Greenhouse gas emissions associated with food packaging for online food delivery services in Australia

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ABSTRACT

The food service industry has seen the advent of online food delivery services (OFDS) due to the development of online retailing and a rise in mobile phone usage. OFDS are growing in popularity around the world and are increasing the use of take-away food packaging and the subsequent environmental implications from its production and disposal. While a large number of studies have considered packaging-related environmental effects, there has been limited focus on the effect of OFDS-related packaging demand on the environment, particularly in relation to greenhouse gas emissions. This study quantifies the packaging-related greenhouse gas emissions associated with OFDS orders. Data on food packaging for a range of the most popular cuisines delivered by OFDS in Australia were collected from restaurants. The assessment was performed using the Packaging Impact Quick Evaluation Tool, which showed that the packaging-related greenhouse gas emissions for a single order ranges from 0.15 to 0.29 kg CO_2e, depending on packaging type. Of this, production of packaging raw materials contributes at least 50%. With the expansion of the OFDS sector, the annual greenhouse gas emissions associated with OFDS food packaging in Australia is predicted to grow by 132% by 2024. This preliminary examination of the greenhouse gas emissions implications of food packaging production and disposal associated with the Australian OFDS industry adds to the limited knowledge in this area and provides valuable insights into the greenhouse gas emissions implications of the emerging global OFDS industry.

KEYWORDS

Life cycle assessment; food packaging; online food delivery services; greenhouse gas emissions.

1. INTRODUCTION

The food service industry has undergone vast changes in the past four decades, influenced by and influencing consumer demands, technological advancements and lifestyles (Sim et al. 2007). A recent change in the industry has been the development of online food delivery services (OFDS) - internet platforms that allow customers to purchase food from partnering restaurants through web applications, and have it delivered to their homes. The advent of OFDS changes the food sector considerably due to the increase in e-commerce and shift from traditional modes of food preparation (home cooking, semi-prepared home cooking and in-restaurant meals) to food delivery (Behzad et al. 2014). As more regions of the world undergo urbanisation and as everyday life gets more fast paced, the use of OFDS is predicted to grow (Lucas & Zhang 2018; Vuong 2018). The rapid uptake of OFDS in the last decade has been attributed to factors such as growth of the internet and e-commerce, hedonic motivation, increasing household discretionary income, and convenience and time-saving in increasingly busier lives (Blumtritt 2018; Song et al. 2018; Yeo, Goh & Rezaei 2017).

In Australia, online food delivery (by restaurants themselves and OFDS) has a penetration rate of 30%, with about 7.3 million active users (Blumtritt, 2018). OFDS are present in Australia's major cities, including Sydney, Melbourne, Adelaide, Brisbane and Perth, with recent expansion to smaller cities, such as Hobart and Bendigo (Vuong 2018). The Australian market for OFDS comprises three major companies as of 2018: Just Eat (Acquisitions) (established 2007; market share 44.9%), Deliveroo Australia (established 2015; market share 28%), and Uber Australia (established 2016; market share 26.6%). The industry has seen an annual growth of 72% over the last 5 years, with a predicted annual growth rate of 15.4% in the coming five years (Vuong 2018). Figure 1 shows the most popular cuisines ordered by Australians through OFDS. The category of 'other' includes drinks, desserts, and other international cuisines.

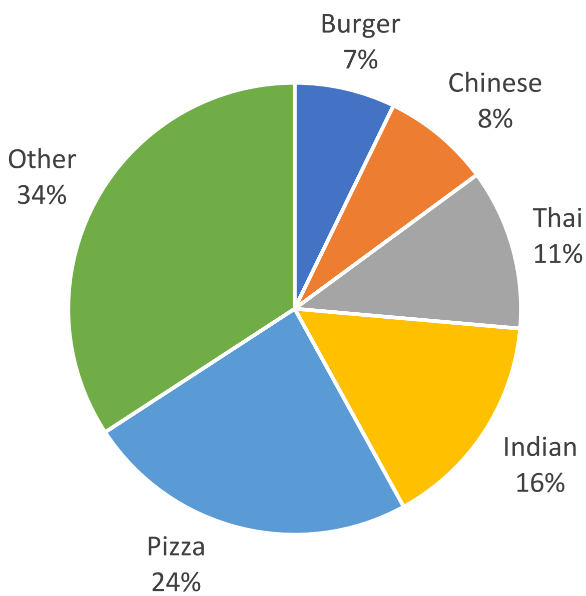

Figure 1 Proportion of OFDS orders in Australia, by cuisine (Vuong 2018)

Online express deliveries, including OFDS, require the products to be contained in delivery packages for their protection. In 2019, the global market volume for containers and packaging consisted of 1.9 billion packaging units which is predicted to increase to 2.1 billion units by 2023 due to the increase in spending on organised retail and packaged goods (MarketLine 2019a, 2019b). The food service industry is a significant driver of this growth, as packaging is an important component of a food product in all stages of the food supply chain (Olsson, Petterson & Jönson 2004). Food packaging serves the following functions: product protection and containment, product use, product promotion, and facilitation of recycling (Orzan et al. 2018). The most common materials used in food packaging are glass, metals, plastic, paperboard and flexible film/paper/foil. Of these, while glass and metal are the most used materials by volume, the lightweight paper and plastic materials are the most significant materials for the food packaging sector by number (Piergiovanni & Limbo 2016).

1.1. Environmental effects

The food supply chain is one of the major contributors to global environmental issues such as land use change, biodiversity loss, climate change, and eutrophication (Molina-Besch, Wikström & Williams 2019). The farm-to-mouth food sector has effects on the environment across all stages of its life cycle - agriculture, processing, transport and waste generation (Sonesson et al. 2005; Behzad et al. 2014). An increase in OFDS use will impact all stages of the food supply chain and will change the magnitude of the effects that the food industry has on the environment. With OFDS specifically, excluding the food production and last mile delivery impacts, significant environmental effects have been suggested to occur from food packaging production and waste generation (Yi et al. 2017; Song et al. 2018).

Large quantities of natural resources (such as energy and raw materials) are used to produce packaging, of which two-thirds are used by the food industry (Orzan et al. 2018; Yi et al. 2017; Piergiovanni & Limbo 2016). This demand for energy and raw materials causes a strain on the environment through the depletion of resources and release of greenhouse gas (GHG) emissions. Packaging production and disposal can also lead to the release of a wide range of pollutants into the environment (Fan et al. 2017). An increase in the use of plastic packaging due to its low production costs and durability is of particular concern, as plastic pollution has emerged as a significant environmental problem in recent years (MarketLine 2019b). Studying the environmental effects of e-commerce packaging is an emerging field of study, with many studies originating from China. Duan et al. (2019) found that 7. 8 million metric tonnes of packaging waste was produced from e-commerce in China. Song et al. (2018)

estimated that 1.5 million tonnes of this was from food delivery, comprising predominantly of plastic bags, utensils and containers, paper slips and wooden chopsticks.

A life cycle assessment (LCA) can be used to quantify the environmental effects associated with packaging production and disposal based on the International Organization for Standardization (ISO) (2006a; 2006b) framework. This approach enables an analysis of the environmental flows occurring across the entire life cycle of a product, from raw materials acquisition to final disposal. Using this approach, Fan et al. (2017) estimated that the production and delivery of express packaging materials in China contributed to 1.2 million tonnes of carbon dioxide (CO_2) emissions in 2015. An LCA of express delivery packaging by Yi et al. (2017) quantified environmental impacts in terms of global warming, acidification, photochemical oxidation and eutrophication, and energy consumption. They found that the production and usage stages of the packaging life cycle contribute greatest to its environmental effects amounting to 79% of its life cycle energy use. Su et al. (2020) estimated that GHG emissions from express delivery packaging in China increased from 0.3 Mt in 2007 to 13.2 Mt in 2018. Specific to OFDS, Jia et al. (2018) estimated that 1.68 million tonnes of OFDS packaging waste was generated in 2016 in China, which needed 58.89 GWh of electricity for processing, and emitted 73.89 Gt of CO_2 equivalent (CO_2e) emissions. Liu et al. (2020) conducted a comprehensive study of OFDS packaging in the Jing-Jin-Ji region of China, assessing waste quantities, and environmental impacts across 18 impact categories, which also showed considerable environmental effects from OFDS packaging production and disposal.

Due to contamination from food particles, food packaging waste is not easily recyclable and often ends up in landfill, incineration, or is illegally dumped (Song et al. 2018). Of all the end-of-life waste management methods, incineration has been shown to produce the greatest environmental damage, as opposed to recycling which can help to reduce the manufacturing-related energy use of new packaging by up to 62% (Yi et al. 2017). Vitale et al. (2018) have analysed the process of separating and recovering materials from contaminated food packaging. They found that this can be a viable option for reducing the environmental effects associated with food packaging disposal, compared to landfilling these materials. This not only reduces disposal related environmental effects, but may also help to further reduce the environmental effects associated with new packaging production through a more circular approach to the packaging life cycle.

The OFDS are aware of the waste issue created by their services. The company Deliveroo in Australia has started a closed loop reusable container scheme in partnership with Returnr, where meals are delivered in a stainless steel container and can be returned to Returnr locations for a refundable fee. While OFDS in Australia are pledging to consider sustainability in their actions such as using more eco-friendly packaging materials, it is at present not common or highly visible.

1.2. Consumer behaviour

Every actor in the food supply chain influences its environmental performance and consumer attitudes are an important factor to consider in understanding the environmental performance of food supply chains (Behzad et al. 2014; Mancini, Marchini & Simeone 2017). Consumer behaviour in the product use and disposal stages is a significant driver of the environmental effects associated with a product, with recycling of waste and diverting from landfill having the ability to contribute to significant emission reductions (Vasileva & Ivanova 2014). Sorting of waste at the source, as opposed to the waste management facility, is more effective as it is cheaper and produces cleaner and higher quality materials, which increases material recycling (Nemat et al. 2019). While waste management interventions have focused on engineering aspects such as manufacturing, recycling and production efficiency, the biggest inhibitor to increasing material recovery and recycling rates has been shown to be cultural and behavioural (Clark, Trimingham & Wilson 2020).

Various studies have analysed consumer packaging disposal behaviour to identify the driving and limiting factors for recycling. According to the theory of planned behaviour, the main psychological factors affecting consumer disposal behaviour are attitude (positive/negative self-perception of performing the behaviour), perceived behavioural control (self-perception of one's ability to perform the behaviour), as well as subjective norms (social pressure to perform the behaviour) (Khan et al. 2019; Nemat et al. 2019). Demographic and external factors such as income level, education level, gender, age and underdeveloped waste infrastructure influence the above psychological factors (Cichocka, Krupa & Mantaj 2020; Vasileva & Ivanova 2014). Lack of knowledge regarding environmental effects and recycling is a barrier to recycling, coupled with confusion regarding the packaging labelling and recycling systems. Lower income and education levels also influence consumer attitudes, with these demographics found to be 'indifferent' to environmentally conscious behaviour

(Vasileva & Ivanova 2014). In those who are not indifferent to recycling, inconvenience is the main factor affecting recycling behaviour, in terms of time, effort, space and packaging attributes. The main packaging attributes that inhibit recycling behaviour include mixed materials in packaging, size, material, and need for emptying and cleaning contaminants.

While there is a general increase in environmental awareness among consumers regarding their purchase practices, there is an awareness-action gap that isn't translating environmental concern into better packaging and waste management behaviour (Orzan et al. 2018). Therefore, it is essential that packaging and waste systems consider consumer behaviour in their designs for environmental efficiency. Packaging that is 'easy to empty, easy to clean, easy to fold, easy to separate, easy to reseal, and [has] availability of information on how to sort' facilitates proper sorting (Nemat et al. 2019).

1.3. Aim and scope

Since the OFDS industry is relatively young, research and discourse around the industry and its effects on the environment are scarce. The predicted expansion of this industry in the coming years highlights the need to monitor its processes and effects. Further, data on consumer behaviour regarding OFDS is scarce and is required in order to inform decision-making as well as educational and policy responses. The aim of this study was to quantify the packaging-related GHG emissions of the OFDS industry. The OFDS industry is complex and involves multiple actors, including industry firms managing bookings, food providers preparing meals, delivery personnel and customers. There are multiple sources of GHG emissions across the OFDS supply chain, however the focus of this study is on the GHG emissions released from the production and disposal of food packaging for OFDS orders.

This paper is structured as follows: Section 2 provides the research approach used in this study. Section 3 provides the results obtained from the quantification of GHG emissions associated with food packaging for OFDS orders. Section 4 discusses the significance of the obtained results for the OFDS and packaging industries, and concludes the paper.

2. RESEARCH APPROACH

The research approach used in this study is shown in Figure 2. To evaluate the GHG emissions associated with the production and disposal of take-away packaging used by OFDS, a life cycle assessment (LCA) approach was used as it enables a comprehensive assessment of a product across all stages of its life cycle (International Organization for Standardization

(ISO), 2006a). To understand OFDS consumer behaviour, a survey was conducted to obtain data on OFDS use and packaging disposal practices.

This section first describes the approach used to study OFDS consumer behaviour, followed by the approach used to quantify the GHG emissions associated with the OFDS packaging (including the goal and scope of the study, functional unit, reference flows, data quality requirements, data collection, and life cycle impact assessment method).

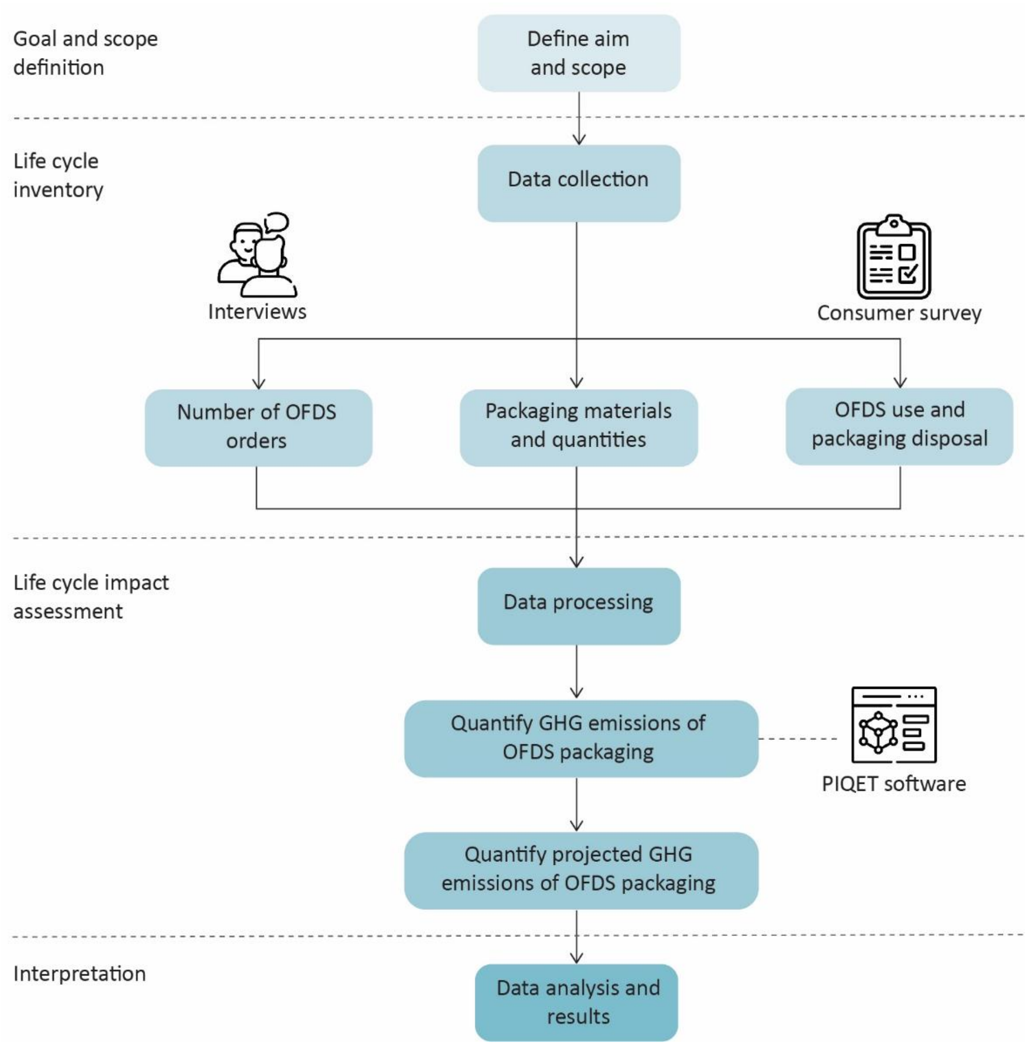

Figure 2 Research approach

2.1. Consumer behaviour study

A consumer survey was conducted to determine the most common disposal practices of OFDS packaging, helping inform the assessment of end-of-life related GHG emissions of these packaging materials. A number of additional questions were asked in order to ascertain the most commonly used OFDS and frequency of use, supplementing data collected from OFDS providers and restaurants. The survey was conducted online using Google Forms. While an online survey was used in the hope of increasing the number of respondents by providing respondents anonymity while answering questions related to personal behaviour (avoiding potentially altered responses due to the researcher's presence), it is acknowledged that this approach limits the ability to obtain additional behavioural data (Williamson & Johanson 2017). The targeted population was adults aged 18-45 living in Australia that have used OFDS, as Vuong (2018) states that this age group constitutes 80% of the customer base of OFDS. Selection of participants for the survey was done by availability and snowball sampling, with stratified sampling also used to filter out potential responses from people outside the targeted survey sample. The target population size was assumed to be 2,400,000, based on Vuong's figure of 80% above and a total of 3,000,000 Australian OFDS users in 2018 (Statista, 2020). The survey was circulated through three online platforms that were considered ideal for sourcing suitable participants - Facebook, LinkedIn and WhatsApp. Participants were encouraged to share the survey with other potential respondents, even though this snowball sampling approach may affect the representativeness of the population sample (Williamson & Johanson 2017). See Appendix A for a sample of the consumer survey.

2.2. OFDS packaging LCA

2.2.1. Goal and scope definition

Collection of data on packaging materials first involved defining the goal and scope of the study, including the relevant system boundary for assessment. The goal of the study was to determine the GHG emissions associated with packaging used for OFDS orders and identify opportunities for emissions reduction. The scope of the study is shown in Figure 3, and includes activities associated with the production and disposal of food packaging for OFDS orders in Melbourne, Australia. The study focusses on food packaging as it has been shown in similar previous studies (Yi et al. 2017; Song et al. 2018) to be the most significant contributor to food-related environmental effects outside of food production. Packaging end-of-life disposal is based on typical consumer practices in Australia, based on the findings of the consumer survey. The food production sector is not included, partly because the LCA methods and databases for agricultural systems are less reliable due to the complexity of the system involving hydro-bio-chemical processes, land and biodiversity (Horne & Grant 2009), but also because these processes are assumed to be identical regardless of whether the food is eaten in a restaurant, taken away or delivered. This is the same reason why food preparation is also excluded. The GHG emissions associated with food delivery is also outside the scope of this study.

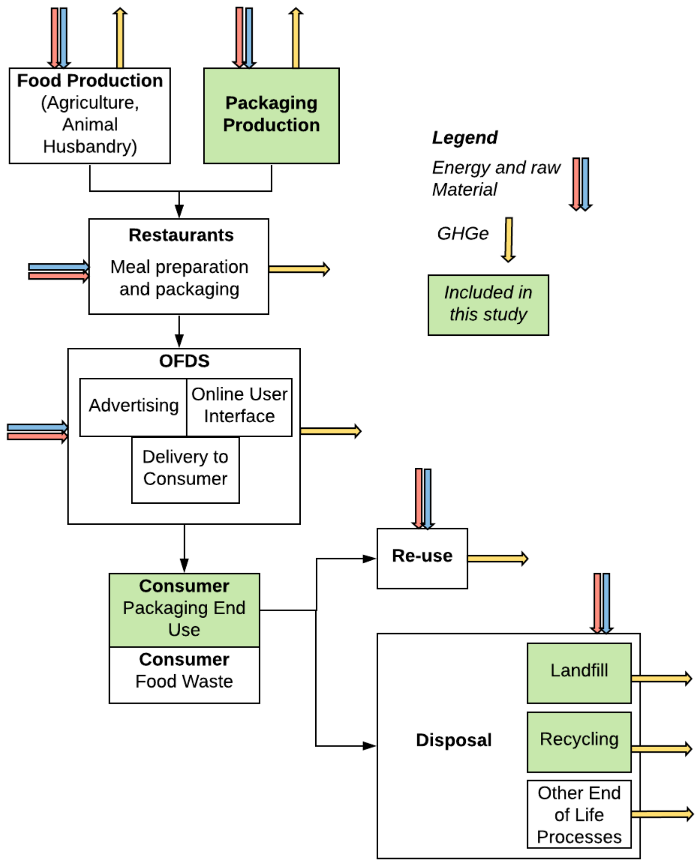

Figure 3 Scope of the study

Functional unit

The functional unit for the study is a single food order for one person made via an OFDS in Melbourne, Australia.

Reference flows

The study analyses the GHG emissions associated with the production and disposal of packaging used for a single order for five different cuisines delivered by an OFDS. The reference flows for each cuisine are provided in Table 1.

Table 1 Reference flows for the study

Cuisine	Packaging component	Packaging weight (g)
Thai	Polypropylene box	16.2
	Polypropylene lid	11
	Kraft paperboard delivery bag	49
Burger	Kraft paperboard delivery bag	45
	Kraft paperboard bag	12
	Unbleached paperboard cup holder	22

	Liquid paperboard drinks cup	9
	Polypropylene drinks lid	2
	Bleached paperboard burger box	22
	Bleached paperboard fries box	6
	Polypropylene straw	0.4
Indian	Kraft paperboard bag	12
	Polypropylene box	18.7
	Polypropylene lid	11
	Low density polyethylene clingfilm	2
	Low density polyethylene delivery bag	4
Pizza	Folding boxboard box for large pizza	110
Chinese	Polypropylene bowl	23.1
	Polypropylene lid	11.1
	Low density polyethylene delivery bag	4

Data quality requirements

Requirements associated with data quality relate primarily to product system and geographic relevance, consistency and reproducibility. Data was required to be ideally no older than ten years and relevant to packaging production and disposal practices at the current date (2020), and be collected over a period of no more than 12 months. Data related to OFDS orders must be relevant to Melbourne, Australia. Data on inputs to the product system (packaging materials, disposal methods) were required to cover >80% of the relevant processes and >80% of the data used was to be representative of the system processes.

2.2.2. Life cycle inventory

Data on packaging materials

In order to quantify GHG emissions associated with the production and disposal of the packaging materials, data on packaging material types and quantities were needed in order to determine inputs (e.g. raw materials and energy) and outputs (waste and GHG emissions) associated with production and disposal practices for each OFDS order. Primary data was sourced from participating restaurants to determine the packaging materials used for OFDS orders.

Structured interviews with restaurant managers and primary data collection from restaurants were used to determine the most common orders made through OFDS and typical packaging materials and quantities. This data was used to inform the establishment of the LCA model with the aim of creating the most representative sample possible. A sample of restaurants using OFDS in the Melbourne CBD and surrounds were selected using the nonprobability sampling techniques of purposeful criterion sampling and availability sampling (Williamson & Johanson 2017). The purposeful criterion used to separate the population stratum was cuisine. As mentioned previously, Australia has five major cuisines that are popular among consumers - Pizza, Indian, Thai, Chinese, and Burger (Vuong 2018), and the sample was limited to these cuisines. Australia has three major OFDS operating in the major cities – Just Eat Acquisitions, Deliveroo and Uber Eats (Vuong 2018). Most restaurants use more than one of these OFDS, but data collected was restricted to Uber Eats orders only, as restaurants had accurate and accessible data only for this OFDS (availability sampling), and initial consumer survey responses suggested that Uber Eats was the most popular OFDS used. Restaurants using Uber Eats for each of the five cuisines were identified in the Melbourne CBD and surrounds by using the Uber Eats mobile application at the centre of the CBD (corner of Bourke and Elizabeth Streets). The restaurant managers were contacted and structured interviews were conducted to acquire data on the most commonly ordered menu items through the OFDS, and the respective food packaging used (see Appendix B for the interview questions).

Specific packaging details such as materials and weights were determined by obtaining samples of the food packaging from each restaurant. Material type (e.g. polypropylene/paperboard/polyethylene etc.) was identified from packaging labelling and item descriptions on packaging company websites. Material weights were determined by measurement. The selection based on cuisine types (purposeful criterion sampling) was considered important, as each type of cuisine has its own specific food packaging (e.g. paperboard pizza box, polypropylene container etc.) and it would ensure a representative sample of packaging types. Managers from 19 restaurants were interviewed, out of which the restaurant with the most detailed data was selected for each cuisine. The primary data collected on packaging materials is given in Table 1.

Data on annual OFDS order numbers

With the rapidly expanding market penetration and use of OFDS worldwide, the study included an analysis of the potential future growth in GHG emissions from OFDS in Australia until 2024. Data on the projected future order numbers through OFDS in Australia was needed to quantify these likely emissions and was sourced from Australian OFDS industry data. Current annual order numbers were determined based on the 2018 market share of the three major OFDS operating in Australia - Just Eat Acquisitions (44.9%), Deliveroo (28%) and Uber

Eats (26.6%), which together make up 99.5% of the Australian market (Vuong 2018). The most accurate and available data for annual orders was the Australia-New Zealand 2018 Just Eat order numbers from their annual report (Just Eat 2019). This value, along with the 2018 Australian market shares were used to determine the 2018 annual order numbers for Australia. Vuong (2018) predicts a 15.4% annual growth rate for the Australian OFDS industry from 2018-2024, and this figure was used to determine the projected number of orders for each year to 2024 in Australia.

2.2.3. Life cycle impact assessment (LCIA)

To determine the GHG emissions associated with food packaging production and disposal, LCA software PIQET (Packaging Impact Quick Evaluation Tool) (Version 4.0) was used. PIQET is an online streamlined LCA software tool that evaluates the environmental effects of packaging materials. It uses the ecoinvent database that has extensive material and process coverage, is independently reviewed, and transparent (PIQET 2019). The PIQET tool requires various data inputs such as country of use, packaging components, packaging material, weights, conversion process (converting raw material to shaped packaging), wholesale, retail and consumer data, end-of-life practices, and transport between each life cycle stage. Using the above data, the tool provides the potential environmental effects of one retail package throughout its life cycle in terms of various impact categories, such as acidification, ozone depletion, eutrophication, climate change, land use etc.. In this study, the GHG emissions associated with packaging materials were quantified within the climate change impact category (in kg CO_2e). PIQET assesses climate change impact over a 100-yr timeframe, as per the IPCC Fourth Assessment Report (Forster et al. 2007). Where available, Australian production data was used. Where this was not available, ecoinvent data is used and modified to reflect Australian energy supply (see Appendix C for data sources).

Quantification of GHG emissions of packaging production and disposal

From the primary data collected from the restaurants, the individual packaging components, material types and weights for each of the cuisines were entered into the PIQET software. For example, the Thai restaurant delivers food packaged in a kraft brown paper delivery bag, polypropylene container and polypropylene lid weighing 49g, 16.2g and 11g, respectively. For end-of-life processes, only landfill and recycling were chosen as the consumer responses showed them to be the most common disposal methods, with incineration not widely practiced in Australia (see Appendix C for proportion of materials per disposal method). The rest of the input data used were either default data provided by PIQET or assumptions (see Appendix C).

Annual OFDS GHG emissions

Data on the split of annual orders per cuisine (based on Figure 1) was used to determine the quantity of each packaging type used on an annual basis. The projected order numbers for each year until 2024, per cuisine, were then multiplied by the packaging-related GHG emissions per order for each cuisine, obtained from the first stage of this study. GHG emissions related to annual packaging demand for each cuisine were then combined to determine the total annual packaging-related GHG emissions for each year to 2024.

3. RESULTS

3.1. Consumer survey results

The results of the consumer survey, conducted to better understand consumer OFDS purchasing and packaging disposal behaviours, are shown in Figures 4-6. A total of 73 responses were obtained from users of OFDS in Australia, showing that 73% used OFDS only once a week or less, with 27% of respondents using OFDS twice or more in a week (Figure 4). With a target population size of 2,400,000, the sample size achieved provides a relative standard error of 11.8% and a confidence interval of 0.11, at a 95% confidence level.

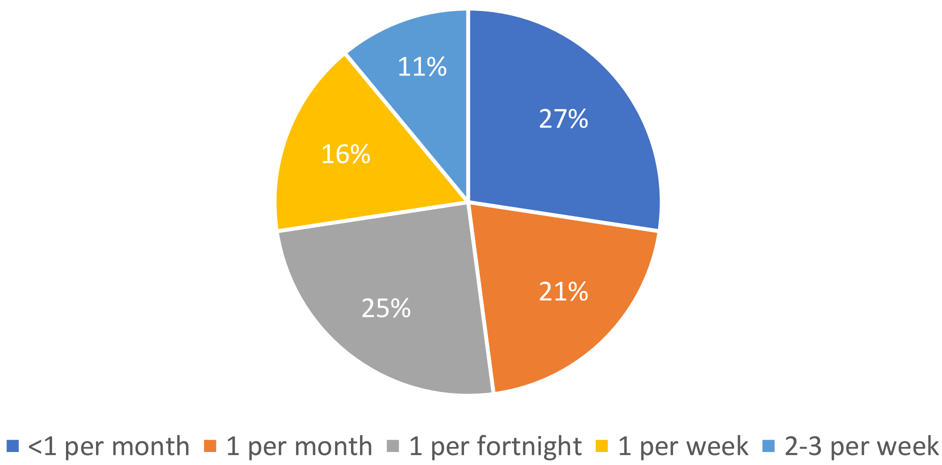

Figure 4 Frequency of OFDS use amongst consumers

A total of 89% of respondents used Uber Eats, 43% used Just Eat, and 29% used Deliveroo; these being the OFDS with the biggest market shares in Australia. Only 1% of respondents used other OFDS. Initial interview responses from restaurants also confirmed that Uber Eats was the most popular as they mentioned higher order numbers through this OFDS.

The survey also asked consumers how they dispose of food packaging, including contaminated items (having contact with food), uncontaminated items (clean), and utensils. Disposal practices can have a considerable influence on the extent of GHG emissions associated with end-of-life processes as each disposal method, whether it be landfill, incineration or recycling, relies on different processing methods and hence, leads to variation in the source and level of GHG emissions. Figures 5 and 6 show the results from the survey of consumer's disposal practices.

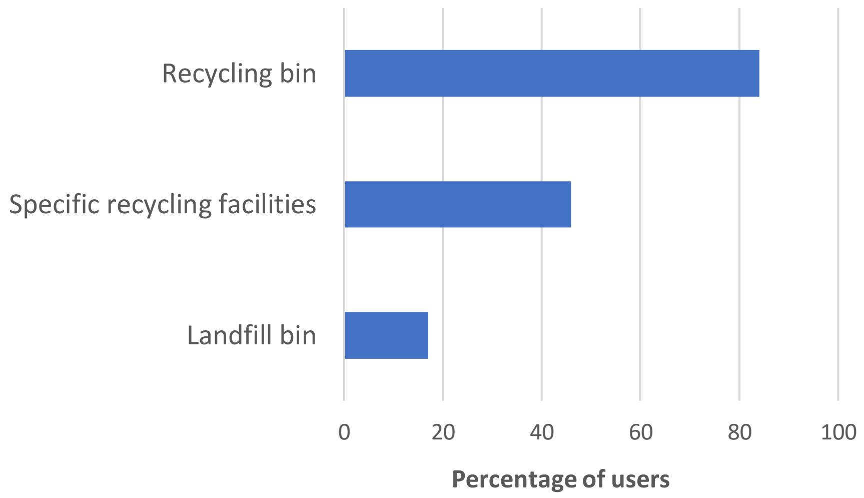

Figure 5 Consumer disposal practices for uncontaminated OFDS packaging

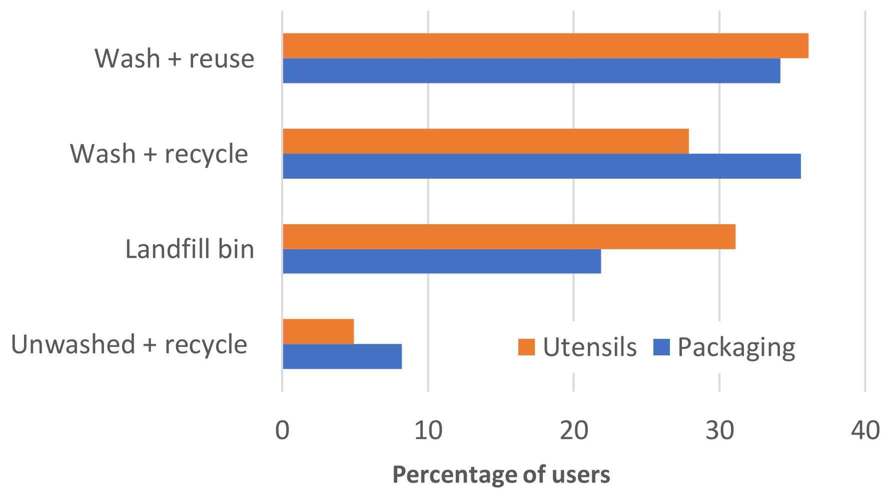

Figure 6 Consumer disposal practices for contaminated OFDS packaging and utensils

With uncontaminated packaging, respondents showed greater environmentally friendly behaviour with over 84% disposing packaging for recycling and 16% into landfill. With contaminated utensils, washing to reuse and disposing to landfill are the most common methods of disposal; while with contaminated packaging, washing to recycle and washing to reuse were more common. Furthermore, utensils are more likely to be disposed into landfill than packaging. Respondents were also questioned on whether they choose to opt out of certain packaging materials (such as bags and utensils) and 60% said they do.

3.2. Packaging LCA results

This section provides the results of the GHG emissions analysis of food packaging for the range of common cuisines delivered by OFDS, as shown in Figure 1. The analysis performed within PIQET provides the GHG emissions associated with each stage of the life cycle of a packaging product and this study calculates the GHG emissions associated with the following stages: packaging raw material production, packaging conversion (converting raw material into shaped product), transport to retailer and end-of-life. The collection of samples of packaging items from restaurants enabled a more in-depth analysis of the different materials used for food packaging for each cuisine. While this excluded the ink used in printing, all other materials were identified and weighed. The various materials used in OFDS deliveries were found to be low-density polyethylene (LDPE), liquid packaging board (LPB), unbleached paperboard (UPB), bleached paperboard (BPB), polypropylene (PP), kraft paperboard (KPB) and folding boxboard (FBB). The packaging types and quantities for each cuisine are provided in Table 1. Figure 7 shows the GHG emissions associated with the food packaging for a single order of each cuisine, by life cycle stage.

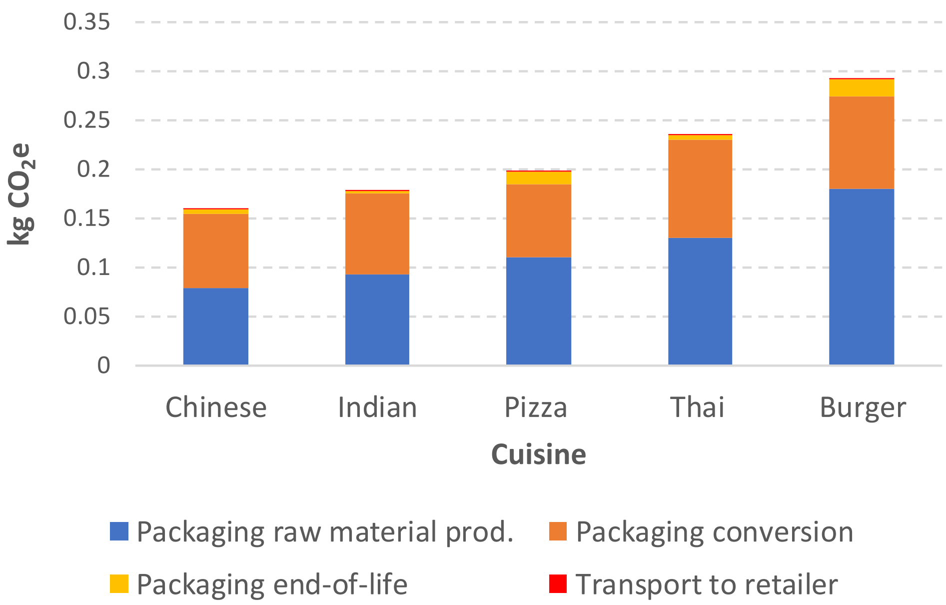

Figure 7 GHG emissions associated with packaging per order, by cuisine and life cycle stage

Figure 8 shows the GHG emissions associated with the food packaging for a single order of each cuisine, by packaging material. For this analysis, the category of 'other' cuisines was excluded, as the packaging could not be generalised. For all other calculations, 'other' cuisines were included, with GHG emissions assumed to be 0.21 kg CO_2e per order (based on the average of all cuisines). The difference in packaging-related GHG emissions for each cuisine is due to the fact that each cuisine uses different packaging types and materials.

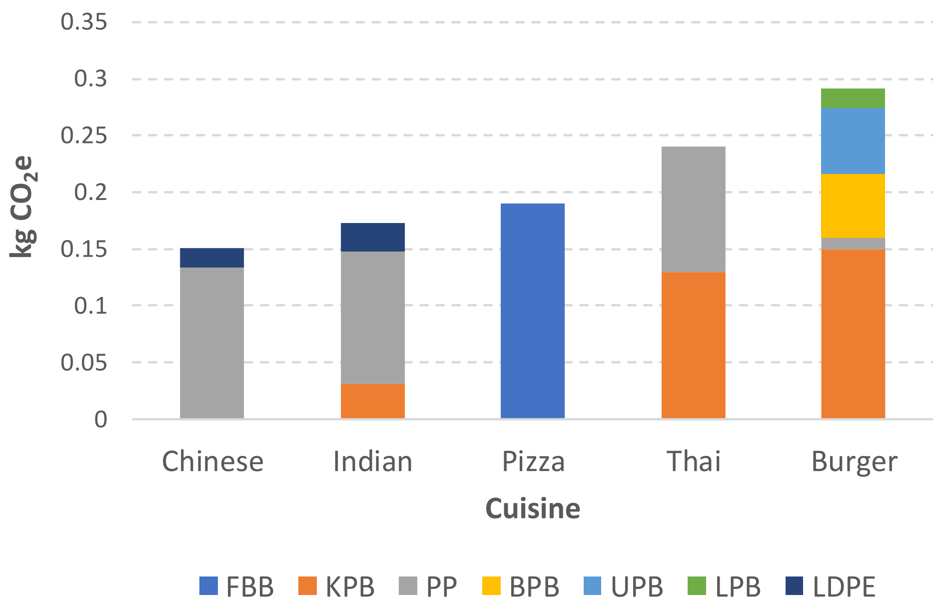

Figure 8 GHG emissions associated with packaging per order, by cuisine and packaging material

This study found that in 2018, 27.6 million orders were made through the three major OFDS in Australia, which released a total of 5.6 kt CO_2e associated with packaging. Excluding 'other' cuisines, the packaging used in 2018 amounted to 1,488 t of materials. Figure 9 shows the quantity of materials used by the three OFDS in 2018 and their associated emissions (excluding the contribution of 'other' cuisines).

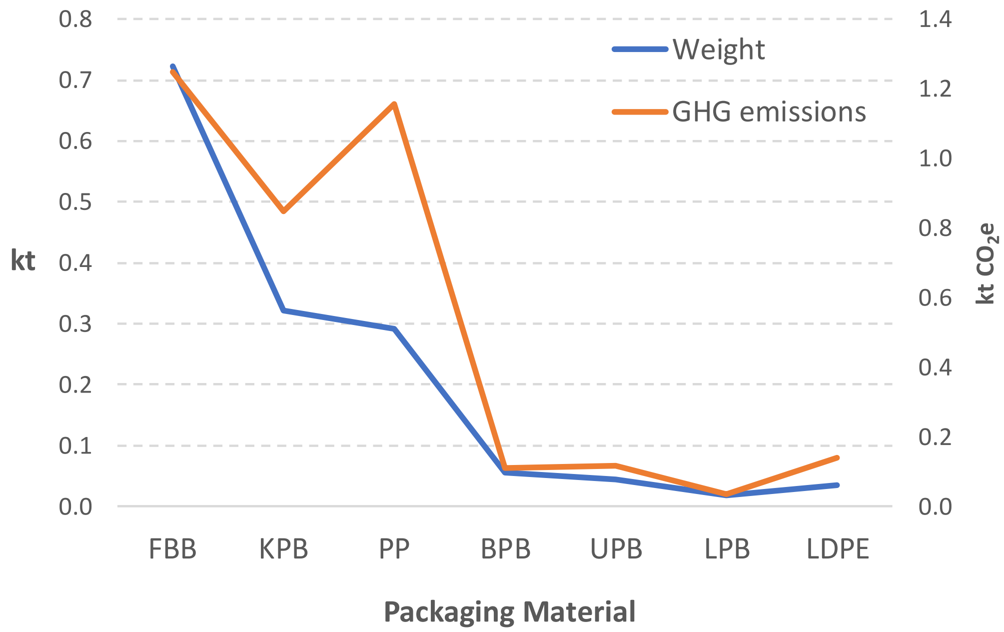

Figure 9 GHG emissions and material weight associated with OFDS packaging in Australia for 2018

Folding boxboard (FBB), the packaging material used for delivering pizzas, is the most common delivery material by quantity, helped by Pizza being the most popular cuisine delivered by OFDS in Australia (Vuong 2018). LPB (plastic coated paper packaging that contain liquids) is the least used material. However, for 1kg of material, LDPE has the largest GHG emissions and FBB has the least.

A comparison was also done of the two different types of delivery bags used for deliveries. Most deliveries were made in a 49g Uber Eats bag made out of kraft brown paper (KBP), but some were delivered in a 4g low-density polyethylene (LDPE) bag. It was found that the KBP bag resulted in higher GHG emissions (0.13 kg CO_2e) across its life than a LDPE bag (0.02 kg CO_2e).

Given the predicted 15.4% growth rate of OFDS in Australia (Vuong 2018), this study also calculated the projected increase in order numbers and GHG emissions for the three major OFDS in Australia from 2018-2024. The findings show an increase from 27.6 million orders and 5.6 kt CO_2e emissions in 2018 to 65.3 million orders and 13.2 kt CO_2e in 2024 (Figure 10).

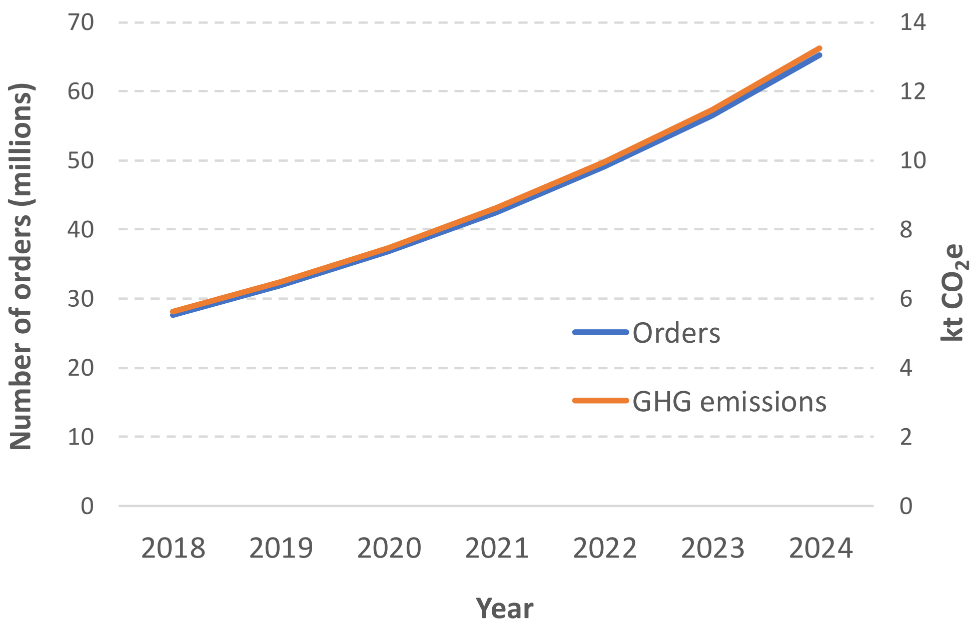

Figure 10 Projected increase in OFDS orders and packaging-related GHG emissions in Australia to 2024

Figure 11 shows the annual GHG emissions from packaging in 2018 and 2024 based on cuisine type. Pizza orders contribute to the greatest annual GHG emissions as a single cuisine, even though emissions from a single pizza order are lower than for several other cuisines. This is due to the larger annual Pizza orders through OFDS than for these other cuisines.

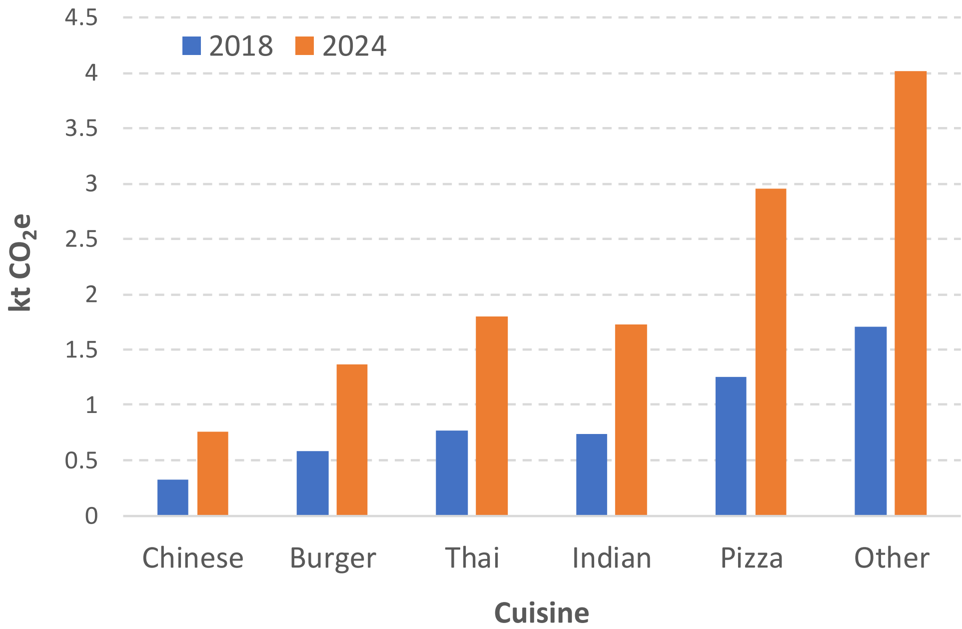

Figure 11 Annual GHG emissions from OFDS packaging in 2018 and 2024, by cuisine

By 2024, it is estimated that at least 3,516 t of packaging materials will be used in Australia for orders delivered through OFDS. Figure 12 shows the weight of packaging material used annually for each cuisine in 2018 and the predicted weights that will be used in 2024. The weight of packaging used for 'other' cuisines could not be calculated as packaging materials were not able to be generalised.

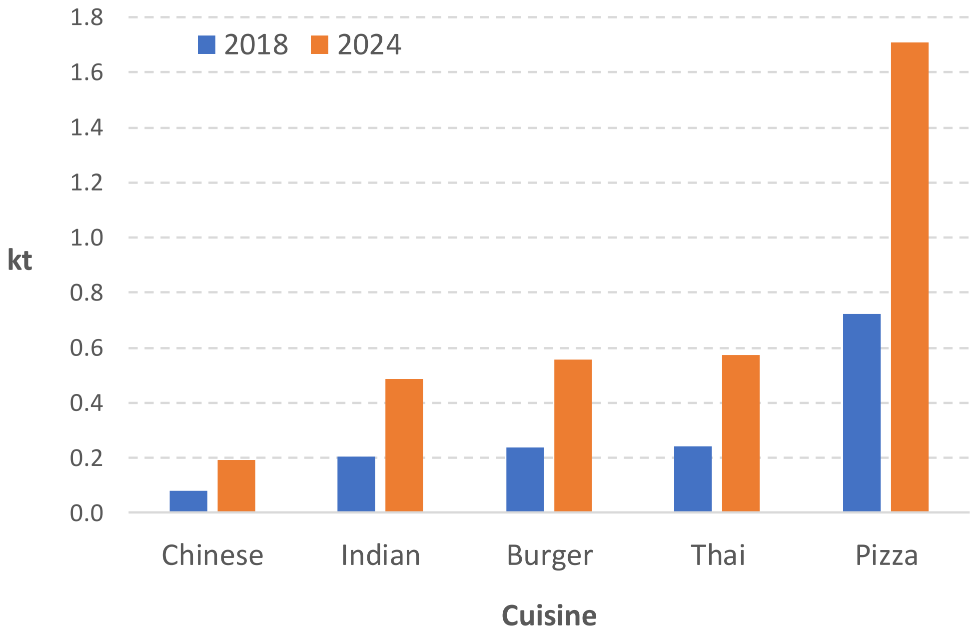

Figure 12 Annual packaging material weight for 2018 and 2024, by cuisine

4. DISCUSSION AND CONCLUSION

In 2018, Australia emitted 537.8 Mt CO_2e. The manufacturing sector contributed 11% of these emissions, out of which 18.1 Mt CO_2e were from production of food packaging (made of paper and plastic). In addition, the waste sector contributed 2.3% of emissions, out of which 9 Mt CO_2e were from disposal of solid waste on land (CoA 2020a; CoA 2020b).

This study estimated that the top three OFDS in Australia contributed 5.6 kt CO_2e in 2018, associated with packaging production and disposal, which amounts to 0.02% of Australia's emissions from the paper and plastic manufacturing and solid waste sectors. Since the OFDS industry is projected to grow in the coming years, with a projected 13.2 kt CO_2e in annual emissions due to packaging by 2024, its contribution to Australia's emissions will not be insignificant.

In terms of the contribution of specific packaging materials to OFDS-related GHG emissions, this study found that FBB contributed the most to annual emissions, even though FBB results in the lowest emissions per kg of material, which is attributed to the high demand for pizza boxes. Another key finding was that the KBP delivery bag used by OFDS results in 412% more GHG emissions than the LDPE delivery bag. This supports the study by Biona et al. (2015) who also found that plastic bags have lower environmental impact than paper bags (at least in terms of climate change, acidification and human toxicity categories). With a ban on the use of lightweight plastic bags across Australia, there is likely to be an increase in the use of KBP bags for delivery, which may result in an increase in per delivery GHG emissions. While it might be the case that KBP bags result in higher GHG emissions, LDPE bags have a greater effect in other environmental impact categories, such as litter potential (Civancik-Uslu et al. 2019).

Across the packaging life cycle, including raw materials, conversion, transport to retail and end-of-life, this study shows that the raw materials stage contributes greater than 50% of total packaging-related GHG emissions, supporting the study by Yi et al. (2017). For all the materials studied, the two major raw material sources are fossil fuels (for plastics) and wood pulp (for paper and board). One way to reduce the GHG emissions associated with the raw materials stage is by increasing the use of recycled materials as raw material feedstock instead of virgin materials. Yi et al. (2017) state that doing so may reduce the energy use in the production of plastic by 62%. However, Wang et al. (2018) state that recycling of takeaway plastic packaging is problematic as enterprises find it cost prohibitive, along with the problem of food contamination of materials. As found from the consumer survey, while recycling behaviour is increasing in Australia, around 30% of participants still dispose packaging into landfill. This is thus a key area where the environmental performance of OFDS packaging can be improved.

4.1. Sensitivity analysis

The raw material production stage was found to contribute to ≥ 50% of GHG emissions in the packaging life cycle. The parameters influencing GHG emissions for this stage include the production process (energy source and method) as well as the proportion of recycled raw materials used. The use of recycled materials reduces the amount of virgin material required in new packaging and the associated GHG emissions for the extraction and processing of these virgin materials. A sensitivity analysis was conducted to determine the influence of the amount of recycled raw material used in packaging on the GHG emission of OFDS orders. Apart from the base case (which used the default PIQET regional averages of recycled material), 50% recycled raw material use and 100% recycled raw material use scenarios were considered. Figure 13 shows the change in GHG emissions associated with raw material production based on each scenario for one order of each cuisine. Figure 14 shows the change in annual GHG emissions from OFDS based on each scenario until 2024.

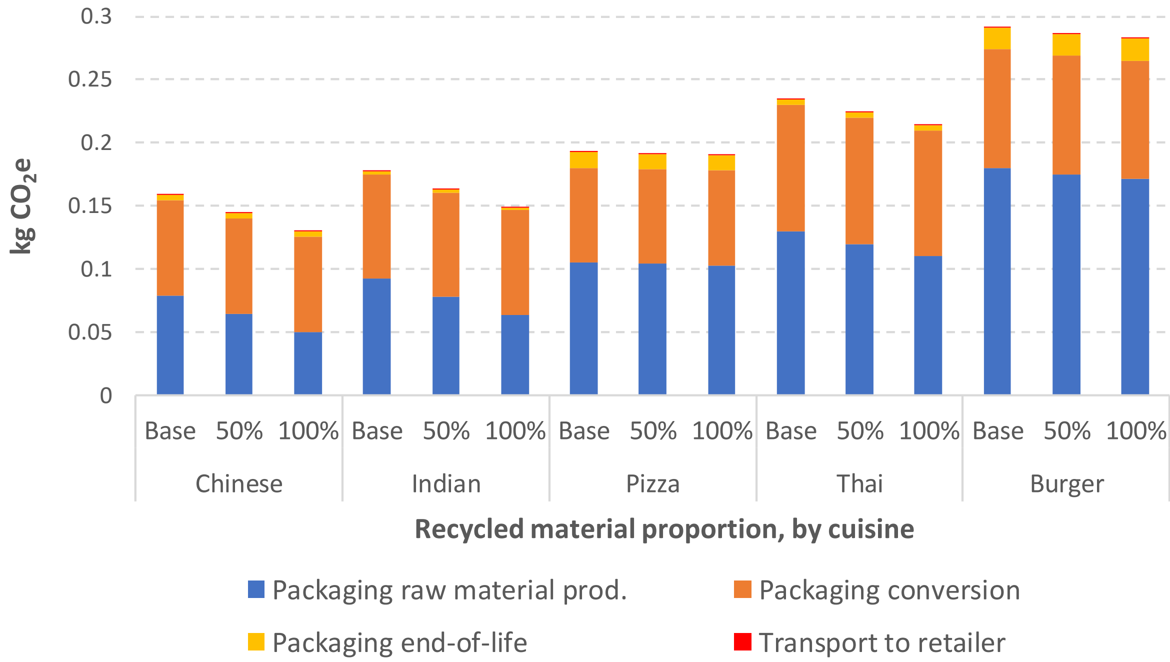

Figure 13 GHG emissions per order, by proportion of recycled material in packaging

Orders with a high proportion of plastic packaging show greater reduction in emissions with use of recycled materials (see Chinese) than packaging made from organic materials like paperboard and brown paper (see Pizza).

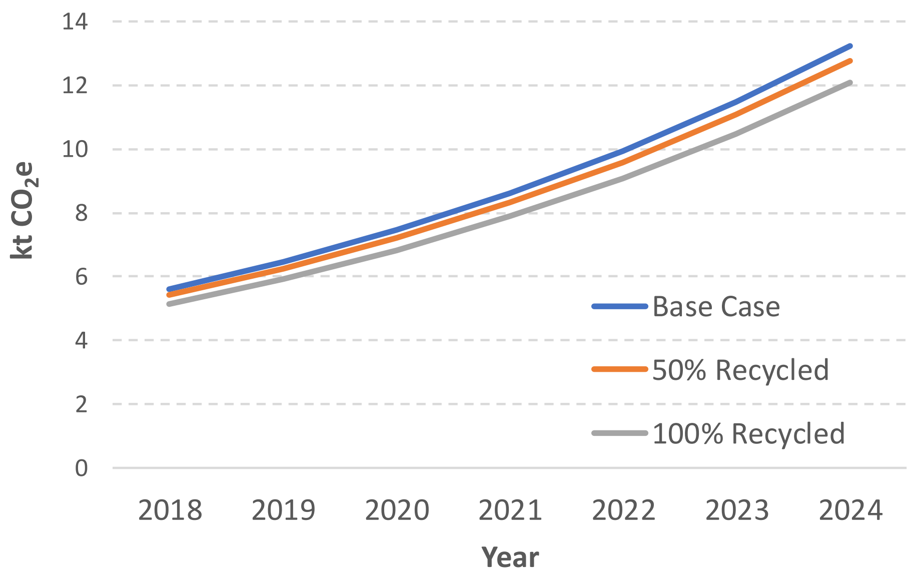

Figure 14 Annual GHG emissions from OFDS, by percentage of recycled material in packaging

Annually, there is a 4% reduction in GHG emissions from OFDS if packaging has 50% recycled raw materials and a 9% reduction with 100% recycled raw materials. This saving isn’t as significant as one might expect, indicating that a considerable amount of the GHG emissions associated with packaging raw material production is associated with the processing of raw materials.

One of the key consumer-influenced variables for GHG emissions of packaging materials is the packaging disposal method. While the study used findings from the consumer survey to determine typical disposal methods for each material, individual consumer behaviour can have a significant effect on how packaging materials are disposed. Therefore, a sensitivity analysis was conducted to determine the influence of packaging disposal method on the GHG emissions of each order. Two alternative disposal methods were considered: a) all packaging materials incinerated (Inc); b) all packaging materials disposed to landfill (Land). Results of this sensitivity analysis are shown in Figures 15 and 16.

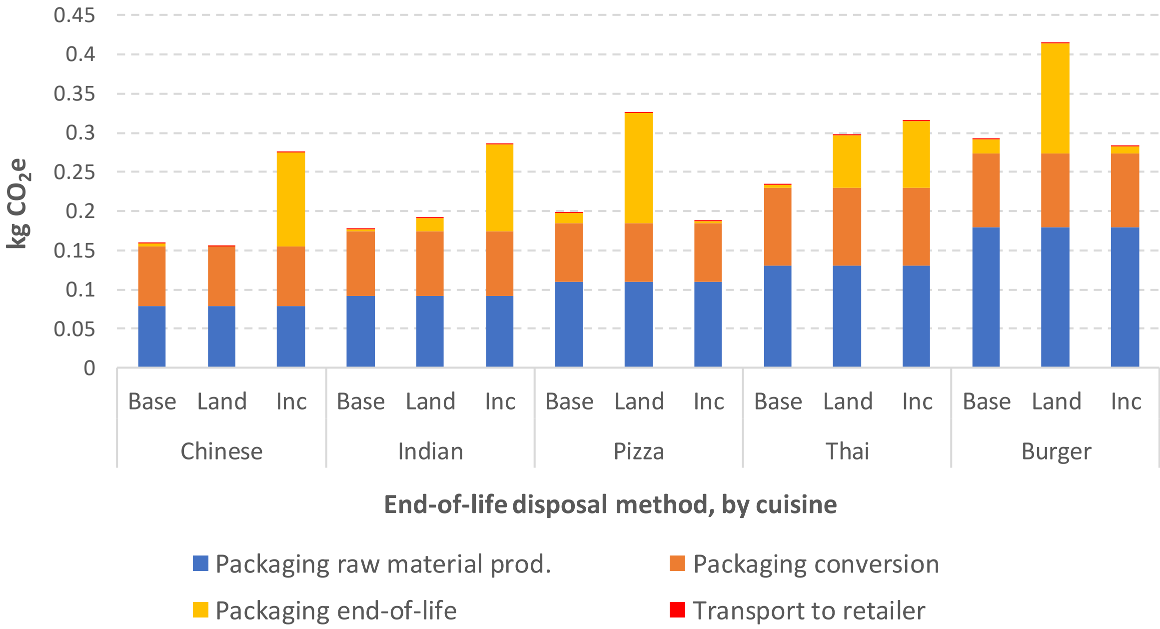

Figure 15 GHG emissions per order, by cuisine and end-of-life disposal method

The sensitivity analysis based on end-of-life disposal method shows that the composition of packaging materials influences GHG emissions for each disposal method. In the scenario where all packaging is sent to landfill, GHG emissions are significantly higher for cuisines which have organic materials such as paperboard and brown paper in packaging (Pizza, Burger), and insignificant for cuisines that have only plastic packaging materials (Chinese). In the case of incineration, synthetic plastics produce higher emissions than organic materials. This indicates that after recycling, incineration may be a viable option for disposal of organic materials to reduce GHG emissions.

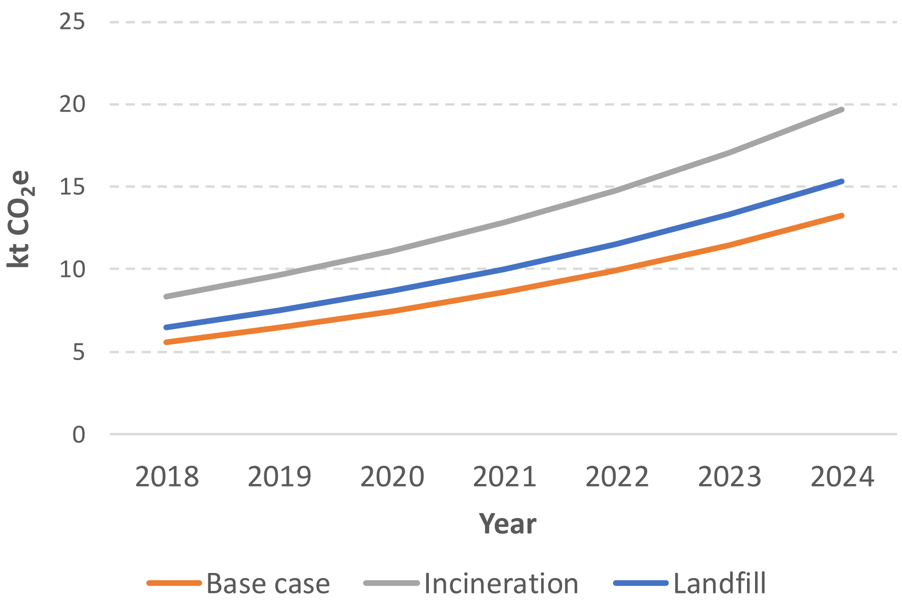

Figure 16 Annual GHG emissions from OFDS orders, by end-of-life disposal method

Annually, there is a 16% increase in GHG emissions from OFDS if all packaging is sent to landfill, and a 49% increase if all packaging is incinerated. This suggests that where materials are unable to be recycled, that from a GHG emissions reduction perspective, a material-specific approach to disposal may be preferred.

4.2. Contributions of the study

This study has contributed to our understanding of the environmental effects of packaging materials, particularly in the food service sector. Almost all existing OFDS studies are based in China, such as those by Song et al. (2018), Jia et al. (2018) and Liu et al. (2020). This study provides the first account of the magnitude of the OFDS industry as well as its environmental effects for Australia. This study used a life cycle assessment approach to evaluate the environmental effects of packaging materials used by the OFDS industry and the methods used can be replicated for any geographical area. However, the results of this study cannot be compared to results of other studies of OFDS or food service and delivery companies since each study is unique from a geographical, temporal and methodological perspective. To obtain comparable and universal results on the environmental effects of an industry, it is suggested that, where feasible, studies across the world follow one approach across the different spatial scales.

The figures obtained in this study, although likely to be an underestimation, provide further knowledge on some of the potential environmental consequences of packaging within the OFDS industry. The quantity of packaging waste generated can be used to inform the recycling industry of additional waste streams being generated now and into the future. However, the breakdown of results for specific packaging materials may not be as useful for decision making relating to the choice of optimal packaging options from a broad environmental perspective unless further impact categories are considered.

4.3. Recommendations from the study

- OFDS should make it easier in the user interface to opt out of certain packaging materials such as utensils, bags and napkins, so unnecessary waste generation can be reduced for those who do not need it. Further, consumers can be educated to increase awareness and usage of reusable container schemes like that of Deliveroo.
- OFDS must re-evaluate the current packaging use by their restaurants and strive to use more environmentally sustainable packaging materials. Restaurants must be provided an incentive to switch from plastic packaging to other materials, as currently plastic is the cheapest option available to them.
- 30% of respondents disposed of OFDS packaging waste into their landfill bin. In order to reduce this behaviour, education of consumers is required to increase awareness of recycling behaviour, coupled with a change to packaging designs to ensure easier use and cleaning by consumers.
- With an increasing number of foreign countries no longer accepting Australian solid waste for recycling (contamination being a primary reason), Australia must increasingly manage these waste streams within its own borders (Blue Environment Pty Ltd 2018). The quantity and processing abilities of waste and resource and recovery centres in Australia will need to be increased to meet this demand; especially in light of the recycling crisis in the state of Victoria, where a shortage of recycling facilities has led to waste being sent to landfill (4,600 t a week at its peak), or being stockpiled (Knight 2019; Oaten 2019).

4.4. Limitations of the study

This study analysed the GHG emissions associated with production and disposal of packaging materials used in OFDS orders. While all attempts were made to maximise system boundary completeness, there are likely to be remaining data gaps due to incomplete inventories for packaging materials which may have led to an underestimation in the results. Additional data gaps resulted from data not being available for all OFDS operating in Melbourne and packaging use for the 'other' cuisines category. In addition, the study did not consider the items that may accompany OFDS orders, such as utensils, napkins and order slips.

The PIQET software used to model GHG emissions may have affected the accuracy and relevance of results due to limitations in the embedded inventory data for material production and disposal practices. However, PIQET was found to be the best available tool for this study due to its use of Australian unit process data and its focus on packaging materials.

This study considers only the greenhouse gas emissions and related climate change implications of packaging materials as part of a streamlined analysis of their environmental performance. This is quite common in the life cycle assessment field and one of the most critical areas of environmental concern currently being faced. However, by focusing on only one impact category (i.e. climate change), this study ignores the effects of packaging production and disposal on other impact categories such as resource use, ozone depletion, acidification etc.. There is a risk that the interpretation of results and subsequent choices or decisions made, if based solely on GHG emissions may lead to inferior environmental outcomes in other areas. Thus, an understanding of the environmental performance of packaging production and disposal practices for OFDS orders is needed across a broader range of impact categories, such as in studies done by Yi et al. (2017) and Liu et al. (2020).

4.5. Further research

This study provides the first environmental assessment of Australia's OFDS industry. The findings from this study demonstrate the extent of the packaging-related GHG emissions associated with OFDS and the contribution to Australia's national GHG emissions, both now and into the future. Being the first ever analysis of the environmental performance of the Australian OFDS industry, there are many areas in which this research can be expanded. The research approach used within this study provides guidance for future similar studies, particularly for its application across larger geographical regions. In depth studies on each of the individual packaging materials used by OFDS, considering multiple impact categories would assist in identifying more environmentally appropriate packaging alternatives. Broadening the scope, including impacts from the agricultural sector and considering transportation of orders from restaurant to consumer would add further insight to the findings from this study. Studies on the comparison between the environmental performance of the five different types of meal preparation (i.e. home cooking, semi-prepared home cooking, restaurant dine-in, take-away, and deliveries (online and otherwise) would help to further contextualise the significance of GHG emissions associated with OFDS.

This study evaluated only the technical and industrial processes, and identified the most efficient technological solution; however, technological solutions are often not sufficient in creating the desired environmental change (Moltesen & Bjørn 2018). Behaviour change in consumers as well as policy change from the government are also required to create lasting change (Wang et al. 2018) and further research to help understand consumer behaviour and its key drivers as well as policy implications in this area are also needed.

Further research is currently being conducted by the authors to broaden the scope of this study to include the impacts of last mile delivery to the consumer. With data on the types of delivery vehicles used for OFDS deliveries nation-wide, the national annual GHG emissions from OFDS deliveries will also be able to be better understood.

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APPENDICES

Appendix A: Consumer survey

1. *Which of the following services do you use?*

   • Deliveroo • Eat Now • Menulog • Uber Eats • Other: ___________________

2. *How often do you make use of Online Food Delivery Services (OFDS)?*

   • Less than once a month • Once a month • Once in two weeks • Once a week
   • Two to three times a week • Four or more times a week

3. *What are the top 5 restaurants you order from?*

   ____

4. *What are the top 5 food items you order (include details such as single item/meals)?*

   ____

5. *Do you choose to opt out of receiving certain packaging/utensils? (e.g. plastic bags, spoons/forks/chopsticks)*

   • Yes: (which materials?) ____________________________ • No

Reference for below questions:
Packaging is any bag or container that is used to store food and/or other containers. *Uncontaminated packaging* is any packaging that does not have food residue on it, such as a clean paper/plastic delivery bag. *Contaminated packaging* is any packaging that has contact with food. *Utensils* include spoons, knives, forks, chopsticks.

6. *How do you dispose uncontaminated packaging? (Select all that apply)*
   • Dispose into landfill bin
   • Dispose into recycling bin
   • Dispose to specific collection services (e.g. soft plastics collection)

7. *How do you dispose contaminated packaging?*
   • Dispose into landfill bin
   • Dispose into recycling bin (without washing)
   • Dispose into recycling bin (with washing)
   • I don't; I wash and reuse them

8. *If you opt for utensils, how do you dispose them?*
   • Dispose into landfill bin
   • Dispose into recycling bin (without washing)
   • Dispose into recycling bin (with washing)
   • I don't; I wash and reuse them

9. *If you dispose/manage packaging in other ways not mentioned above, please state:*

   ____

Appendix B: Restaurant Manager interview questions

1. How many orders do you receive through OFDS in a month?
2. What are your most popular menu items that are ordered through OFDS?
3. What packaging do you use for OFDS orders?

Appendix C: PIQET input data

1. Packaging level: 1 Retail unit
2. Manufacturing data and processes (default for Australian setting)

Material	Recycled	Source	Time period	Geography	Processes
FBB	21%	Ecoinvent 3.3 + FEFCO 2015	2015	European process data modified for Australian energy supply	Average data from European producers
PP	0%	Ecoinvent 3.3	2016	Australian process data	Polymerisation of propylene, electricity consumption included
KBP	0%	Ecoinvent 3.3	2016	European process data modified for Australian energy supply	Unbleached kraft paper from a variety of wood feedstocks
LDPE	0%	Franklin 2007	2007	Australian process data	Polymerisation of ethylene, electricity consumption included
BPB	25%	Ecoinvent 3.3	2016	European process data modified for Australian energy supply	Solid bleached board (SBB) in a mix of integrated mills - including transport to paper mill, wood handling, chemical pulping and bleaching, board production, on site energy production, internal waste water treatment
UPB	25%	Ecoinvent 3.3	2016	Finnish database and former Swiss packaging study. European average process data modified for Australian energy supply	FBB in an integrated paper mill - including transport to paper mill, wood handling, chemical pulping and bleaching, board production, on site energy production, internal waste water treatment
LPB	0%	ELCD 3.0	2013	European process data modified for Australian energy supply	Average liquid packaging board (80%) and polyethylene (20%)

3. Conversion process selected
    a. PP: Injection PP
    b. LDPE: Blown film
    c. KBP: Paperboard conversion
    d. UPB: Paperboard conversion (25% recycled)

    e. BPB: Liquid paperboard (25% recycled)
    f. FBB: Box folding (21% recycled)
    g. LPB: Liquid paperboard
4. Transport to converter
    a. 50km by average lorry/trailer
5. Product mass (added to offset the assumed weight in PIQET)
    a. For car delivery: 20,000kg
    b. For motorbike and bicycle delivery: 10,000kg
6. Transport to filler (i.e. restaurant)
    a. All materials: 30km by average lorry/trailer
7. Wholesale: Excluded
8. Retail
    a. Thai, Pizza, Indian: Stored for 5 days; Room temperature, small store
    b. Burger: Stored for 5 days; Cooling counter, large store
9. End-of-life

Table D.1 Assumed end-of-life material diversion

Material	Landfill (%)	Recycling (%)
FBB	23.20	76.80
KBP	23.20	76.80
PP	81.90	18.10
LDPE	77.00	23.00
BPB	23.20	76.80
UPB	23.20	76.80
LPB	80.00	20.00

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