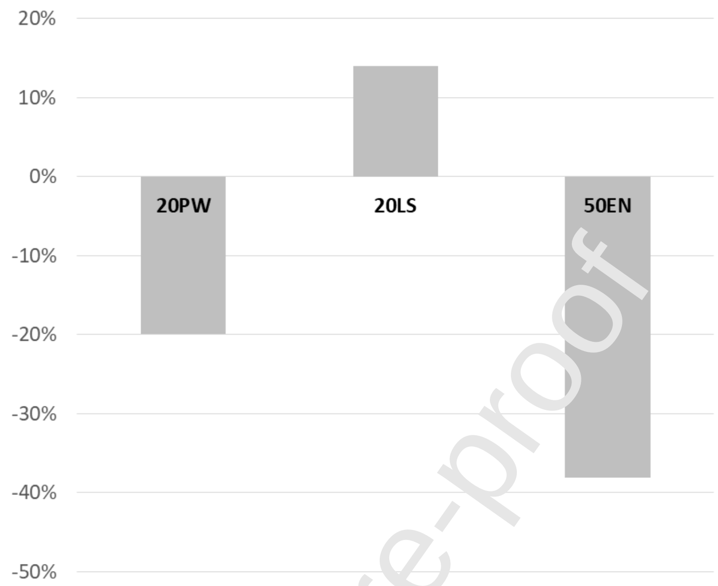


Figure 4. Relative difference of the Climate Change impact for the four sensitivity analysis scenarios

As Chakori et al. (2021) expresses regarding drivers on the use of single-use plastics, the food packaging problem is a food system problem, not a packaging problem. To make possible a reduction of packaging waste, structural changes in the supply chains, consumption habits and policy have to be made. Policy has determining implications on targeting single-use packaging systems. Plastic bags bans have occurred in different countries across the world, starting in South Africa (2002), India (2002-2005), Canada (2007-2010) and other countries (Xanthos and Walker, 2017). Legislation has been extended in a number of single-use plastic items across countries. The European Union has set up the Directive 2019/904 with the pursuit to ban not only disposable packaging but also plastic cutlery, coffee cups and straws (Lozano Cutanda and Poveda, 2019). The Chinese scene differs from Europe but is not far away. The communication on 1st January 2021 (Zhang, 2021), about government ban towards single-use straws that are sold in restaurants and shops across the country and the plan to ban non-degradable bags in all cities by 2022, are examples of the direction they aim to take. On top of this, governments and institutions can go further to enforce a transition towards the circular economy by applying strategies of eco-modulation, such as the case of EPR (extended producer responsibility) in France, which creates incentive schemes for eco-design (Micheaux and Aggeri, 2021).

Overall, the two underlying findings of this paper are the potential benefits of (1) the already targeted recycling rate of 35% and (2) of the introduction of reusable systems. Based on these findings, changes in the Chinese delivery sector are recommended. In terms of reusable packaging strategies and initiatives, we highlight the transition to a product-service economy (Vezzoli et al., 2017). The product, meaning the packaging, is seen as the object of the service, and therefore the production and consumption phases become more efficient and the value of the asset is optimized; delivering a quality product, with a continuous business-consumer relationship. Servitizing is presented as a viable solution of circular economy systems, with the potential to reduce by 30% the costs of servitizised companies (Baines et al., 2014). In this line, further research is needed to assess and compare the life-cycle costs associated with single-use and reusable packaging systems.

5. Conclusions

This study highlights three issues of the current Chinese food delivery sector. First, the importance of the climate change impact associated with the packaging waste generated by the sector. Based on the results from this study, and assuming an average consumption frequency of four times per week and a total number of users of 263.1 Million in 2019 (Statista, 2019), the single-use packaging involved in the Chinese food delivery sector in 2019 emitted about 13.35 million tons of CO_2eq. By taking into account the user growth forecast from Statista (2019), the estimated emissions would be 44% higher in 2024. Second, this article demonstrates the potential climate change benefits of: (1) achieving the targeted 35% recycling rate, (2) using reusable food packaging and (3) using recycled material for food packaging. To be able to put them into action, three key stakeholders must be involved: (1) the government to ensure the collection and the recycling of plastic waste, (2) the citizens to properly sort the waste, and, (3) the companies (i.e., delivery platforms and restaurants) to improve their current food delivery packaging systems. In this regard, the Chinese government is advancing with the relatively new policy on MSW sorting; but policies that stimulate and make possible further commitment of companies to establish sustainable initiatives are needed. Finally, further research on the economic impacts of introducing the new food delivery packaging, as well as on consumers' perception are recommended.

Acknowledgments

The authors are grateful for the funding of the Spanish Ministry of Science and Competitiveness, grant number KAIROS-BIOCIR Project PID2019-104925RB-C33 (AEO/FEDER, UE).

The authors are responsible for the choice and presentation of information contained in this paper as well as for the opinions expressed therein, which are not necessarily those of UNESCO and do not commit this Organization.

References

Accorsi, R., Cascini, A., Cholette, S., Manzini, R., Mora, C., 2014. Economic and environmental assessment of reusable plastic containers : A food catering supply chain case study. Int . J . Prod. Econ. 152, 88–101. https://doi.org/https://doi.org/10.1016/j.ijpe.2013.12.014

Arendorf, J., Bojczuk, K., Sims, E., Menkveld, R., Golsteijn, L., Gaasbeek, A., Boyano, A., Medyna, G., Kaps, R., 2014. Revision of European EU Ecolabel Criteria for Detergents for Dishwashers.

Chen, F., Chen, Z., 2021. Cost of economic growth: Air pollution and health expenditure. Sci. Total Environ. 755, 142543. https://doi.org/10.1016/j.scitotenv.2020.142543

Chen, X., Geng, Y., Fujita, T., 2010. An overview of municipal solid waste management in China. Waste Manag. 30, 716–724. https://doi.org/10.1016/j.wasman.2009.10.011

Chen, Y., Cui, Z., Cui, X., Liu, W., Wang, X., Li, X., Li, S., 2019. Life cycle assessment of end-of-life treatments of waste plastics in China. Resour. , Conserv. Recycl. 146, 348–357.

Chen, Z., Chen, S., Liu, C., Nguyen, L.T., Hasan, A., 2020. The effects of circular economy on economic growth: A quasi-natural experiment in China. J. Clean. Prod. 271, 122558. https://doi.org/10.1016/j.jclepro.2020.122558

Cheng, J., Shi, F., Yi, J., Fu, H., 2020. Analysis of the factors that affect the production of municipal solid waste in China. J. Clean. Prod. 259, 120808. https://doi.org/10.1016/j.jclepro.2020.120808

Cherry, C.R., Weinert, J.X., Xinmiao, Y., 2010. Comparative environmental impacts of electric bikes in

China. Transp. Res. Part D 14, 281–290. https://doi.org/10.1016/j.trd.2008.11.003

Civancik-uslu, D., Puig, R., Hauschild, M., Fullana-i-palmer, P., 2019. Life cycle assessment of carrier bags and development of a littering indicator. Sci. Total Environ. 685, 621–630. https://doi.org/10.1016/j.scitotenv.2019.05.372

Gallego-schmid, A., Manuel, J., Mendoza, F., Azapagic, A., 2020. Environmental impacts of takeaway food containers. J. Clean. Prod. 211, 417–427. https://doi.org/https://doi.org/10.1016/j.jclepro.2018.11.220

Gallego-schmid, A., Mendoza, J.M.F., Azapagic, A., 2018. Improving the environmental sustainability of reusable food containers in Europe. Sci. Total Environ. 628–629, 979–989. https://doi.org/10.1016/j.scitotenv.2018.02.128

Hao, Y., Liu, H., Chen, H., Sha, Y., Ji, H., Fan, J., 2019. What affect consumers' willingness to pay for green packaging? Evidence from China. Resour. Conserv. Recycl. 141, 21–29. https://doi.org/10.1016/j.resconrec.2018.10.001

Hong, J., Li, X., Zhaojie, C., 2010. Life cycle assessment of four municipal solid waste management scenarios in China. Waste Manag. 30, 2362–2369. ttps://doi.org/10.1016/j.wasman.2010.03.038

ISO 14044, 2006. Environmental management - Life Cycle Assessment - Requirements and Guidelines.

Ji, D.J., Zhou, P., 2020. Marginal abatement cost, air pollution and economic growth: Evidence from Chinese cities. Energy Econ. 86. https://doi.org/10.1016/j.eneco.2019.104658

Ketelsen, M., Janssen, M., Hamm, U., 2020. Consumers' response to environmentally-friendly food packaging - A systematic review. J. Clean. Prod. 254. https://doi.org/10.1016/j.jclepro.2020.120123

Li, J., Song, G., Ma, S., Wan, B., Batlle-Bayer, L., Zhang, D., Zhang, L., Fullana-i-Palmer, P., Zhang, S., 2020. Dietary acculturation generates virtual carbon flow: The overlaid effects of geographically varied dietary patterns and population migration in urban and materials-flowing China. J. Clean. Prod. 276. https://doi.org/10.1016/j.jclepro.2020.124283

Liang, W., Yang, M., 2019. Urbanization, economic growth and environmental pollution: Evidence from China. Sustain. Comput. Informatics Syst. 21, 1–9. https://doi.org/10.1016/j.suscom.2018.11.007

MEFD, M. of E. and F. of D., 2018. Life Cycle Assessment of grocery carrier bags. The Danish

Environmental Protection Agency.

Ministry of Housing and Urban-Rural Development(MHURD), 2000. Announcement of Housing Waste Classification and Collection in Pilot Cities, 2000. Available online: https://www.lawxp.com/statute/s437248.html. (accessed on 5th February, 2021, in Chinese)

Ministry of Housing and Urban-Rural Development of China(MHURD). Views on Further Promoting the Housing Waste Classification, 2020. Available online: http://www.gov.cn/zhengce/zhengceku/2020-12/05/5567136/files/36069741fd91433f9dd9426b26eeae8b.docx . (Accessed on 5th February 2021, in Chinese)

National Bureau of Statistics (NBSC). China Statistical Yearbook 2020. Available online: http://www.stats.gov.cn/tjsj/ndsj/2020/indexeh.htm. (accessed on 2nd February 2021, in Chinese)

Nessi S., Bulgheroni C., Garbarino E., Garcia-Gutierrez P., Orveillon G., Sinkko T., Tonini D., Pant R. Draft report for stakeholder consultation (part II): - Selection of relevant plastic articles - Screening LCA case studies. https://eplca.jrc.ec.europa.eu/permalink/PLASTIC_LCI/Plastic_LCA_Report%20II_2018.11.20.pdf

Rundh, B., 2005. The multi-faceted dimension of packaging: Marketing logistic or marketing tool? Br. Food J. 107, 670–684. https://doi.org/10.1108/00070700510615053

Song, G., Zhang, H., Duan, H., Xu, M., 2018. Packaging waste from food delivery in China ' s mega cities. Resour. Conserv. Recycl. 130, 226–227. https://doi.org/10.1016/j.resconrec.2017.12.007

Wang, H., Jiang, C., 2020. Local nuances of authoritarian environmentalism: A legislative study on household solid waste sorting in China. Sustain. 12. https://doi.org/10.3390/su12062522

Wang, H., Liu, X., Wang, N., Zhang, K., Wang, F., Zhang, S., Wang, R., Zheng, P., Matsushita, M., 2020. Key factors influencing public awareness of household solid waste recycling in urban areas of China: A case study. Resour. Conserv. Recycl. 158. https://doi.org/10.1016/j.resconrec.2020.104813

Wang, W.Q., 2012. 2012 LCA of Competing Product Systems.

Wu, Z., Zhang, Y., Chen, Q., Wang, H., 2020. Attitude of Chinese public towards municipal solid waste sorting policy: A text mining study. Sci. Total Environ.

https://doi.org/10.1016/j.scitotenv.2020.142674

Xu, Q., Xiang, J., Ko, J.H., 2020. Municipal plastic recycling at two areas in China and heavy metal leachability of plastic in municipal solid waste. Environ. Pollut. 260, 114074. https://doi.org/10.1016/j.envpol.2020.114074

Ye, Q., Anwar, M.A., Zhou, R., Asmi, F., Ahmad, I., 2020. China's green future and household solid waste: Challenges and prospects. Waste Manag. 105, 328–338. https://doi.org/10.1016/j.wasman.2020.02.025

Yuan, Z., Zhang, Y., Liu, X., 2016. Life cycle assessment of horizontal-axis washing machines in China. Int. J. Life Cycle Assess. 21, 15–28. https://doi.org/10.1007/s11367-015-0993-5

Zhou, M.H., Shen, S.L., Xu, Y.S., Zhou, A.N., 2019. New policy and implementation of municipal solid waste classification in Shanghai, China. Int. J. Environ. Res. Public Health 16. https://doi.org/10.3390/ijerph16173099

Zhou, Y., Li, X., Liu, Y., 2020. Land use change and driving factors in rural China during the period 1995-2015. Land use policy 99, 105048. https://doi.org/10.1016/j.landusepol.2020.105048

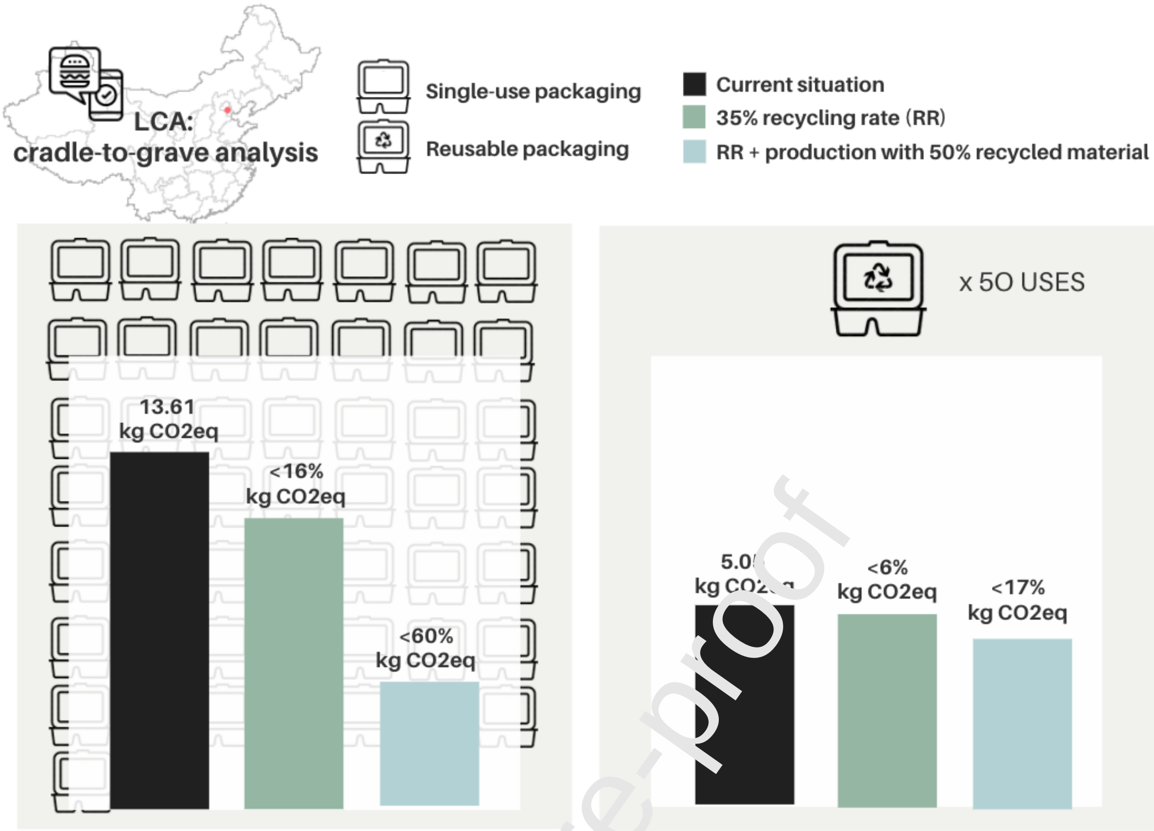
Credit author statement

Laia Camps Posino and Laura Batlle-Bayer: Writing - original draft, Methodology, Conceptualization, Formal analysis. Guobao Song: Investigation and reviewing. Huimin Quin: Data gathering. Ramón Xifré: Investigation and reviewing. Rubén Aldaco: Investigation and reviewing, Pere Fullana-i-Palmer: Conceptualization, Supervision.

Declaration of interests

☒ 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:



Graphical abstract

Highlights

- The impact of single-use food delivery packaging on climate change is assessed.
- The manufacture of the packaging contributes to 63% of current emissions
- End-of-life waste management is responsible of 35% of the emissions
- Introducing reusable packaging reduces 54% of current emissions
- Higher recycling rates and recycled content are also key to reduce emissions.