Ministry of the Environment and Water Resources

National Environment Agency
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FACTSHEET ON FINDINGS FROM LIFE-CYCLE ASSESSMENT STUDY ON CARRIER BAGS AND FOOD PACKAGING

- A study commissioned by NEA has found that consumers can reduce their impact on the environment by opting to use reusable bags and food containers, instead of disposables.
- The waste challenges faced by countries are not identical. In Singapore, as we incinerate our waste, promoting certain types of disposables (e.g. paper or bio-degradable disposables) may not be better for the environment.
- A more sustainable approach is to tackle the excessive consumption of all types of disposables. NEA will step up collaborations with organisations to implement outreach and publicity initiatives that encourage consumers to take only what they need, and bring their own reusable bags and containers.

Background

1 In 2017, about 1.67 million tonnes of waste disposed of in Singapore came from domestic sources such as households. Of this, about one-third consisted of packaging waste, which includes single-use disposables such as plastic bags and food packaging. The amount of packaging waste thrown away yearly in Singapore is enough to fill more than 1,000 Olympic-size swimming pools.

2 While single-use plastic bags are needed by households to bag waste, the excessive consumption of disposables is a waste of resources and it contributes to our carbon footprint and climate change. To work towards our vision of becoming a Zero Waste Nation, the National Environment Agency (NEA) continually explores ways to promote the 3Rs of reduce, reuse and recycle.

3 NEA has put in place measures over the years to curb the amount of packaging generated at source. One such measure is the Singapore Packaging Agreement (SPA) – a voluntary agreement where organisations commit to reducing packaging waste in their business operations. In 2017, NEA had also announced plans to mandate the reporting of packaging data and waste reduction plans by businesses by 2021.

4 In September 2016, NEA commissioned local academic Dr Kua Harn Wei to conduct a life-cycle assessment (LCA) of the environmental impact of commonly used disposables in Singapore. The study was conducted in two phases – the first phase on carrier bags and the

second on food packaging used for dine-in and take-away meals. The results of the study are being used to inform our policies on the use of such disposables.

LCA study results for carrier bags

5 In an LCA study, products are compared on the basis of their providing the same unit of service. The study estimated that the functional use of one reusable bag over a year could replace the use of 125 single-use plastic/degradable bags, or 52 single-use paper bags.

6 Due to their single-use design and function, plastic bags were found to have the biggest environmental impact in terms of greenhouse gas emissions and energy use. The greenhouse gases associated with the processing of crude oil used as source material to manufacture the bags, and the greenhouse gases from the bags' incineration, contribute to climate change.

7 Single-use paper bags and degradable bags are often seen as eco-friendly alternatives to plastic bags. However, paper bags need large amounts of water to make and cannot be used to bag wet items. Some types of degradable bags, such as oxo-degradable bags, are made of plastic, with additives to accelerate the degradation process. In Singapore, waste is incinerated and not left in landfills to degrade. This means that the resource requirements of oxo-degradable bags are similar to that of plastic bags, and they also have similar environmental impact when incinerated. In addition, oxo-degradable bags could interfere with the recycling process when mixed with conventional plastics. Plant-based degradable bags, such as polylactic acid (PLA) bags and corn-starch bags, require large tracts of forest land to be converted into farmland and large amounts of water to grow their raw materials.

8 Taking into consideration both the monetised cost and environmental impact, reusable bags emerged as the most environmentally-friendly option for carrying groceries and similar items. Other than using reusable bags, consumers can also reduce their impact on the environment by reusing single-use bags. More details on the study are available in **Annex A**.

LCA study results for plates and food packaging

9 The second phase studied the packaging used to contain food for dine-in and take-away. Dine-in food packaging options included single-use plastic, degradable and paper plates, as well as reusable melamine and porcelain plates. Take-away food packaging options included single-use plastic, polystyrene and paper containers, as well as reusable plastic and metal food containers. The study approximated that the functional use of one reusable plate/container over five years could replace the use of 3,650 pieces of single-use plates/containers[1].

<u>Dine-in packaging (plates)</u>

10 Similar to the results for carrier bags, the study found that single-use plastic plates resulted in the most greenhouse gas emissions and energy use during their life cycle as they are made from crude oil. It also found that the manufacturing process for plant-based corn starch plates is energy intensive. Single-use paper plates score relatively low (refer to Table 2 in **Annex**

[1] Assuming the reusable containers are used for two meals every day.

B) on greenhouse gas emissions, water and energy use, but their production results in the modification of large tracts of forest land. Melamine and porcelain plates were found to have lower impact on the environment in comparison to the disposables in general as they can be reused multiple times, and hence take up less resources and emit less greenhouse gases during their life-cycle.

<u>Take-away packaging (containers)</u>

11 The study on take-away food containers likewise found that single-use plastic containers resulted in the most greenhouse gas emissions and energy use. Single-use paper boxes with an inner plastic sheet (used for dishes such as fried rice) were equally energy intensive to make. Furthermore, the nature of the raw materials entails high consumption of water and the conversion of large tracts of forest land.

12 Reusable containers consume relatively more water than some other disposables during their life cycle due to washing needs. However, in other aspects such as greenhouse gas emissions and energy use, they were among the more environmentally friendly food packaging options. More details on the study are available in **Annex B**.

13 While the study showed that the environmental impact of certain disposables was comparable to that of reusables, some environmental consequences of the use of disposables were not considered. For example, the study did not account for potential littering issues arising from the use of disposables. In addition, the use of disposables results in incineration waste which increases the load on Singapore's limited landfill space. For example, a food shop using polystyrene plates over five years would generate around 2,300kg of disposables[2] to be sent to our incineration plants, and the resulting incineration ash needs to be landfilled at Singapore's Semakau landfill.

Promoting the use of reusables

14 In Singapore, we incinerate our waste. Given our approach to waste management, our waste challenges may not be the same as that faced by other countries. As such, a switch from one type of disposables to another may not necessarily be better for the environment in our context. A more sustainable approach would be to tackle the excessive consumption of all types of disposables.

15 There are various private sector initiatives to discourage the use of disposables. For example, NTUC FairPrice has an on-going Green Rewards Scheme where a 10-cent rebate is given to customers who bring their own bags and spend a minimum of $10 in the supermarkets. Recently, Dairy Farm also launched an incentive scheme where shoppers who bring their own bags are rewarded with additional points on their Passion card. Retailers such as Miniso, Bossini and IKEA also charge for plastic bags and/or sell reusable bags. NEA encourages more businesses to implement initiatives to reduce the use of disposables, and will continue to work with organisations, such as Zero Waste SG, to implement outreach and publicity initiatives that

[2] Assuming the food shop uses 250 pieces of polystyrene plate (each weighing 5g) per day.

encourage consumers to only take what they need, and bring their own reusable bags and containers.

16 “After last year’s successful run of the Bring Your Own (BYO) Singapore campaign, Zero Waste SG is working with NEA to explore expanding the programme to reach out to more members of the public and businesses. We hope to encourage more people to develop the BYO habit and play their part in reducing the use of disposables. This will help conserve resources, reduce our carbon emissions, and create a healthier planet for our future generations to enjoy,” said Ms Pek Hai Lin, Manager at Zero Waste SG.

17 For new hawker centres – such as the hawker centres at Our Tampines Hub, Pasir Ris Central and Yishun Park – NEA and the Ministry of the Environment and Water Resources (MEWR) have disallowed the use of disposables for dine-in. NEA will continue working with stakeholders to encourage stallholders in existing hawker centres and operators of private food establishments to use reusables where possible. NEA will also be studying the results of the LCA study further and explore more ways to reduce the use of disposables.

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Annex A

Background of Life-Cycle Assessment Study of Carrier Bags

1 The life-cycle assessment (LCA)[3] study of carrier bags covered the common types of single-use plastic, degradable and paper bags, as well as reusable bags, used in Singapore. In an LCA study, products are compared on the basis of their providing the same unit of service, also known as the functional unit. For this study, the functional unit was the volume of items a family of four would approximately buy over the course of one year. The functional unit is needed to determine how many of each type of bag are needed to carry the items. The study found that the functional use of 10 reusable bags (non-woven polypropylene or nylon bags) over a year is equivalent to the use of 1,248 plastic or degradable bags, or 520 paper bags.

The study assumed that a family buys 50 items per week. The 50 items were placed in the different types of bags studied to determine how many of each type of bag were needed to carry the 50 items.

Bags studied

Single-use plastic bags

2 Two types of commonly used single-use plastic bags were studied – high-density polyethylene bags (HDPE) and linear low-density polyethylene (LLDPE) bags. Polyethylene is currently the most widely used material for making plastic bags, and is made up of polymerised ethylene molecules. Ethylene is derived from fossil fuels such as natural gas and crude oil, which are non-renewable resources. To make these bags, fossil fuels are extracted and refined, and the purified ethylene is polymerised to produce polyethylene plastic granules. The granules are heated up and shaped into plastic bags.

Single-use degradable bags

3 Three types of single-use degradable bags were studied - polylactic acid (PLA) bags, corn starch bags and oxo-degradable bags. Globally, the most common commercial biodegradable polymers are PLA polymers. PLA is derived from renewable sources such as corn starch, sweet potatoes and sugarcane. To grow the starch sources for PLA and corn starch

[3] A life-cycle assessment study evaluates the environmental impact associated with the various stages of a disposable and reusable item's life cycle.

bags, large amounts of resources such as water and land are needed. The starch sources are then treated through different processes to form PLA or corn starch granules, which are shaped into bags.

4 Oxo-degradable bags are also used by some retailers in Singapore. Due to price considerations, some companies that used to sell plant-based degradable bags have switched to selling oxo-degradable bags instead. Oxo-degradable bags are made from polyethylene (PE), polypropylene (PP) or polystyrene (PS), which are similar to conventional plastics, except that additives are added in to accelerate the degradation process. These metal ion additives are obtained through mining and smelting processes.

5 In Singapore, degradable bags are incinerated at the waste-to-energy plants when they are disposed of, instead of being landfilled. Some studies have suggested that certain conditions are important in determining the rate of degradation (e.g. presence of heat, UV radiation, oxygen), and degradable bags may not break down quickly if not exposed to sunlight and air (e.g. if the degradable bags are thrown into the sea). Oxo-degradable, PLA and corn starch bags are also generally not recyclable; they would contaminate and interfere with the recycling process, if mixed with conventional plastics.

(From left to right) HDPE bag; LLDPE bag; PLA bag; corn starch bag; and oxo-degradable bag.

Single-use paper bags

6 For paper bags, unbleached and bleached kraft bags were studied. Similar to PLA and corn starch bags, large amounts of water are needed to grow trees for harvesting wood. The harvested wood is then processed into wood pulp, which can be bleached prior to drying to produce white paper bags. Pulp produced using the kraft method creates paper that is stronger than that made from other pulping methods.

Reusable bags

7 To compare the use of single-use bags to reusable alternatives, two commonly distributed reusable bags were studied - nylon bags and non-woven polypropylene bags. Nylon bags are made from plastic granules, which are processed into fibres and woven to produce carriers.

8 Non-woven polypropylene bags are made from plastic fibres, which are made into a sheet using heat, mechanically or with an adhesive. This process makes them durable and easy to clean. The non-woven process also allows bags to be made faster and with greater flexibility, making them cheaper than nylon bags.

(From left to right): Unbleached kraft bag; bleached kraft bag; nylon bag; and non-woven polypropylene bag.

Overall cost and environmental performance comparison of the bags

9 Four main types of environmental impact and resource use were studied, namely global warming potential[4], water requirement, energy consumption and land use change[5]. The study found that the greatest environmental impact occurred at the raw materials acquisition, manufacturing and incineration stages of the bags' life cycles. Compared to these stages, the other stages (e.g. transportation and landfilling of the ash after incineration) contributed less or negligible environmental impact.

10 Table 1 on the next page summarises the impact of the bags studied in each category, based on how each performs relative to the others. The arrangement of the bags in the table does not represent the bags' overall ranking as the weightage of each category in the overall impact may differ.

[4] Global warming potential is a measure of how much heat energy the emissions of one tonne of gas will absorb over a given period of time, relative to the emissions of 1 tonne of carbon dioxide.
[5] Land use change takes into account the transformation of forestland into land needed to manufacture the bags.

Table 1: Scoring for environmental and cost impact for carrier bags[6]

	Global warming potential	Water requirement	Energy consumption	Land use change	Cost
LLDPE plastic bags (1,248 bags)	🏭🏭🏭🏭🏭	💧💧💧	⛽⛽⛽⛽⛽	🌳	$$$
HDPE plastic bags (1,248 bags)	🏭🏭🏭🏭🏭	💧💧💧	⛽⛽⛽⛽⛽	🌳	$
Oxo-degradable bags (1,248 bags)	🏭🏭🏭🏭🏭	💧💧	⛽⛽⛽⛽⛽	🌳	$$
Corn starch degradable bags (1,248 bags)	🏭🏭	💧💧💧💧	⛽⛽⛽	🌳🌳🌳🌳🌳	$$$$$
PLA degradable bags (1,248 bags)	🏭🏭	💧💧💧	⛽⛽⛽⛽	🌳🌳🌳🌳🌳	$$$
Unbleached paper bags (520 bags)	🏭🏭	💧💧💧💧💧	⛽	🌳	$$$$$
Bleached paper bags (520 bags)	🏭	💧💧💧💧💧	⛽⛽	🌳🌳🌳🌳	$$$$$
Reusable nylon bags (10 bags)	🏭	💧💧💧💧	⛽	🌳	$
Reusable non-woven PP bags (10 bags)	🏭	💧	⛽	🌳	$

The table shows the various rankings of the bags for each criterion, with five symbols indicating the highest impact, and one indicating the lowest impact[7].

[6] The findings from the study are context specific to Singapore and the time period in which the study was carried out. This is as the environmental impact of products is dependent on the sources in which the raw materials come from and where the products were manufactured, which differs for each country and may change over the years.

[7] For global warming potential and energy consumption, the difference between the largest and smallest impact figures was divided equally into five ranges, for which one to five symbols were allocated. For water requirement and land use change, outlier figures that would skew the allocation of icons were given five symbols, and the rest had their grading divided by four.

Background of Life-Cycle Assessment Study of Food Packaging

1 The life-cycle assessment (LCA) study of food packaging covered the common types of 1) dine-in plates, and 2) take-away containers used in Singapore. For this study, the functional unit was the service provided by the plates/containers over five years, with two meals served daily. Based on this functional unit, the use of one reusable container would replace the use of 3,650 single-use containers.

Food containers studied

Single-use plastic plates and containers

2 Two types of plastic plates (i.e. single-use polypropylene (PP) plate and single-use polystyrene (PS) plate) and three types of plastic containers (i.e. single-use PP container, single-use PS container and single-use high density polyethylene (HDPE) string-tie bag) were studied.

3 PP is the world's second most widely used synthetic plastic. Similar to ethylene, PP is made from fossil fuels such as natural gas or crude oil, which is polymerised to produce PP plastic granules. The granules are then heated and moulded to form different shapes.

(From left to right) Single-use PP plate; single-use PS plate; single-use PP container, single-use PS clam shell container; and HDPE string-tie bag.

Single-use corn starch plate

4 The use of biodegradable corn starch tableware is becoming more common in Singapore. To make corn starch plates, corn stalks are harvested, the starch is extracted from the grains and additives are added to form corn starch granules. The corn starch granules are then heated and moulded to form plates.

Single-use paper plate and containers

5 In addition to a paper plate, three types of paper containers were studied (i.e. single-use kraft paper box with an inner plastic sheet, single-use kraft paper box with a wax coating, and single-use brown paper wrapping with a plastic coating). Single-use paper plates and containers are made from harvested wood that has been processed into wood pulp. The plastic used to coat some paper boxes and paper wrappers is made from polyethylene, which is made from fossil fuels.

(From left to right) Corn starch plate; paper plate; paper container with inner plastic sheet, paper container with wax coating; and brown paper wrapping with plastic coating.

<u>Reusable plates and containers</u>

6 Two types of reusable plates (i.e. melamine plate and porcelain plate) and two types of reusable containers (i.e. reusable PP container and stainless steel tiffin container) were studied. Melamine ware is commonly used in eateries in Singapore as the material is light and durable. Melamine ware is made from melamine and formaldehyde, which are both derived from fossil fuels. Porcelain plates are commonly used in Singapore households and they are made from clay which is combined with other materials and baked.

7 Reusable PP containers are made from fossil fuels and stainless steel tiffin containers are made from iron and chromium.

(From left to right) Melamine plate; porcelain plate; reusable PP container and stainless steel tiffin container.

Overall cost and environmental performance comparison of the plates and containers

8 Four main types of environmental impact and resource use were studied, namely global warming potential, water requirement, energy consumption and land use change. For single-use plates and containers, the study found that the greatest environmental impact occurred at the raw materials acquisition, manufacturing and incineration stages of the containers' life cycles. Compared to these stages, other stages such as the transportation and landfilling of the ash after incineration, contributed less or negligible environmental impact. For reusable plates and containers, the greatest environment impact occurred from the washing of the plates over five years.

9 Table 2 and 3 on the next page summarises the impact of the containers studied in the dine-in and take-away categories, based on how each performs relative to the others. The arrangement of the plates and containers in the tables do not represent their overall ranking as the weightage of each category in the overall impact may differ.

Table 2: Scoring for environmental and cost impact for dine-in plates[8]

	Global warming potential	Water requirement	Energy consumption	Land use change	Cost[9]
Single-use PP plate (3,650 pieces)	🏭🏭🏭🏭🏭	💧	⛽⛽⛽⛽⛽	🌳	$$$$$
Corn starch plate (3,650 pieces)	🏭🏭🏭	💧💧💧💧💧	⛽⛽⛽⛽⛽	🌳	$$$$$
Single-use PS plate (3,650 pieces)	🏭🏭	💧	⛽	🌳	$
Single-use paper plate (3,650 pieces)	🏭	💧💧	⛽⛽	🌳🌳🌳🌳🌳	$$
Melamine plate (One piece)	🏭	💧	⛽	🌳	$$$
Porcelain plate (One piece)	🏭	💧	⛽	🌳	$$$

The table shows the various rankings of the plates for each criterion, with five symbols indicating the highest impact, and one indicating the lowest impact[10].

[8] The findings from the study are also context specific to Singapore and the time period in which the study was carried out. This is as the environmental impact of products is dependent on the sources in which the raw materials come from and where the products were manufactured, which differs for each country and may change over the years.
[9] For reusable plates, the cost includes cost of washing the plates over five years.
[10] For the four key environmental impacts, the difference between the largest and smallest impact figures was divided equally into five ranges, for which one to five symbols were allocated.

Table 3: Scoring for environmental and cost impact for take-away containers

	Global warming potential	Water requirement	Energy consumption	Land use change	Cost[11]
Single-use PP box (3,650 pieces)	🏭🏭🏭🏭🏭	💧	⛽⛽⛽⛽⛽	🌳	$$$
Single-use PS clam shell (3,650 pieces)	🏭🏭🏭	💧	⛽	🌳	$$$
Single-use kraft paper box with LLDPE sheet (3,650 pieces)	🏭🏭	💧💧💧💧💧	⛽⛽⛽⛽⛽	🌳🌳🌳🌳🌳	$$$
Single-use kraft paper box with wax coating (3,650 pieces)	🏭🏭	💧💧	⛽⛽⛽	🌳🌳🌳🌳	$$$$$
Reusable PP container (One piece)	🏭	💧💧💧	⛽	🌳🌳	$
Stainless steel container with steel lid (One piece)	🏭	💧💧💧	⛽	🌳🌳	$
Brown paper with LLDPE coating (3,650 pieces)	🏭	💧	⛽⛽	🌳🌳🌳🌳🌳	$
Disposable HDPE bag (3,650 pieces)	🏭	💧	⛽	🌳	$

The table shows the various rankings of the containers for each criterion, with five symbols indicating the highest impact, and one indicating the lowest impact[12].

[11] For reusable food containers, the cost includes cost of detergent for consumers to wash food containers at home over five years.

[12] For the four key environmental impacts, the difference between the largest and smallest impact figures was divided equally into five ranges, for which one to five symbols were allocated.

Annex C

Methodology and Assumptions

ISO14040 Life Cycle Assessment Framework

1 The Life Cycle Assessment (LCA) was conducted according to the international standard ISO 14044: 2006 – Environment management – Life cycle assessment – requirements and guidelines. The LCA method, as defined in the standard, consists of four phases:

Phase 1 – goal and scope definition	Based on the goal of the LCA, the functional unit, reference flows, and system boundaries of the products being studied are defined. a) The functional unit describes a service or performance to be provided by the products, and provides a basis for comparison of the environmental impact of the products. b) Reference flows quantify the amount or flows of each product under study that is needed to carry out the service/performance described by the functional unit. c) The system boundary determines which life cycle stages are to be considered in the LCA.
Phase 2 – inventory analysis	A life cycle **inventory analysis** refers to the process for compiling and estimating the consumption of resources such as raw materials, energy and water (termed as "inputs") and emissions including wastes (termed as "outputs") throughout the life cycle of a product or system. At this phase, the "inputs" and "outputs" associated with a product are quantified using country-specific information that is obtained from international life cycle inventory databases[13].
Phase 3 – impact assessment	The environmental impact due to each input and output is estimated.
Phase 4 – interpretation	The implications of the inputs, outputs, and environmental impact are analyzed and interpreted in relation to the goal and scope definition.

[13] The international databases used in this study were Ecoinvent and GaBi. If data for a specific country of interest is not available, data of a similar technology that is applied in another country is used instead. This in line with recommendations by ISO 14044: 2006.

Phase 1 – Goal and Scope Definition

a) Functional Unit and b) Reference Flows

2 The goal of the study was to assess and compare the environmental impact of commonly used disposables as well as their reusable alternatives in Singapore, over their entire life cycle. It was assumed that the products under study are disposed of through Singapore's waste collection and disposal system after being used, instead of being re-used, recycled, or littered. There are three main groups of products under the study – (a) carrier bags, (b) dine-in plates, and (c) take-away food containers.

Carrier Bags

3 For this study, the **functional unit** of carrier bags was the volume of grocery items a family of four would buy approximately over the course of one year. It was assumed that the family of four comprised two adults and two children, and it was assumed that all meals were prepared at home and grocery shopping was done weekly. The average number of grocery items per family was derived empirically by averaging the number of items bought by two families that fit the assumed criteria. It was found that, on average, each family requires 50 grocery items per week.

4 The study also found that these 50 grocery items per week required 24 polyethylene (PE) carrier bags. When the 50 items were carried in reusable and paper carrier bags, it was found that 10 of each type of carrier bag were needed per week. The study thus derived the **reference flows** in terms of bags per year for the carrier bags under study, as tabulated below.

<table>
<tr><th>Type of carrier bag</th><th>Basis and Assumptions</th><th>Reference flow (no. of bags)</th></tr>
<tr><td>LLDPE plastic bags</td><td rowspan="2">Each bag has a 12-litre volume. In order not to introduce bias in the assumption of number of bags required to carry the grocery items, it was left to the cashiers to pack and bag the grocery items, including whether certain items needed to be "double-bagged".</td><td>1,248</td></tr>
<tr><td>HDPE plastic bags</td><td>1,248</td></tr>
<tr><td>Oxo-degradable bags</td><td rowspan="3">The texture and thickness were assumed to be similar to that of PE-based carrier bags, and hence an equivalent reference flow was assumed.</td><td>1,248</td></tr>
<tr><td>Corn starch degradable bags</td><td>1,248</td></tr>
<tr><td>PLA degradable bags</td><td>1,248</td></tr>
<tr><td>Unbleached paper bags</td><td rowspan="2">Each bag has a 15-litre volume. Unlike PE-based carrier bags, no "double-bagging" was required as the paper bags were thicker.</td><td>520</td></tr>
<tr><td>Bleached paper bags</td><td>520</td></tr>
<tr><td>Reusable nylon bags</td><td rowspan="2">Each bag has a 15-litre volume. Unlike PE-based carrier bags, no "double-bagging" was required as the reusable bags were thicker. It was assumed that a reusable bag has a one-year lifespan.</td><td>10</td></tr>
<tr><td>Reusable non-woven PP bags</td><td>10</td></tr>
</table>

Food packaging

5 It was assumed that reusable plates or containers have a lifespan of five years. The **functional unit** for food packaging was therefore based on the service provided by plates or containers over five years, assuming two meals are served daily. Based on this functional unit, the **reference flow** in terms of quantity of single-use plates or containers over 5 years was taken as 3,650, and that of reusable plates or containers was 1. However, the reusable plates or containers will have to be washed a total of 3,650 times over the five years. These reference flows are tabulated below.

Type of plate / container	*Basis and Assumptions*	*Reference flow (no. of plates / containers and washes)*
Dine-In Plate		
Single-use PP plate	One plate per meal, two plates used per day, every day, over 5 years	3,650 plates, 0 washes
Corn starch plate		3,650 plates, 0 washes
Single-use PS plate		3,650 plates, 0 washes
Single-use paper plate		3,650 plates, 0 washes
Melamine plate	One plate per meal, washed twice a day, every day, over 5 years	1 plate, 3,650 washes
Porcelain plate		1 plate, 3,650 washes
Take-Away Container		
Single-use PP box	One container per meal, two containers used per day, every day, over 5 years	3,650 containers, 0 washes
Single-use PS clam shell		3,650 containers, 0 washes
Single-use kraft paper box with LLDPE sheet		3,650 containers, 0 washes
Single-use kraft paper box with wax coating		3,650 containers, 0 washes
Disposable HDPE bag		3,650 containers, 0 washes
Brown paper with LLDPE coating		3,650 containers, 0 washes
Reusable PP container	One container per meal, washed twice a day, every day, over 5 years	1 container, 3,650 washes
Stainless steel container with steel lid		1 container, 3,650 washes

c) System Boundaries – Life Cycle Stages

6 The key life cycle stages for the carrier bags studied were: materials acquisition and manufacturing (including packaging of the materials or products for transportation), usage, incineration and landfilling, as well as the transportation between each stage. The life cycle stages for the food packaging studied were similar to that of the carrier bags, except that during usage, washing of the reusable food packaging containers was also taken into consideration. These stages are shown in Figure 1.

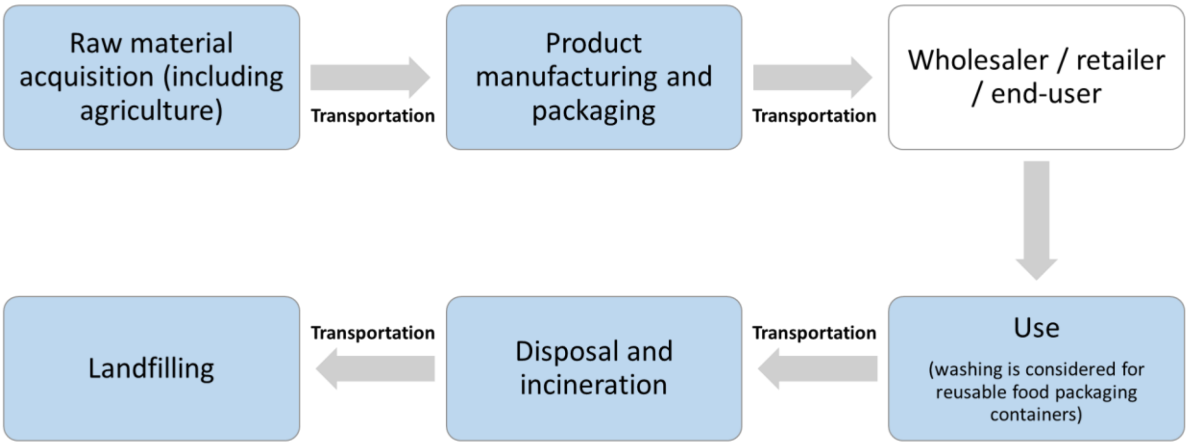

Figure 1. Life cycle stages for carrier bags and food packaging considered in this study.

Phase 2 – Inventory Analysis

7 The methodology and assumptions used for inventory analysis of the inputs and outputs of the various life cycle stages are listed below.

Life Cycle Stage	*Methodology and Assumptions*
Raw material acquisition, product manufacturing and packaging	The main producing/exporting countries of each material/product type were selected based on International Trade Centre data as well as knowledge shared by industry. Where possible, inputs and outputs were weighted according to the percentage of trade of the material/product from the selected countries.
International transportation	The mode of transportation – inter-oceanic, air transportation, or mixed mode of transportation – of the material/product to or from the selected countries was identified. **<u>Inter-oceanic transportation</u>** i. Ports of export in the producing/exporting countries were identified using online catalogues and trading sites. ii. Distances between these ports and Singapore were estimated using an online calculator (Sea-distances.org) that measures the distances between seaports.

	iii. Where there was more than one port of embarkation in a particular country, the average distance between the ports and Singapore was calculated and taken as the distance that the goods have to travel from that country to Singapore. iv. It was assumed that trans-oceanic tankers had an average capacity of 32,500 metric tonnes and moved with an average vessel speed of 10 knots. **Air transportation** v. Average distance between the exporting country and Singapore was estimated using Google Maps. vi. It was assumed that the trip was undertaken by the relevant model of cargo planes with adequate fuel range and fully loaded. **Multiple Countries of Import** vii. Where there was more than one importing country for a certain type of material/product (which can either be transported by inter-oceanic or air transport), the weighted average fuel consumption (per kg of that particular material/product) was derived, based on the relative proportions of material/product imported from each country. The inputs and outputs attributed to transporting the material/product to Singapore were calculated based on this weighted amount of fuel consumption.
Local transportation	It was assumed that 5-tonne trucks were used for transportation of goods in Singapore and were fully loaded. The average distance was taken to be between Keppel Port (taken as the main port of entry) or Jurong Island (for plastic materials) and local processing plants/wholesalers.
Use (for washing of reusable plates/ containers)	It was assumed that reusable plates were machine-washed. Besides the water and energy requirements of the dishwashers, pre-rinsing as well as the use of cleaning agents were included in the estimation of the impact. For reusable take-away containers, it was assumed that these were hand-washed. As there was no existing established standard on how dishes are to be washed by hand, the resource usage of hand-washing of the containers was estimated through measurements conducted over 30 trials by the LCA study researchers, based on a set sequence of washing actions.
Incineration and landfilling	It was assumed that all products were incinerated after disposal. For transportation of ash from the incineration plants to Tuas Marine Transfer Station (TMTS), the distance was calculated based on the estimated average round-trip distance between TMTS and the four waste-to-energy incineration plants in Singapore – Tuas South Incineration Plant, Tuas Incineration Plant, Keppel Seghers Tuas Waste-to-Energy Plant, and Senoko Waste-to-Energy Plant.

Phase 3 – Impact Assessment

Environmental Impact

8 For the inputs and outputs of the various life cycle stages, four main types of environmental impact and resource use were considered:

a. **Global warming potential**, which is a measure of how much heat energy the emissions of one tonne of a greenhouse gas will absorb over a period of time, relative to the emissions of one tonne of carbon dioxide (measured in kg CO_2-equivalent). For this study, the time period used is 100 years.
b. **Land use changes**, which takes into account the area of land that is modified due to the activities undertaken in the life cycle stages (measured in square metres, m^2).
c. **Water requirement** by the activities and processes in the life cycle stages (measured in cubic metres, m^3), and
d. **Energy requirement** by the activities and processes in the life cycle stages (measured in Megajoules, MJ).

9 Based on the data collected from the life cycle inventory databases in the Inventory Analysis stage, which was adjusted in relation to the functional unit, the inventory results were classified into the four types of environmental impact and resource use, for each product.

Financial Costs

10 Given that financial costs would typically be one of the key parameters in purchasing decisions by consumers, the financial costs related to the purchase and usage of the product were considered. The purchase prices of the products in Singapore were based, as far as possible, on prices offered by local retailers. If these were not available, prices from local and international marketplace websites were used. For the usage costs (applicable to reusable food packaging containers only), this includes the cost of washing the items over five years (e.g. cost of detergent and water consumption in the local context).

Phase 4 – Interpretation

11 Based on the results obtained in the Impact Assessment stage, the products in each product group (namely carrier bags, dine-in plates, and take-away food containers) were ranked from 1 to 5 for each type of environmental impact/resource use listed in paragraph 8, with 5 indicating the highest impact and 1 indicating the lowest impact. Appropriate symbols were used to denote the rankings of the products.

12 To obtain the ranks, the difference between the largest and smallest impact values of the products in each product group were divided equally into five ranges, for which 1 to 5 symbols were allocated. However, if there was significant value difference between the product with largest impact value and the other products, it would be difficult to show the relativity in the differences among the other products. Hence, in such a scenario, the largest impact value product would be assigned 5 symbols, and the difference between the second largest and the smallest impact values was then divided equally into four ranges. Doing so allows for a nuanced comparison of the impact of the various products, by preventing the relative differences in impact from being obscured by one outlier value.

13 The purchase prices and usage costs were also ranked, to allow for a comparison of the total financial costs of the products with their related environmental impact.

Limitations and Assumptions

14 The findings from the LCA are context-specific to Singapore and the time period in which the study was conducted, because the environmental impact of products is dependent on the sources that raw materials come from and where the products are manufactured, which may differ over the years.

15 The LCA did not take into account the possible re-use of products meant for single-use e.g. re-use of single-use plastic bags for bagging trash or wet clothes, or re-use of single-use PP take-away containers for containing frozen food. As mentioned in Paragraph 2, it also did not consider the impact of littering nor recycling. This is because of the complexities in estimating the percentage of each type of single-use carrier bag or container that is re-used, recycled, or littered.

16 It was assumed that reusable dine-in plates were machine-washed, while reusable take-away containers were assumed to be hand-washed by consumers.

17 A cut-off criterion of 3 per cent was applied – the environmental impact and resource consumption of any ingredient or component that has a mass less than 3% of the total mass of a product were not assessed. This technique of applying cut-off criteria is common in LCA.

18 The data used in the studies was mainly obtained from Ecoinvent and GaBi, which are both internationally recognized and widely subscribed databases. Data from these databases was obtained mainly from industrial averages, simulation exercises, or/and peer reviewed scientific journal publications. In reality, actual process values may be slightly different from the input or output information used in the modelled processes studied in this LCA study.

19 Land use change is a relatively new variable in life cycle methodology and the databases used for this study may not fully contain the latest data on land use changes. The LCA also considered that land use change occurred only when land was converted from primary forestland to industrial, residential or other alternate uses for up to 20 years. Hence, if agricultural activities or factory production were carried out on a piece of land that was converted from primary forestland more than 20 years ago, no land use change was considered.