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Master’s Dissertation 2021

Proposal of Zero Packaging Prioritization Indicator Based on Life Cycle Assessment to Incorporate Zero Packaging Practices into Japanese Department Stores

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SUMMARY OF MASTER'S DISSERTATION

Student Identification Number	81934560	Name	CHUNG Si Ying
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Proposal of Zero Packaging Prioritization Indicator Based on Life Cycle Assessment to Incorporate Zero Packaging Practices into Japanese Department Stores			

Abstract

The purpose of this research is to aid department store managers in Japan to incorporate zero packaging practices into their current operations by proposing a zero packaging prioritization (ZPP) indicator that takes in the environmental perspective as well as the missing economic and social perspectives and testing it using case studies.

For the qualitative part, a case study was done by interviewing Tokyu department store, Hiyoshi to understand what they think about zero-packaging. It was found out that cost reduction (economic perspective) and customer acceptance (social perspective) were important factors that they consider when incorporating zero-packaging practices into their current operations. With conventional indicators showing only environment perspective, there is a need for a new indicator incorporating both economic and social perspectives.

Life Cycle Assessment (LCA) was first conducted to model the carbon emissions of four products: bottled coffee, bananas, soybeans and daikon radish. LCA was done to ensure that this study is comparable with existing studies which were all based on LCA. Primary data in were collected from Tokyu department store, Hiyoshi and secondary data were mainly from Japanese sources in order to maintain geographical integrity of the data. Next, a cost analysis was done to find out the cost of packaging to provide the missing economic perspective. In this study, not only the primary packaging (i.e. the packaging visible to end consumer) but the secondary packaging used for transportation were considered as well. Next, the ZPP indicator incorporating all three perspectives: Environmental, Economic and Social, was proposed to help department stores prioritize the products to implement zero-packaging practices. The Weighted Sum Method was used in deriving the ZPP indicator with the weights from Tokyu Department store, Hiyoshi. The ZPP indicator shows that Tokyu department store should prioritize the implementation of zero-packaging practices in the following order: daikon radish, soybeans, bananas followed by bottled coffee.

Comparison of the ZPP indicator with conventional indicators was done as a form of V&V by applying the same dataset used for the ZPP indicator to conventional indicators. Results show that after taking into consideration the social and economic perspectives, bottled coffee which is highly favorable for packaging removal when only viewed from the environmental perspective, turns out to be not.

This study provides Japanese department stores with a quantitative method that acts as the first step required to start reducing packaging usage. Japanese department stores would go down the prioritization list derived from the ZPP indicator starting from the food product with the highest score to start looking at ways to reduce packaging.

Key Word(5 words)

Life Cycle Assessment, Plastic Packaging, Zero-Packaging, Food, Department Stores

Contents

List of Acronyms

CC_{Pa} – Climate Change Impact Factor of Packaging

CC_{Pr} - Climate Change Impact Factor of Product

CFP – Carbon Footprint

FTP – Food to Packaging

GHG – Green house gases

GWP – Global Warming Potential

IPCC – Inter-govvernmnetal Panel on Climate Change

LCA – Life Cycle Assessment

LDPE – Low-density polyethylene

PET – Polyethylene terephthalate

PHA – Polyhydroxyalkanoate

PLA – Polylactic Acid

PP – Polypropylene

PS – Potential Score

PtP_{CC} – Package to Product Indicator based on Climate Change impact category

UNEP – United Nations Environment Programme

ZPP – Zero Packaging Prioritization

1. Introduction

1.1 Background of plastics waste management in Japan

The excessive generation of plastic waste has been an ongoing problem for many countries, in part due to the heavy consumption of plastic. About 9030 thousand tons of plastic waste was generated in Japan, in 2017 alone [1]. Only 23% of this was mechanically recycled (9% was done in-house while 14% was exported overseas), while 58% of the plastic waste was incinerated with energy recovery as shown in Figure 1 below [1]. Even with strict municipal waste segregation rules, the amount of plastic waste that actually gets reused as recycled plastic still does not measure up to the amount of plastic waste that was burned for energy.

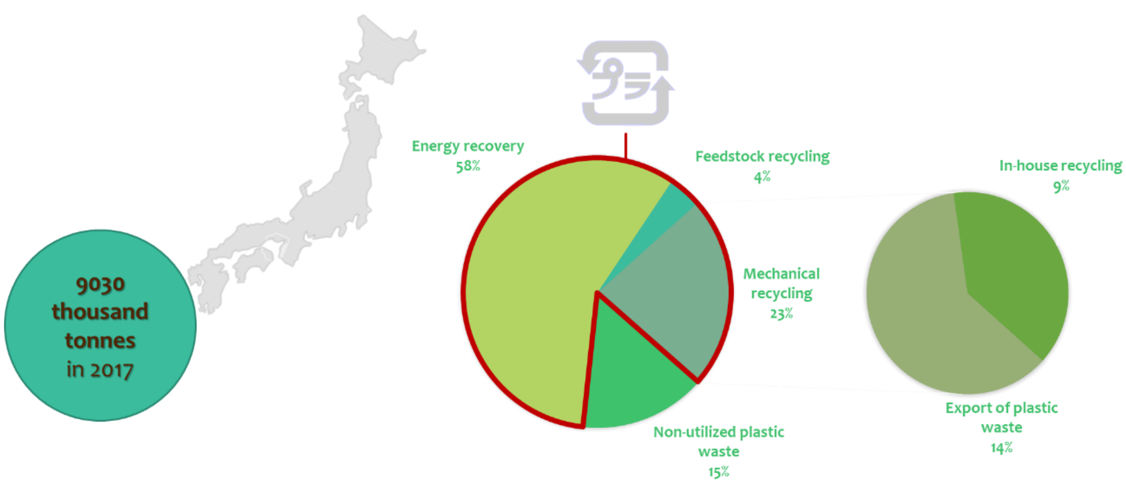

Figure 1: The plastic situation in Japan [1]

1.2 Environmental impact of marine plastic waste

Plastic might not seem like much of a problem in terms of carbon emission if we were to compare it directly with other resources like electricity. However, if we were to look at plastic waste from a wider scope, the environmental impact of plastic waste could be comparable, if not higher than traditionally high impact resources. In a study published in Science Magazine in which an estimation was done to determine the amount of plastic waste flowing into the ocean from each country, China came up as the top generator of marine plastic waste followed by Indonesia, Philippines and Vietnam which can be seen in Table 1 [2]. China, Indonesia and Vietnam are all major importers of plastic waste from G7 countries and are known to have inadequate waste management systems [3]. Till this day, nobody has a complete picture of the amount of marine plastic waste existing in our oceans, which leaves much of the environmental impact of marine plastic waste to be unknown. One thing we do know is that there is an urgent need to limit the amount of plastic waste even being generated in the first place.

Rank	Country	Vol. of plastic inflow into ocean
1	China	1,320,000 ~ 3,530,000 tons/year
2	Indonesia	480,000 ~ 1,290,000 tons/year
3	Philippines	280,000 ~ 750,000 tons/year
4	Vietnam	280,000 ~ 730,000 tons/year
5	Sri Lanka	240,000 ~ 640,000 tons/year
20	America	40,000 ~ 110,000 tons/year
30	Japan	20,000 ~ 60,000 tons/year

Table 1:Estimation of marine plastic waste inflow from land for each country [2]

1.3 Plastic packaging with the largest proportion

The main culprit of plastic waste generation is unsurprisingly, plastic packaging. In a study published by United Nations Environment Programme (UNEP), it was found that 36% of the global plastic production went to single-use plastic packaging, which was the largest sector as can be seen in Figure 2 below [4]. Furthermore, Japan is second in the world for plastic packaging waste generated per capital as shown in Figure 3 below [4].

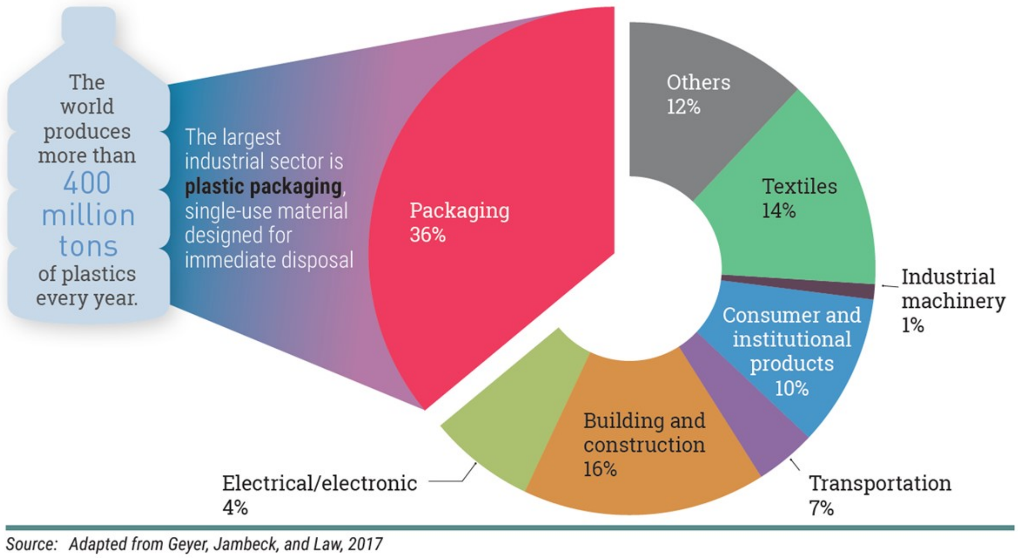

Figure 2:Overview of global plastic production

Figure 3:Japan is second in the world in terms of plastic packaging waste generated per person [4]

1.4 Existing strategies to reduce plastic consumption

From a life cycle perspective, reduction would always be better than recycling. This is due to the fact that recycling actually consumes a lot of resources and can have high carbon emissions. The transporting, sorting, cleaning, crushing and drying of waste plastics during the recycling process requires fuel, water, electricity and heat. There is a need to explore methods other than recycling to reduce plastic packaging waste in Japan.

1.4.1 Policy strategies

Prata et al. [5] did a review of integrated strategies that looks at reducing the amount of plastic even entering the environment in the first place. One of the strategies mentioned was policies which is probably the most straightforward strategy in terms of waste management. However, policies might cause disruptions in supply chain and shifting of problem (e.g. increase in trash bag sale after plastic bag levy implemented in Irelend) [5,6]. Moreover, as mentioned by Prata et al [5,7], constant monitoring for certain types of policies might actually cost more in terms of aggregate environmental impact. In addition, policies might have an immediate and significant impact when first applied but its impact is known to dwindle as time passes. As such, there is a general lack of long-term studies of the impact of policies [8]. Top down approaches like policies are known to be more limiting and not all countries and governments have the capability and freedom to implement such strategies. Hence, there is a need to look at other strategies.

1.4.2 Technological advancements

Another strategy to look at is technological advancements in the form of material science technology and redesign. Bio-based/biodegradable plastics like Polylactic acid (PLA) [9,10] and polyhydroxyalkanoate (PHA) [11] has been around for awhile now and has even been manufactured and sold on a large scale [12]. Research has also been done to replace the plastic in circuit boards with biodegradable fibres [13]. In terms of redesign, major companies like Unilever, Michelin, GM and Cargil to name a few, have been spearheading efforts to redesign their packaging and products which resulted in direct reduction of plastic waste. However, research projects like this usually requires generous amount of investment and is subject to failure. Hence, big corporations are usually the only ones who can afford to take the initiative to research on alternative materials. Not to mention, the introduction of alternative materials into existing waste streams would cause disruptions that requires careful planning [5]. In addition, materials or products that are marketed to be kinder for the environment could bring about a 'rebound effect' which is the increase in consumption of said products due to psychological effects [14]. Technical solutions are not able to work by itself without first understanding human behavior [8].

1.4.3 Social-scientific strategies

On the same note, shifting human behavior just through education and awareness is insufficient to bring about a sustainable change. As mentioned by Heidbreder et al. [8] who did a review of social-scientific work on reducing plastic consumption, that even though awareness of global warming/climate change is high, humans being habitual creatures, are still not changing their behavior for the good of the environment. The paper identified that to initiate behavior change, there must be some kind of trigger in the form of changes in external environment, for example relocation. Provision of alternatives was found to be a potential candidate to initiate behavior changes as well.

1.4.4 Zero-waste concept

The zero-waste concept is a great example of a hybrid of all the strategies mentioned above. A well-known example is the zero-waste city of Kamikatsu as well as the zero waste academy which is active in education and the spreading of the awareness of the zero-waste concept. Despite zero-waste initiatives like kamikatsu being well-known, it remains difficult to see zero-waste initiatives actually happening in other parts of Japan. Zero-waste grocery stores for example, serves a very niche consumer market. A study [19] mentions that a more transformative pathway to make zero-waste more mainstream is for existing conventional supermarkets to adopt zero-waste practices.

As such, this study looks at integrating zero-waste concept in Japanese department stores to reduce plastic packaging consumption. The case study is chosen to be in Japanese department stores since they have a well-known problem of over-packaging. Furthermore, the price range of department store goods attracts a more affluent group of customers. The rich having more freedom to change their consumption patterns is expected to be a leverage point for this study.

2. Materials and Methods

2.1 Overview

In the following chapters, we will first be doing a literature review to find out what the academia world is doing to implement zero-waste concept in the food product sector in chapter 2.2. This would be followed by an introduction of Life Cycle Assessment (LCA) in chapter 2.3 and a literature review of existing LCA studies in the food product sector in chapter 2.4. Next, the quantitative component of this study would be shown in chapter 2.5 in the form of an interview with Tokyu department store, Hiyoshi. The purpose and objectives of this study would then be established in chapter 2.6 followed by an explanation of the uniqueness of this study in the form of a proposed Zero

Packaging Prioritization (ZPP) indicator in chapter 2.7. The goal and scope of the LCA would be fixed in chapter 2.8 following which we will round off the section with a detailed explanation of the four case studies in chapter 2.9.

2.2 Literature Review of Zero-waste Concept Implementation

Literature review was done to find out what the academia world is doing to implement the zero-waste concept in the food product sector. Two existing studies [27,30] proposed indicators looking at the comparison between carbon emissions from the packaging used and carbon emissions from the food component for specific food products. These indicators are helpful in giving perspective to which particular packaging system for specific food products should the focus be on to yield the largest impact in terms of overall carbon emission reduction. They take into account both the packaging and food component of a food product which gives a more holistic view.

For the first study [30], the following indicator shown in Equation (1) was proposed to assess the environmental impacts of the packaging together with the corresponding product in an attempt to achieve a universal methodology that would enable this complex assessment [30].

$$PtP_{CC}(\%) = \sum CC_{Pa} / \sum CC_{Pr} * 100, \quad (1)$$

$PtP_{CC}(\%)$ represents the ratio of the environmental impacts of the packaging ($\sum CC_{Pa}$) when compared to the packaged product ($\sum CC_{Pr}$).

For the second study [27], the following indicator shown in Equation (2) was proposed to illustrate both the importance of considering food waste when comparing packaging alternatives, and the potential for using packaging to reduce overall system impacts by reducing food waste [27].

$$FTP_E = \frac{\left[E\left(\frac{agricultural\ (farm\ gate) production}{kg\ food}\right) + E\left(\frac{food\ processing}{kg\ food}\right)\right]}{E\left(\frac{packaging\ materials}{kg\ food}\right)}, \quad (2)$$

FTP represents the food to packaging environmental impact relationship with E being the environmental impact indicator of interest. At very low FTP ratios, it is likely preferable to focus attention on reducing the impact of the packaging through light weighting, alternative material selection, etc. as food waste reduction will not have significant influence on the total system environmental performance.

Although the two indicators have slightly different purposes their end goal remains the same, and that is to look at the food products, inclusive of both the food and packaging component, from the environmental perspective in an attempt to rethink packaging. In both studies, environmental impact was their only form of measure with the economic and social perspectives missing. Additionally, both studies were based on the Life Cycle Assessment (LCA) methodology.

2.3 Life Cycle Assessment (LCA)

LCA is used to evaluate environmental impacts by assessing the carbon footprint across the entire life cycle of products and services [16,17]. To ensure that this study remains coherent and comparable with the two existing studies that were both based on LCA, there is a need to do LCA for our study. The methodology applied for this assessment is based on the International Organizational Standard for life cycle assessment ISO 14040/44, ISO 14067 [20,21,22]. An approach of life cycle assessment is employed to quantify the emissions of six key GHGs including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). The impacts of these GHGs are converted into the weight measurement of CO_2 equivalent (CO_2e) on a 100-year time scale, using global warming potential (GWP) recommended by the Inter-governmental Panel on Climate Change (IPCC).

The reason why we are focusing on global warming potential as an indicator is because climate change and carbon emission are the more well-known keywords among the general public, we deem it as a good place to start for our study in order to bring their attention to the carbon footprint in their daily lives. In addition, both of the conventional indicators used global warming potential as their measure. The paper will be structured according to the life cycle assessment framework presented in ISO14040:2006 as shown in Figure 4 below [21].

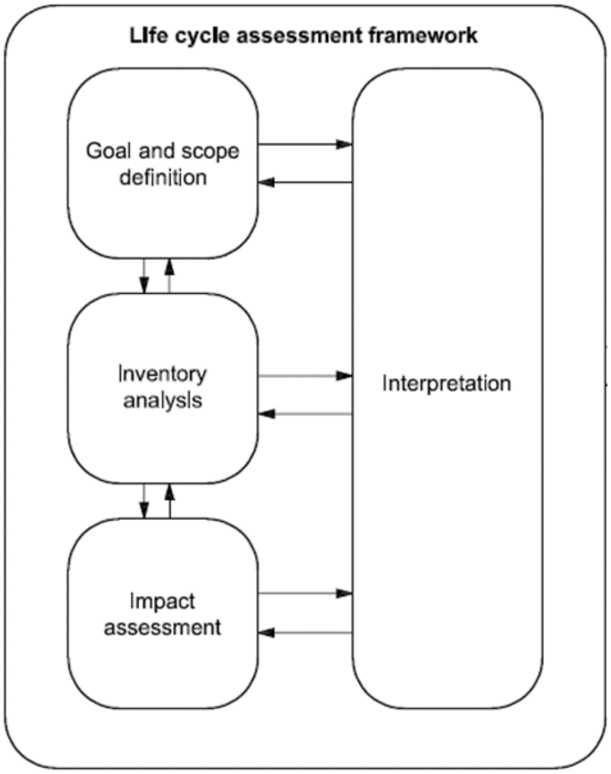

Figure 4:Life cycle assessment framework from ISO14040 [21]

2.4 Literature review of existing LCA studies in the food and packaging context

LCA studies have been conducted for supermarkets [24,25] and across the food supply chain [29]. LCA has also been conducted for plastic carrier bags made from different combinations of plastics and comparative studies between conventional plastic bags and bioplastic bags [23]. The general consensus in the LCA community is that there is a lack of perspective with regards to the food waste and loss generated during distribution and retail due to the reduction of packaging across the food chain [26,27]. There is a need for more LCA studies that pay equal attention to both the food component and the packaging component [28].

2.5 Qualitative Study: Tokyu Department Store, Hiyoshi

Currently, Japanese department stores have started charging for their paper and plastic bags in the hopes of reducing customer consumption of packaging. Prices for plastic bags range from 2 to 8 yen while paper bags go for 20 yen per piece. According to the Japan Department Stores Association, they are going to push for something called 'smart wrapping' which promotes the use of eco-bags and packing of things together in the same bag to reduce packaging used [15].

An interview was conducted with the waste manager of Tokyu department store, Hiyoshi in order to find out what they think about zero packaging and what do they prioritize if they were to implement it in their stores. The findings are summarized in Table 2 below.

Topic of concern	Findings from interview with Tokyu department store, Hiyoshi
Current operations	• Paying recycling companies to collect their packaging waste which is mainly tertiary packaging with cardboard boxes being the main waste stream • Does in-house recycling of tertiary plastic packaging waste (i.e. processing into bars) • Pays a third-party recycling company to collect their recycled plastics which is their current pain point because the recycling companies are increasing the prices • Leave amount of primary and tertiary packaging used to their suppliers • No plans or actions to reduce plastic packaging
Largest plastic waste stream in shop front	• Food section (plastic bags and food containers)
Zero-waste concept	• They will like to consider zero waste concept • If customers are able to accept they would love to reduce even more because this translates to cost reduction for them

	• Another factor of consideration is how much resource usage are they reducing

Table 2:Summary of interview with Tokyu department store Hiyoshi

From the interview, we can gather that the department store would like to incorporate zero-waste concept into their operations if it translates to cost reduction and their customers are able to accept the new business operations. At the same time, they currently do not have plans for a zero-waste food section.

Contrary to what the academia world thinks, environmental impact is not the only thing that matters. Department stores consider the social (customer acceptance) and economic (cost reduction) perspectives to be important as well.

2.6 Purpose and objectives of this study

The purpose of this study is to aid department store managers in Japan to incorporate zero-waste concept into their current operations by proposing a zero packaging prioritization indicator takes in the environmental perspective as well as the missing economic and social perspectives and testing it using case studies.

The objectives of this study are: 1) Life Cycle Assessment (LCA) to model and benchmark the carbon emissions from both the food and packaging components. LCA will be done to ensure that this study is comparable with existing studies which were all based on LCA. 2) Cost analysis to find out the cost of packaging to provide the missing economic perspective. 3) Propose a new indicator to help department stores prioritize the products to implement zero-packaging practices. Conventional indicators lack the perspectives desired by Japanese department stores, namely economic and social perspectives. The indicator proposed in this study takes into account the environmental perspective, the economic perspective and the social perspective.

2.7 Proposed indicator for this study

This study builds on the two indicators proposed by the two studies [27,30] by incorporating the emissions from food production and processing into a single factor (i.e. $\mathrm{CFP-FOOD}_i$) in order to simplify the sub-function since we have no need for such details for the scope of our study. The ratio of emissions from packaging to $\mathrm{CFP-FOOD}_i$ then makes up the first sub-function which gives us an environmental perspective. Sub-functions for the economic and social perspectives were added in order to ensure better applicability in the context of Japanese department store food sections. The proposed indicator as shown in Equation (3) that would be studied using four case studies would be as follows:

$$ZPP_i = w_1 \frac{\mathrm{CFP-PACKAGING}_{,i}}{\mathrm{CFP-FOOD}_i} + w_2 \frac{\mathrm{Cost-PACKAGING}_i}{\mathrm{Cost-UNIT\ PRODUCT}_i} + w_3 \mathrm{PS}_i \,, \qquad (3)$$

i : food product ; Coffee = 1, Banana = 2, Soybean = 3, Daikon = 4

i refers to the food product selected for each case study with $i = 1$ referring to the case of coffee, $i = 2$ referring to the case of bananas, $i = 3$ referring to the case of soybeans and $i = 4$ referring to the case of daikon radish. ZPP_i refers to the Zero Packaging Prioritization indicator for food product i; $\mathrm{CFP-PACKAGING}_{,i}$ refers to the carbon footprint of packaging per kg food product i sold; $\mathrm{CFP-FOOD}_i$ refers to the carbon footprint of food production and processing per kg food product i sold; $\mathrm{Cost-PACKAGING}_i$ refers to the cost of packaging used across the life cycle per unit product for food product i;

$\mathrm{Cost-UNIT\ PRODUCT}_i$ refers to the selling price of the unit product for food product i; PS_i refers to the Potential Score which is the potential for food product i to adopt zero-packaging practices. This score was given by stakeholders across the supply chain, including the consumers and provides us with the social perspective with regards to packaging removal. w_1, w_2 and w_3 are the weightages for each of the sub-functions and they were obtained from a separate interview with Tokyu department store, Hiyoshi.

In addition to carbon emission found in conventional indicators, ZPP is the new indicator proposed in this study which includes both the economic and social perspectives. Both cost reduction and customer acceptance were identified as desirable factors of consideration by Tokyu department store, Hiyoshi during our interview. ZPP will help department stores prioritize the products to implement zero-packaging practices.

2.8 Goal and scope definition for LCA

The goal of this LCA study would be to assess the environmental impact of packaging (mostly plastic) across the food chain together with the environmental impact of food production. The functional unit chosen is 1kg of product sold at the department store.

The packaging included in the scope of this study includes the primary and secondary packaging. Šerešová and Koˇcí [30] gave a great definition for the three different groups of packaging:

Primary packaging is the packaging that comes into direct contact with the food and serves multiple functions such as protection and labelling. All of the primary packaging used for the four case studies are made from plastic and the cradle to grave emissions from all the primary packaging would be included in the scope of this study.

Secondary packaging facilitates the transport of multiple primary packages during the distribution stages within the food chain. It essentially functions as a means for group packaging. The secondary packaging included in the scope of this study would be the cardboard boxes and plastic lining being used for group packaging when transporting products in bulk across the supply chain.

Tertiary packaging is to facilitate transportation of the grouped products. Resources being used for tertiary packaging are usually reused multiple times before disposal or recycling (e.g. pallets). Hence, they are not included in the scope of this study since the focus of this study is on single use plastic packaging.

A generic process flow used for all four case studies is shown in Figure 5 below. The study will include four life cycle stages, namely: Raw material extraction, Processing, Distribution and End-of-Life. The scope of the study does not include usage by the consumers because that would be out of the control of the department store management. Emissions from transportation and incineration of waste packaging after usage by the department store as well as consumers are taken into account. The department store at Hiyoshi does in-house processing of the plastic film they receive along with the logistical transportation of the goods before sending the resulting plastic pellets to a third-party recycler. Emissions from this in-house processing is taken into account in the scope of this study and placed under the process “Recycling”. However, the actual recycling done by the third-party company as well as the avoided emissions from using recycled plastic pellets in the production of plastic packaging is not taken into account in the scope of this study mainly because the plastic packaging used in this study was not made from recycled plastic. On the other hand, the avoided emissions of electricity production from the incineration process of plastic packaging and other waste were included in this study as energy recovery from biomass.

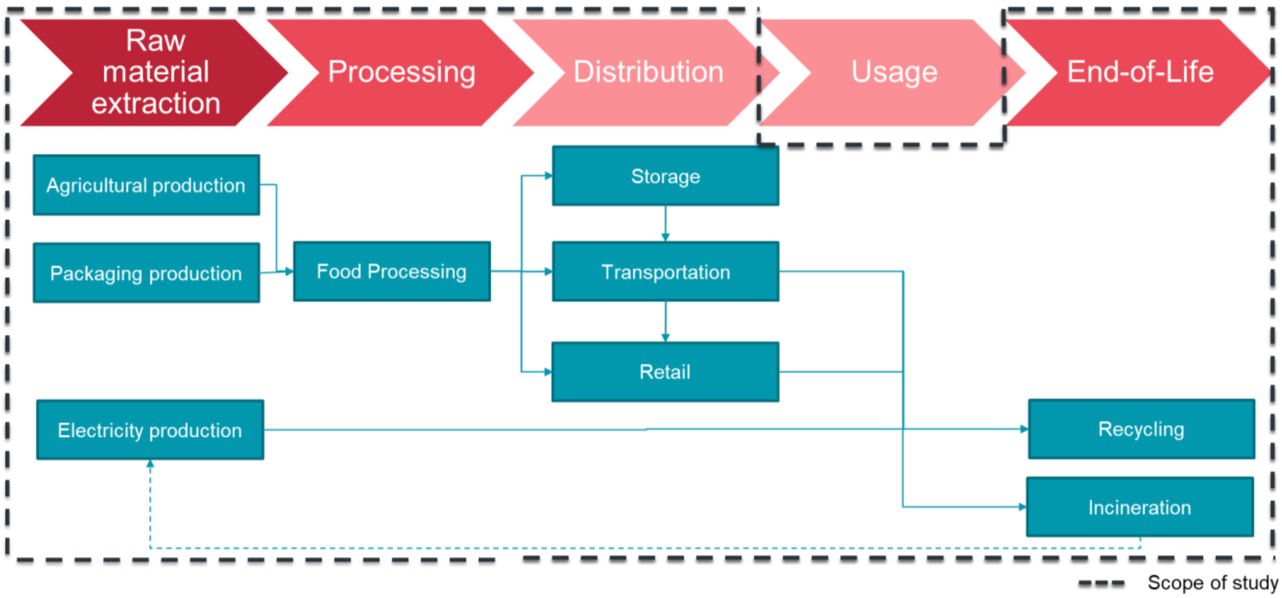

Figure 5:Generic process flow and scope used for case studies

2.9 Case Study

2.9.1 Selection of food products

The four case studies in this study were chosen based on a previous study done by Heller et al. [27]. In the previous study, it was concluded that it is likely preferable to reduce impacts of packaging for food types like beverages, fruit, legumes/nuts and vegetables as food waste reduction would not have significant influence on total system environmental performance. A table of the food products chosen for each food type for our context of Japanese department store can be found in Table 3 below.

Food type	Food product	Reason
Beverage	Coffee (bottled)	70.66% of respondents of Japan stated they drink coffee regularly [31]

Fruit	Bananas	6kg of bananas (out of 25.5kg of fresh fruits) were purchased by a Japanese person for the whole of 2016, making bananas the most purchased fresh fruit that can be singularly identified [32]
Legumes/nuts	Soybeans	Soybean is the most planted legume in Japan with annual productions going up to 231,700tons [33].
Vegetables	Daikon radish	Daikon radish is the top consumed vegetable in Japan as found by this study [34].

Table 3:Food products chosen for the case study

2.9.2 Process Flow

Building upon the generic process flow and keeping within the scope defined in Figure 5 above, a process flow is created for each of the case study and presented in the following sections.

2.9.2.1 Process flow for case study of bottled coffee

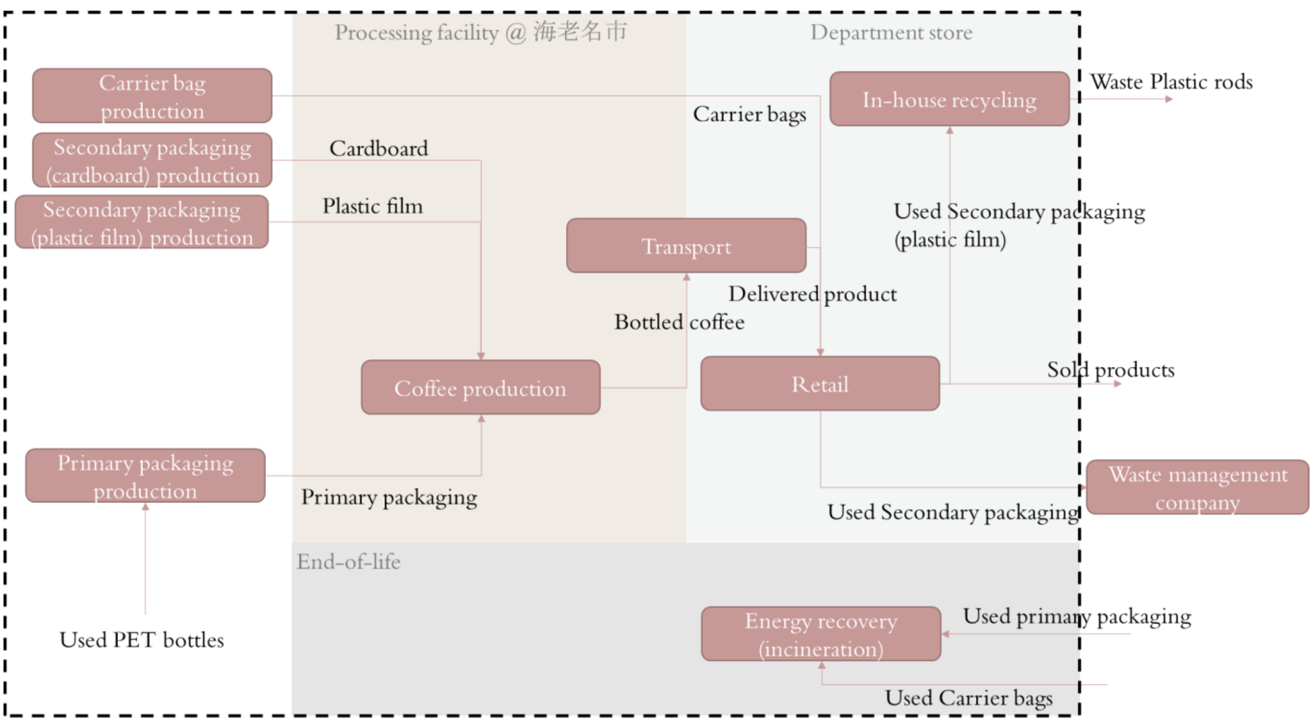

Figure 6:Process flow for bottled coffee

The process flow for bottled coffee is presented in Figure 6 above. Primary packaging production is taken to be at the bottle manufacturing plant of Suntory in Gunma prefecture [36]. Coffee production is taken to be at their processing plant in Ebina, Kanagawa prefecture [37]. The emission from the recycling of PET bottles and incineration of waste plastic from the primary and secondary packaging are taken into account in this study.

2.9.2.2 Process flow for case study of Bananas

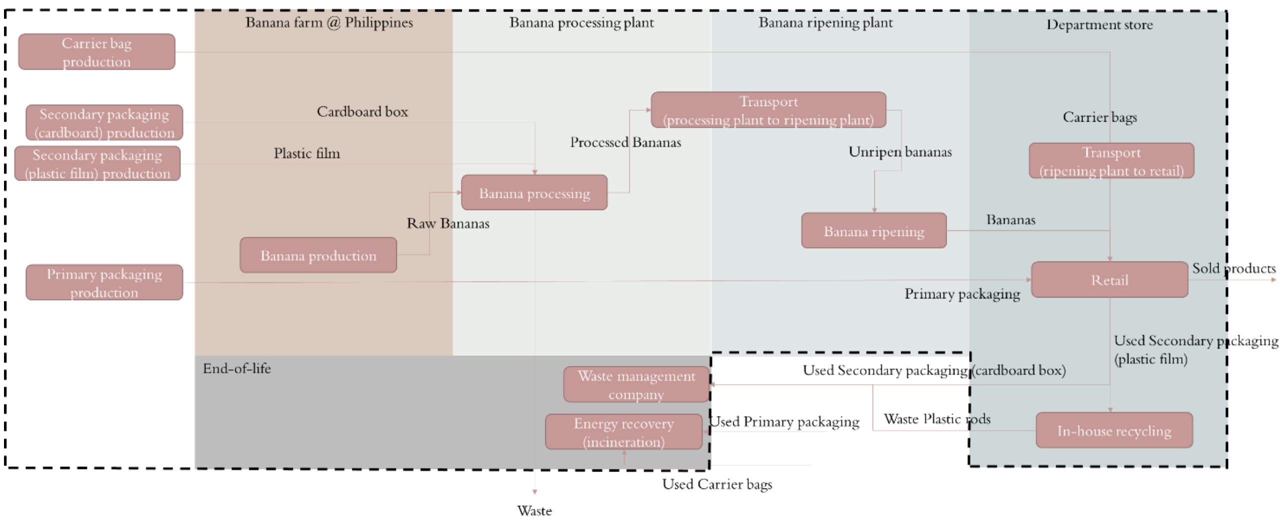

Figure 7:Process flow for bananas produced in the Philippines

The process flow for bananas for our case study is shown in Figure 7 above. The bananas were assumed to be grown in the island of Mindanao in the Philippines according to Dole's website for this particular type of bananas [38], which is assumed to be the Cavendish type. The bananas are then processed and packed before being shipped to Tokyo where it will go through a ripening process and finally distributed to the stores for retail. Due to bananas being relatively fragile, it is deemed necessary to transport them in a refrigerated setting. Hence, emissions from the refrigeration during transport during freight shipping and ground transport were all taken into account for this case study. Furthermore, due to the fact that bananas are deemed even more fragile after the ripening process, ripening facilities are built within a 200km distance away from central Tokyo [43]. This process flow of bananas was formed by the help of other published studies on the supply chain of bananas [39, 40].

2.9.2.3 Process flow for case study of Soybeans

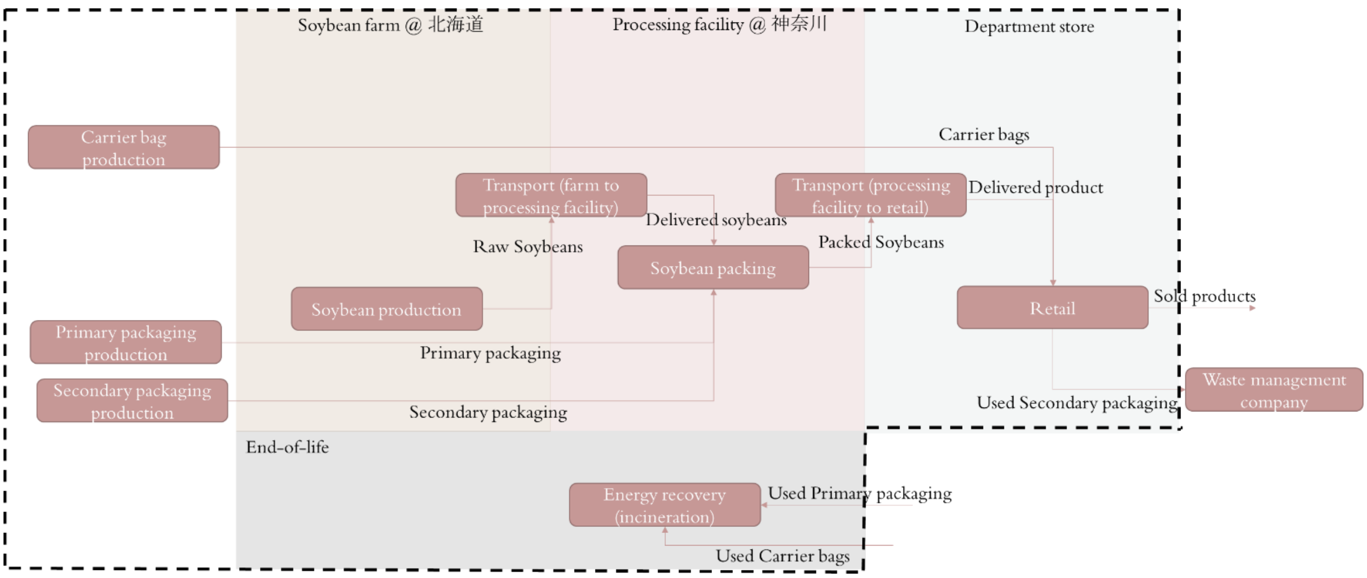

Figure 8:Process flow for soybeans

The process flow of soybeans for our case study is presented in Figure 8 above. The soybeans are indicated to be produced in the Hokkaido prefecture and processed in a facility in Kanagawa prefecture on its primary packaging. In this study, it was assumed that the soybeans were produced in a farm in Naganuma because this city has the largest soybean production in Hokkaido [51]. The soybeans are then assumed to be transported to Sagamihara, Kanagawa as indicated in the primary packaging of the soybeans. Soybeans are assumed to be bulk transported [41,42], hence packaging is only introduced into the flow at the processing facility.

2.9.2.4 Process flow for case study of Daikon Radish

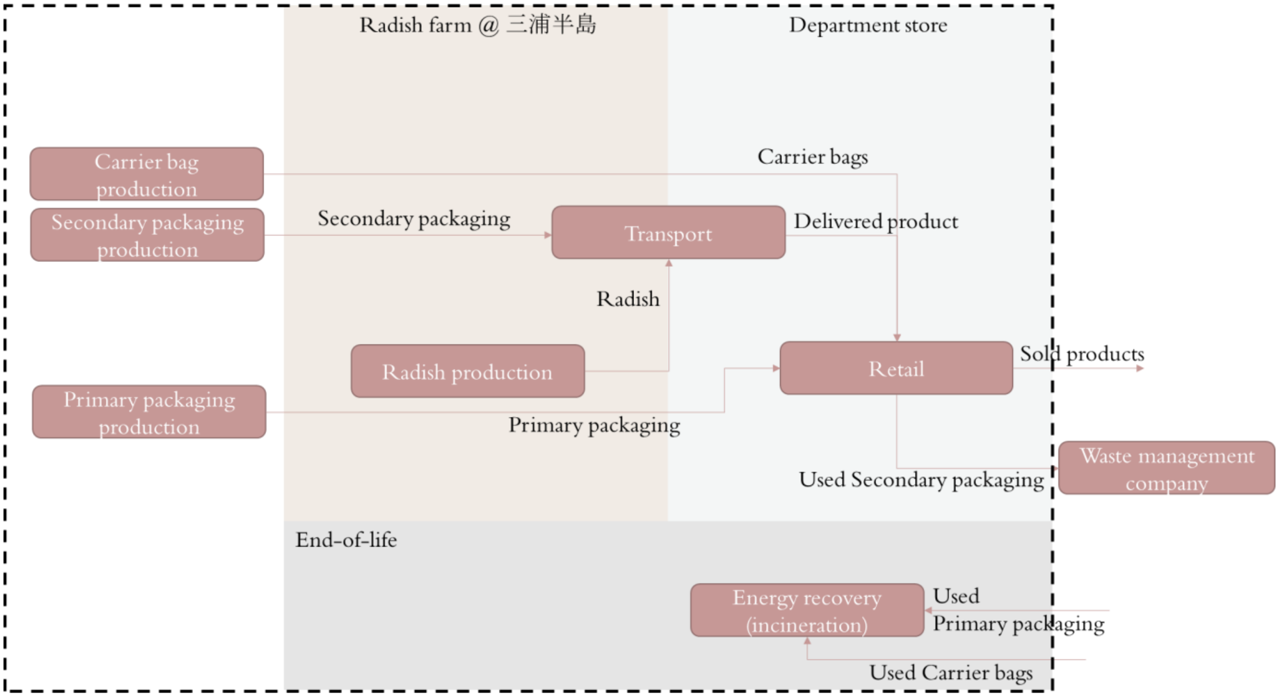

Figure 9:Process flow for daikon radish

The process flow for Daikon radish is presented in Figure 9 above. The daikon radish is indicated to be produced in the Kanagawa prefecture and further processed at Tokyu department store, Hiyoshi on its primary packaging. In this study, it was assumed that the daikon radish are produced in Miura island in Kanagawa prefecture.

2.9.3 Life Cycle Inventory

The primary data collected for this study includes the primary packaging used for the four food items chosen for the case study that are being sold in the food section of Tokyu department store, Hiyoshi. The primary data collected can be found in Table 4 below. Primary data was collected by weight measurement of the packaging.

Food product	**Origin**	**Amount of food (kg)**	**Material of primary packaging**	**Weight of primary packaging (kg)**	**Price (¥)**
Bottled coffee	Japan	0.5	PET (bottle) PP (cap)	0.016 0.002	178

			LDPE (label)	0.001	
Bananas	Philippines	0.523	PP	0.003	290
Soybeans	Hokkaido	0.204	LDPE	0.005	220
Daikon radish	Kanagawa	0.418	LDPE film	0.001	91

Table 4:Primary data collected for primary packaging used for chosen products sold in Tokyu department store, Hiyoshi

The secondary data collected are mainly from Japanese sources in order to preserve the geographical accuracy of this study. The emission factors collected and used for the four case studies and their sources are recorded in Table 5 below.

Output	Emission Factor	Source
Electricity	0.464 kgCO2e/kWh	Agency for Nature Resources and Energy, Japan [35]
500ml PET bottle with label and cap[1]	3.99 kgCO2e/kg	The Institute of Life Cycle Assessment, Japan [44]
Brewed coffee[2]	0.053 kgCO2e/200ml	The Institute of Life Cycle Assessment, Japan [44]
Cardboard box[3]	0.554 kgCO2e/kg	The Japan Corrugated Case Association 全国段ボール工業組合連合会 [45]
LDPE film[5]	2.06 kgCO2e/kg	Ministry of Environment, Japan [46]
Carrier bags[4]	4.85 kgCO2e/kg	Ministry of Environment, Japan [46]
Ground transportation (4t truck, 50% filled)	0.325 kgCO2e/t.km	Ministry of Environment, Japan [46]
PP	4.63 kgCO2e/kg	Ministry of Environment, Japan [46]
LDPE liner[5]	1.53 kgCO2e/kg	Ministry of Environment, Japan [46]
Bananas	0.22 kgCO2e/kg	International Journal of Life Cycle Assessment [40]
Processed bananas	0.017 kgCO2e/kg	International Journal of Life Cycle Assessment [40]
Ripened bananas	0.286 kgCO2e/kg	Ajinomoto [47]
Large container ship transportation	1.12E-05 kgCO2e/kg.km	International Journal of Life Cycle Assessment [40]
Refrigerant for ship	0.08E-03 kgCO2e/kg	International Journal of Life Cycle Assessment [40]
Refrigerated cargo truck transportation	9.83E-05 kgCO2e/kg.km	Ministry of land, infrastructure, transport and tourism, Japan 国土交通省[48]
Recycled plastic pellets, in-house	1.21 kWh/kg	Nihon Yuki Co. Ltd. 日本油機 [49]
LDPE packaging[4]	4.67 kgCO2e/kg	Ministry of Environment, Japan [46]
Soybeans	0.371 kgCO2e/kg	Ajinomoto [47]
LDPE film[4]	5.2 kgCO2e/kg	Ministry of Environment, Japan [46]
Daikon	0.18 kgCO2e/kg	City of Nagoya [50]

Table 5:Emission factors sourced for this study

[1]Inclusive of carbon emissions from production of PET bottle with label and cap and disposal and recycling

[2]Inclusive of production of coffee beans and brewing of coffee which was taken to be in Japan
[3]Assumed recycled since cardboard boxes are made mostly from recycled paper pulp
[4]Inclusive of production, transportation at End-of-Life stage and Incineration
[5]Excluding End-of-Life stage transportation and incineration

The secondary data were all calculated in the context of Japan with the coffee production being converted to being produced in Japan in the published study. The only exception being the production, processing and harbor handling of bananas. The data was taken from a published study that did data collection from a banana production site in Costa Rica. As details of the published data for the Costa Rican banana case study were not intricate enough for me to modify the study to better suit the context of our case study i.e. the Philippines, the uncertainty due to the secondary data used would be further analyzed in a sensitivity analysis in the later part of this study.

Secondary data was also collected for the cost of the resource flows for each of the case studies. They were mainly collected from Japanese sources as well in order to maintain the geographical integrity of the data. The recycling costs of the packaging were calculated using equation (4) published by The Japan Containers and Packaging Recycling Association [53].

$$Recycling\ fee = amount\ of\ output \times Calculation\ coffeicient\ \times Recycling\ unit\ cost, \quad (4)$$

In addition, the cost of cardboard box production and recycling is calculated based on the flow depicted by Corrugated Packaging Recycling Council, Japan [57]. The cost data for all the case studies can be found in Table 6 below.

Resource	Cost	Source
Electricity, 1kWh	21.87 ¥	GlobalPetrolPrices [52]

Recycling fee, PET bottle	(4.5¥ × 0.38352)/kg	The Japan Containers and Packaging Recycling [54]
Production cost, PET bottle	4374¥/kg	Rakuten [55]
Production cost, cardboard box	10¥/kg	The Japan Corrugated Case Association 全国段ボール工業組合連合会 [56]
Recycling cost, cardboard box	(5+2+10) ¥/kg	こづか株式会社 [58] Ministry of Economy, Trade and Industry, Japan [59]
Production cost, plastic film	33¥/kg	東洋紡[60]
Recycling cost, plastic film	(51¥ × 0.38352)/kg	The Japan Containers and Packaging Recycling [54]
Production cost, carrier bags	593¥/kg	Adpoly [61]
Recycling cost, carrier bags	(51¥ × 0.62711)/kg	The Japan Containers and Packaging Recycling [54]
Production cost, PP packaging	2163¥/kg	Monotaro [62]
Recycling cost, PP packaging	(51¥ × 0.60437)/kg	The Japan Containers and Packaging Recycling [54]
Production cost, LDPE liner	19¥/kg	Rakuten [63]
Recycling cost, LDPE liner	(51¥ × 0.60437)/kg	The Japan Containers and Packaging Recycling [54]

Table 6: Cost data for resource flows

2.9.4 Life Cycle Impact Assessment

In this study, the matrix-based method would be used to evaluate the environmental impact [18] due to the fact that the matrix-based method is a more efficient modeling method as compared to the conventional process-based model. A matrix-based method streamlines the calculation by removing the need to normalize [18]. The fundamental Equation (5) governing this method is:

$$s = A^{-1}f, \tag{5}$$

in which *f* is the functional unit, $\boldsymbol{A^{-1}}$ is the inverse of the technology matrix ***A*** which depicts the flows going in and out of each process and s is the scaling vector. The purpose of the scaling vector is to proportionate the technology matrix according to the functional unit defined.

The carbon emission and packaging cost, also known as ***g***, from each case study is then calculated using Equation (6) below:

$$g = Bs, \tag{6}$$

Where ***B*** refers to the intervention matrix which represents all the flows which comes from or g to the environment. *s* is the scaling vector derived from equation (iv). **g** in this study represents all the environmental flows in the system associated with the reference flow under consideration. In our case, **g** consists of both greenhouse gas emissions in terms of carbon dioxide equivalent and packaging costs for our cradle-to-grave system of 1kg of food sold. The technology matrix ***A***, functional unit *f*, scaling vector *s,* intervention matrix **B**, and resulting inventory vector **g** for each case study would be presented in the subsequent sections. For a more detailed look at the process flows and calculations, please refer to the attached appendix for the excel sheets.

2.9.4.1 Life Cycle Impact Assessment for the case of Bottled Coffee

For the case study of bottled coffee, the flows going in and out of each process is presented in $\boldsymbol{A}_{bottled\ coffee}$ as shown in Equation (7) below. The matrix is built according to the processes mapped out in Figure 6. Equation (8) represents the functional unit which is 1kg of bottled coffee sold in Tokyu department store Hiyoshi.

$$\boldsymbol{A}_{bottled\ coffee} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & -0.019 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.519 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & -0.0044 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & -0.0029 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1.0073 & -0.519 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & -0.068 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.587 \end{pmatrix}, \qquad (7)$$

$$f_{bottled\ coffee} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}, \qquad (8)$$

Using Equation (5), we have:

$$s_{bottled\ coffee} = \boldsymbol{A}^{-1}_{bottled\ coffee} f_{bottled\ coffee}$$

$$= \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0.0366 & 0 & 0 & 0.036 & 0 & 0.032 \\ 0 & 0 & 1.92 & 0 & 0 & 1.913 & 0 & 1.69 \\ 0 & 0 & 0 & 1 & 0 & 0.0044 & 0 & 0.004 \\ 0 & 0 & 0 & 0 & 1 & 0.0029 & 0 & 0.0025 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0.1158 \\ 0 & 0 & 0 & 0 & 0 & 0.993 & 0 & 0.8777 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.70 \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}$$

$$= \begin{pmatrix} 0 \\ 0.032 \\ 1.7 \\ 0.00386 \\ 0.0025 \\ 0.116 \\ 0.88 \\ 1.7 \end{pmatrix}, \qquad (9)$$

With $s_{bottled\ coffee}$ being the scaling vector, which is needed to proportionate the technology matrix, $\boldsymbol{A}_{bottled\ coffee}$ according to our defined functional unit, $f_{bottled\ coffee}$.

The inventory matrix representing all the flows which comes from or goes to the environment is defined in Equation (10) below:

$$\boldsymbol{B}_{bottled\ coffee} = \begin{pmatrix} 0.464 & 3.99 & 0.13 & 0.554 & 2.06 & 4.85 & 0.013 & 0.00163 \\ 21.87 & 4375 & 0 & 27.1 & 63.8 & 625.1 & 0 & 0.0768 \end{pmatrix}, \qquad (10)$$

Applying both inventory matrix $\boldsymbol{B}_{bottled\ coffee}$ along with the scaling vector derived in Equation (9), $s_{bottled\ coffee}$ to Equation (6), we have:

$$g_{bottled\ coffee} = \boldsymbol{B}_{bottled\ coffee}\, s_{bottled\ coffee} = \begin{pmatrix} 0.932 \\ 213.4 \end{pmatrix}, \qquad (11)$$

With the top row being the greenhouse gas emissions in terms of carbon dioxide equivalent and the bottom row being the packaging costs for our cradle-to-grave system of 1kg of bottled coffee sold in Tokyu Department store, Hiyoshi.

2.9.4.2 Life Cycle Impact Assessment for the case of Bananas

For the case study of bananas, the flows going in and out of each process is presented in $\boldsymbol{A}_{bananas}$ as shown in Equation (12) below. The matrix is built according to the processes mapped out in Figure 7. Equation (13) represents the functional unit which is 1kg of bananas sold in Tokyu department store Hiyoshi.

$$
\boldsymbol{A}_{bananas} = \begin{pmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & -0.0057 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & -0.0014 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & -0.0709 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1.0013 & 0 & -1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.006 & 0 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -0.526 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & -0.068 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.594
\end{pmatrix}, \qquad (12)
$$

$$
f_{bananas} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}, \qquad (13)
$$

Using Equation (5), we have:

$$
s_{bananas} = \boldsymbol{A}_{bananas}^{-1} f_{bananas}
$$

$$
= \begin{pmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0.057 & 0.0057 & 0 & 0.005 \\
0 & 0 & 0 & 1 & 0 & 0.0708 & 0.0708 & 0.0704 & 0.07 & 0 & 0.06 \\
0 & 0 & 1 & 0 & 0 & 0.0014 & 0.00139 & 0.0014 & 0.0014 & 0 & 0.001 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0.114 \\
0 & 0 & 0 & 0 & 1 & 0.9987 & 0.9987 & 0.993 & 0.993 & 0 & 0.88 \\
0 & 0 & 0 & 0 & 0 & 0.9987 & 0.9987 & 0.993 & 0.993 & 0 & 0.88 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.994 & 0.994 & 0 & 0.88 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0.994 & 0.994 & 0 & 0.88 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0.88 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.68
\end{pmatrix}
\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}
$$

$$= \begin{pmatrix} 0 \\ 0.005 \\ 0.06 \\ 0.001 \\ 0.114 \\ 0.88 \\ 0.88 \\ 0.88 \\ 0.88 \\ 0.88 \\ 1.68 \end{pmatrix}, \tag{14}$$

With $s_{bananas}$ being the scaling vector, which is needed to proportionate the technology matrix, $\boldsymbol{A}_{bananas}$ according to our defined functional unit, $f_{bananas}$.

The inventory matrix representing all the flows which comes from or goes to the environment is defined in Equation (15) below:

$$\boldsymbol{B}_{bananas} =$$

$$\begin{pmatrix} 0.464 & 4.63 & 0.554 & 1.53 & 4.85 & 0.22 & 0.017 & 0.286 & 0.0966 & 0.01625 & 0.0015 \\ 21.87 & 2194 & 27.13 & 49.54 & 625.1 & 0 & 0 & 0 & 0 & 0 & 0.0705 \end{pmatrix}, \tag{15}$$

Applying both inventory matrix $\boldsymbol{B}_{bananas}$ along with the scaling vector derived in Equation (14), $s_{bananas}$ to Equation (6), we have:

$$g_{bananas} = \boldsymbol{B}_{bananas}\, s_{bananas} = \begin{pmatrix} 1.18 \\ 84.5 \end{pmatrix}, \tag{16}$$

With the top row being the greenhouse gas emissions in terms of carbon dioxide equivalent and the bottom row being the packaging costs for our cradle-to-grave system of 1kg of bananas sold in Tokyu Department store, Hiyoshi.

2.9.4.3 Life Cycle Impact Assessment for the case of Soybeans

For the case study of soybeans, the flows going in and out of each process is presented in $\boldsymbol{A}_{soybeans}$ as shown in Equation (17) below. The matrix was built according to the processed mapped out in Figure 8. Equation (18) represents the functional unit which is 1kg of soybeans sold in Tokyu department store Hiyoshi.

$$\boldsymbol{A}_{soybeans} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & -0.0245 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & -0.0273 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1.052 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -0.209 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & -0.068 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.277 \end{pmatrix}, \quad (17)$$

$$f_{soybeans} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}, \quad (18)$$

Using Equation (5), we have:

$$s_{soybeans} = \boldsymbol{A}_{soybeans}^{-1} f_{soybeans}$$

$$= \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0.0233 & 0.0233 & 0 & 0.0176 \\ 0 & 0 & 1 & 0 & 1 & 0.95 & 0.95 & 0 & 0.717 \\ 0 & 0 & 0 & 1 & 0 & 0.026 & 0.026 & 0 & 0.02 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0.2455 \\ 0 & 0 & 0 & 0 & 0 & 0.95 & 0.95 & 0 & 0.717 \\ 0 & 0 & 0 & 0 & 1 & 0.95 & 0.95 & 0 & 0.717 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0.75 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3.61 \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}$$

$$= \begin{pmatrix} 0 \\ 0.0176 \\ 0.717 \\ 0.02 \\ 0.25 \\ 0.717 \\ 0.717 \\ 0.755 \\ 3.61 \end{pmatrix}, \tag{19}$$

With $s_{soybeans}$ being the scaling vector, which is needed to proportionate the technology matrix, $\boldsymbol{A}_{soybeans}$ according to our defined functional unit, $f_{soybeans}$.

The inventory matrix representing all the flows which comes from or goes to the environment is defined in equation (20) below:

$$\boldsymbol{B}_{soybeans} = \begin{pmatrix} 0.464 & 4.67 & 0.371 & 0.554 & 4.853 & 0 & 0.39 & 0.012 & 0 \\ 21.87 & 49.54 & 0 & 27.1 & 625 & 0 & 0 & 0 & 0 \end{pmatrix}, \tag{20}$$

Applying both inventory matrix $\boldsymbol{B}_{soybeans}$ along with the scaling vector derived in Equation (19), $s_{soybeans}$ to Equation (6), we have:

$$\mathrm{g}_{soybeans} = \boldsymbol{B}_{soybeans}\, s_{soybeans} = \begin{pmatrix} 1.84 \\ 154.9 \end{pmatrix}, \tag{21}$$

With the top row being the greenhouse gas emissions in terms of carbon dioxide equivalent and the bottom row being the packaging costs for our cradle-to-grave system of 1kg of soybeans sold in Tokyu Department store, Hiyoshi.

2.9.4.4 Life Cycle Impact Assessment for the Case of Daikon radish

For the case study of daikon radish, the flows going in and out of each process is presented in $\boldsymbol{A}_{daikon}$ as shown in Equation (22) below. The matrix is built according to the processes mapped out in Figure 9. Equation (23) represents the functional unit which is 1kg of daikon radish sold in Tokyu department store Hiyoshi.

$$A_{daikon} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & -0.001 \\ 0 & 0 & 1 & 0 & 0 & -10 & 0 \\ 0 & 0 & 0 & 1 & 0 & -0.97 & 0 \\ 0 & 0 & 0 & 0 & 0 & 10.97 & -0.418 \\ 0 & 0 & 0 & 0 & 1 & 0 & -0.068 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.487 \end{pmatrix}, \quad (22)$$

$$f_{bottled\ coffee} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}, \quad (23)$$

Using Equation (5), we have:

$$s_{daikon} = A_{daikon}^{-1} f_{daikon}$$

$$= \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0.002 \\ 0 & 0 & 1 & 0 & 0.912 & 0 & 0.782 \\ 0 & 0 & 0 & 1 & 0.088 & 0 & 0.0759 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0.14 \\ 0 & 0 & 0 & 0 & 0.091 & 0 & 0.08 \\ 0 & 0 & 0 & 0 & 0 & 0 & 2.0534 \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}$$

$$= \begin{pmatrix} 0 \\ 0.002 \\ 0.78 \\ 0.0759 \\ 0.14 \\ 0.078 \\ 2.05 \end{pmatrix}, \quad (24)$$

With s_{daikon} being the scaling vector, which is needed to proportionate the technology matrix, A_{daikon} according to our defined functional unit, f_{daikon}.

The inventory matrix representing all the flows which comes from or goes to the environment is defined in Equation (25) below:

$$\boldsymbol{B}_{daikon} = \begin{pmatrix} 0.464 & 5.2 & 0.18 & 0.554 & 4.85 & 0.214 & 0 \\ 21.87 & 63.8 & 0 & 27.1 & 625.1 & 0 & 0 \end{pmatrix}, \quad (25)$$

Applying both inventory matrix $\boldsymbol{B}_{daikon}$ along with the scaling vector derived in Equation (24), s_{daikon} to Equation (6), we have:

$$g_{daikon} = \boldsymbol{B}_{daikon}\, s_{daikon} = \begin{pmatrix} 0.888 \\ 89.5 \end{pmatrix}, \quad (26)$$

With the top row being the greenhouse gas emissions in terms of carbon dioxide equivalent and the bottom row being the packaging costs for our cradle-to-grave system of 1kg of daikon radish sold in Tokyu Department store, Hiyoshi.

3. Results

With the completion of life cycle impact assessment according to the goal and scope defined for the study and using the life cycle inventory collected, we have a set of results for the four case studies which were defined and elaborated in the previous chapter.

In the following sections, the results of carbon emissions, the cost of packaging as well as the Zero Packaging Prioritization (ZPP) indicators for the four case studies would be presented.

Following which a sensitivity analysis would be conducted to account for the uncertainties introduced from our use of secondary data.

3.1 Results of Carbon Emissions

The carbon emissions from each of the four case studies are presented in a graph as shown in Figure 10 below. The carbon emissions from each of the four case studies shown in Figure 10 are broken down into the four life cycle stages, namely: raw material extraction, processing, distribution and End-of-Life (EoL). As can be seen in Figure 10, the carbon emissions per kg of soybeans sold at Tokyu department store, Hiyoshi is the highest among the four case studies. This is followed by bananas, bottled coffee and lastly, daikon radish.

The proportions of carbon emission from each of the life cycle stages are compared between the four case studies and displayed in Figure 11 as shown below. As can be seen in Figure 11, the carbon emissions from the EoL stage is generally the largest in proportion for the four case studies, followed by raw material extraction, processing and lastly, distribution.

Some exceptions worth pointing out are the carbon emissions from the processing of bananas and the carbon emissions from the distribution of soybeans. These two categories are comparatively larger than for the other case studies.

For the processing of bananas, one possible reason could be the fact that bananas go through a chemical ripening process upon arriving at the port of the country which they will go on sale. This chemical ripening process takes place in a warehouse in a controlled environment whereby the bananas are exposed to ethylene gas for 3 to 4 days. The carbon emissions for the chemical usage of ethylene and for the resources required to maintain the controlled environment is taken into account in the processing stage for the banana case study, which could explain why the proportion of carbon emissions for the processing stage for the banana case study is comparatively larger than for the other case studies.

As for the soybean case whereby the carbon emission from distribution is proportionately larger than its counterparts from the other case studies, a possible explanation could be the fact that the distance travelled by ground transport for the soybeans from its production site (i.e. Hokkaido) to the processing site (i.e. Kanagawa) is exceptionally large (i.e. 1200km) as compared to the distances travelled by ground transport for the other products (50 to 200km).

One might argue that the distance travelled for bananas is way higher than for soybeans or the other products since bananas are the only food product that is being imported from outside of Japan (i.e. the Philippines). However, as can be seen in Figure 11, the proportion of carbon emissions from distribution of bananas is not as large as the proportion of carbon emissions from distribution of soybeans. One possible explanation could be the fact that the data used for the banana case study was for bulk cargo shipment on sea. The high density of products for a single shipment naturally makes this process highly carbon efficient which is why when compared to ground truck transport of soybeans, the transport of bananas is comparatively less in term of carbon emission.

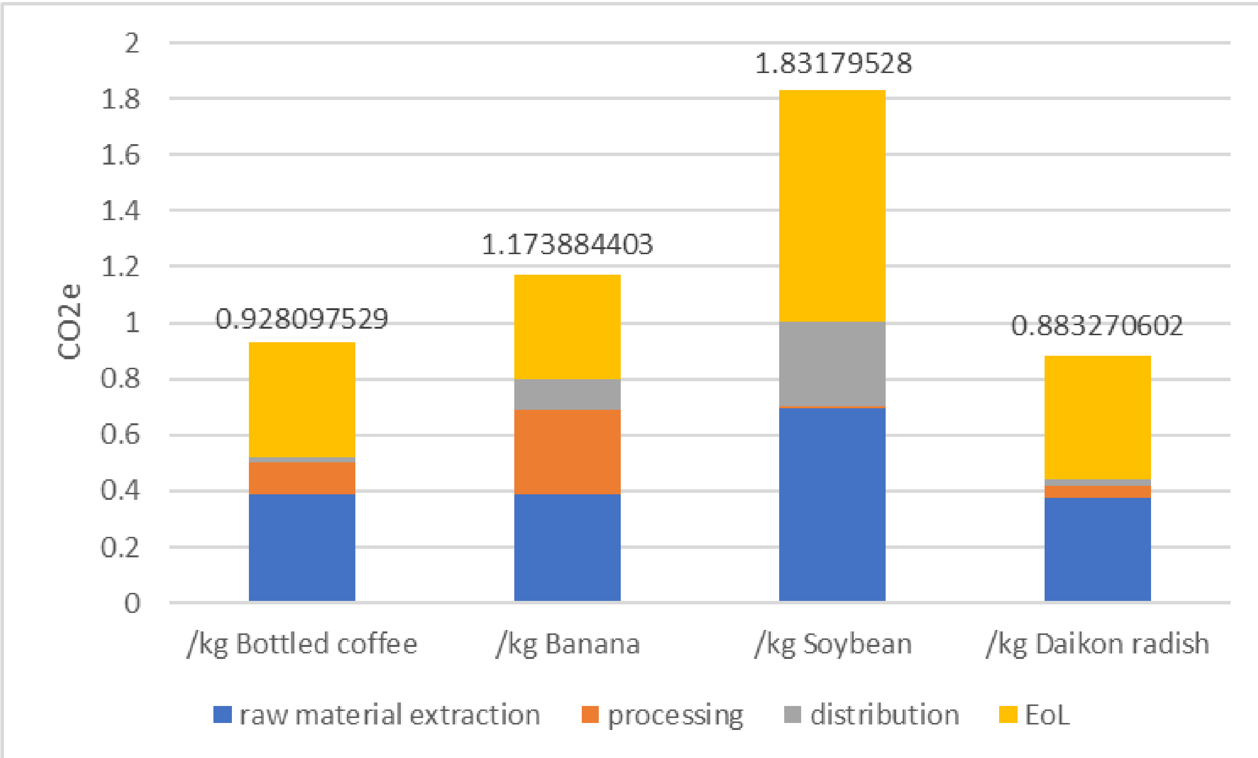

Figure 10: Carbon emission breakdown for the four case studies

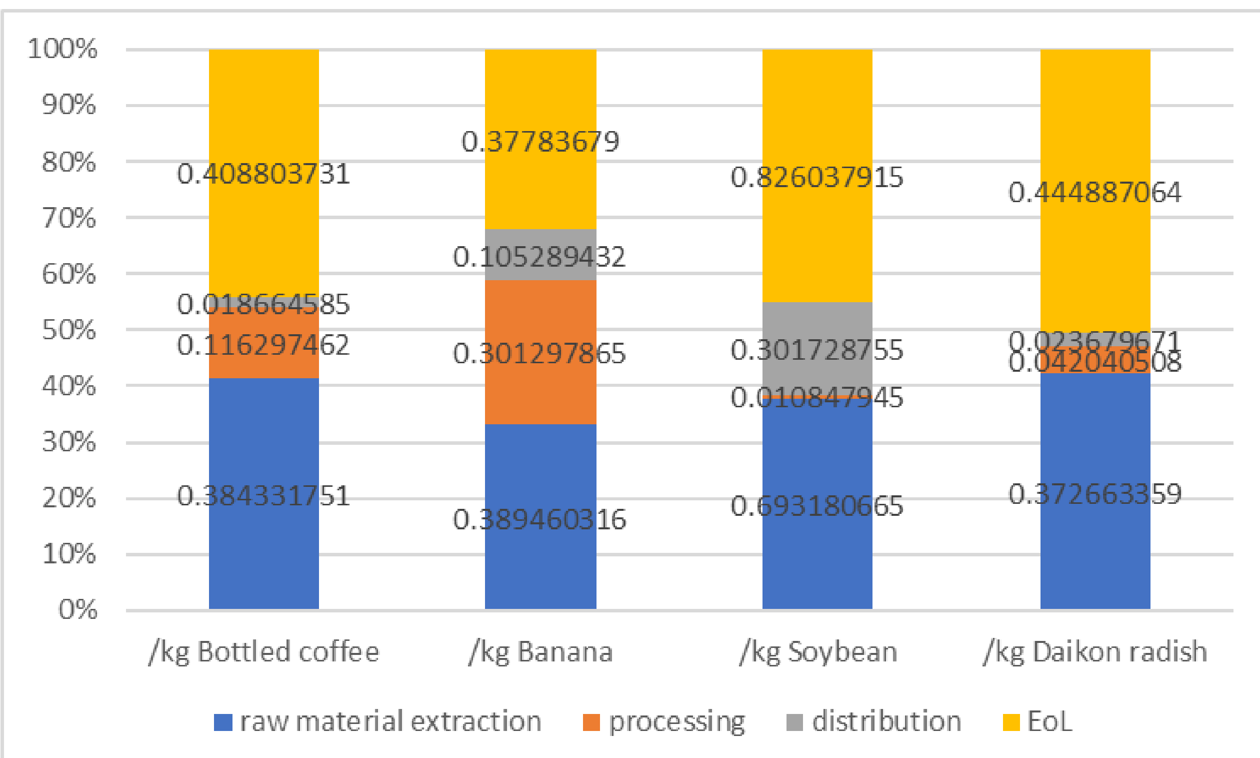

Figure 11:Carbon emission proportions for the four case studies

The carbon footprint of packaging used throughout the entire food chain is compared with the carbon footprint of the food component for each of the four products studied in our case studies. The results of which are presented in Figure 12 below. As can be seen, the carbon footprint of packaging per kg of soybean is the highest out of the four case studies. This could be due to the fact that the data collected for the soybean case study was based on a unit product of 200g of soybeans, which was then scaled to the functional unit of 1kg of soybeans.

In general, the carbon footprint of the packaging component was higher than the food component for all of the four case studies.

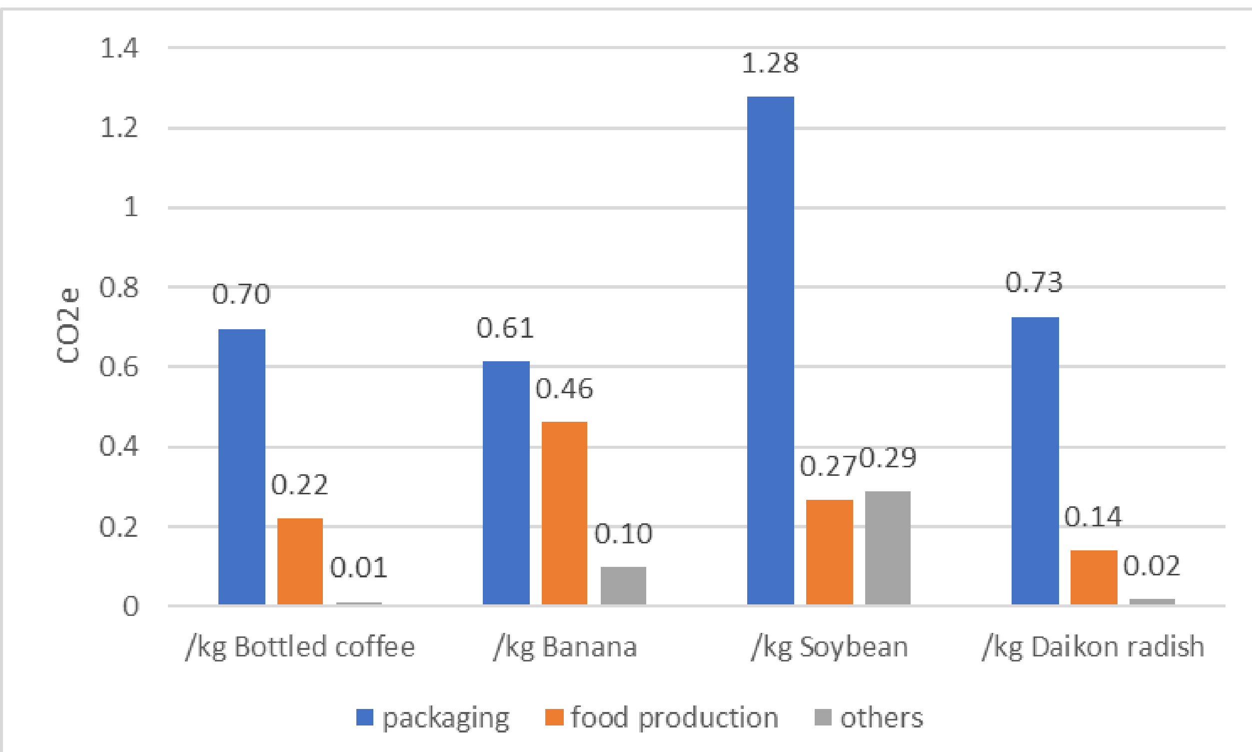

Figure 12:Carbon emissions from packaging VS food production

The carbon footprint of the different types of packaging used for each of the four case studies were compared and shown in Figure 13 below. As can be seen, the carbon footprint from the carrier bag was proportionately larger than for the other types of packaging, namely: primary packaging and secondary packaging.

This could be due to the fact that the data collected for the case studies was based on using a single carrier bag to hold one unit of product. The carbon footprint from carrier bags could be relatively lower when consumers pack as many products as possible into one single carrier bag, which would then result in the carbon footprint of the carrier bag being shared across the different products. However, despite this possible explanation, the fact remains that the carbon footprint of carrier bags are multiple folds more than the other types of packaging. This provides some form of support for the carrier bag levy being imposed on major retail stores here in Japan.

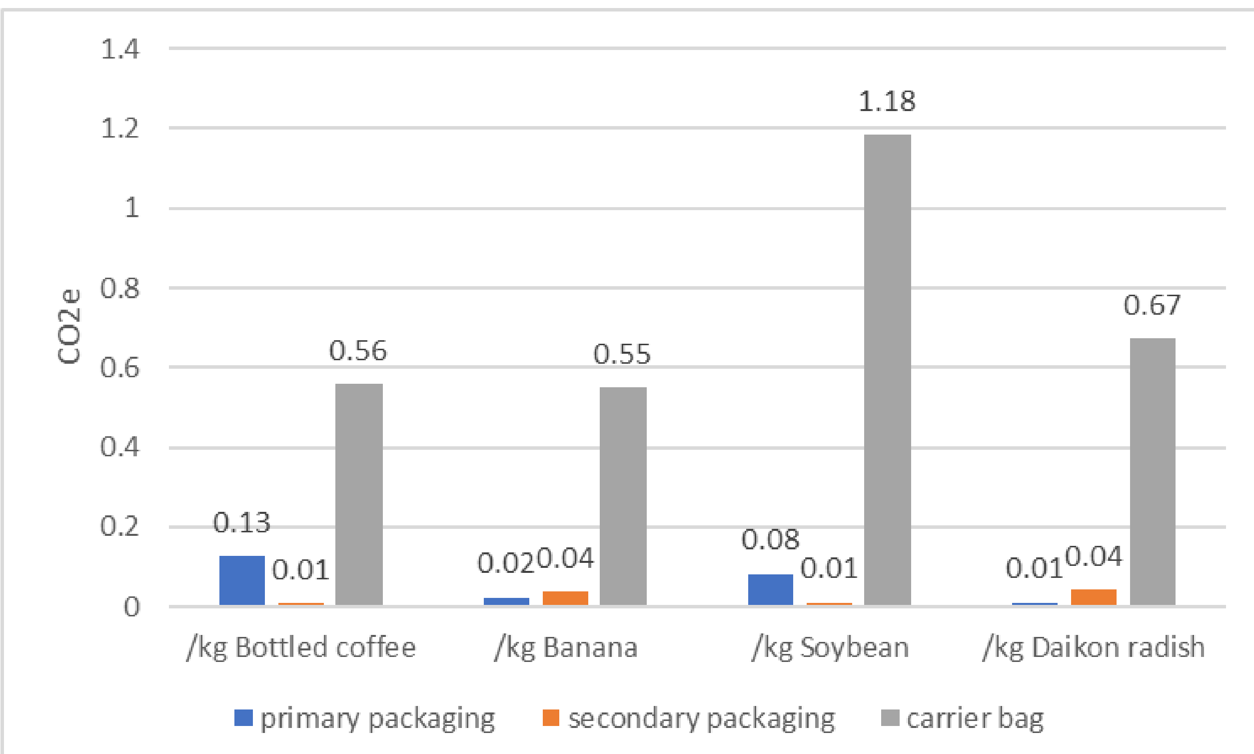

Figure 13:Carbon emissions from the different types of packaging

3.2 Packaging Cost Comparisons

Following the carbon footprint analysis for the four case studies as presented above, we will now take a look at the packaging costs for the four case studies in the following section.

The costs for the primary packaging, secondary packaging and carrier bags for each of the four case studies are shown in Figure 14, along with the total cost of packaging per kg of product sold. Echoing the carbon footprint analysis for the different types of packaging for each of the case studies as presented in the above section, the cost for the carrier bags takes up the largest proportion for all four case studies.

In general, the cost of packaging was the highest for the case of bottled coffee. This was largely due to the comparatively higher cost of the primary packaging for bottle coffee, namely PET bottles, labels and caps.

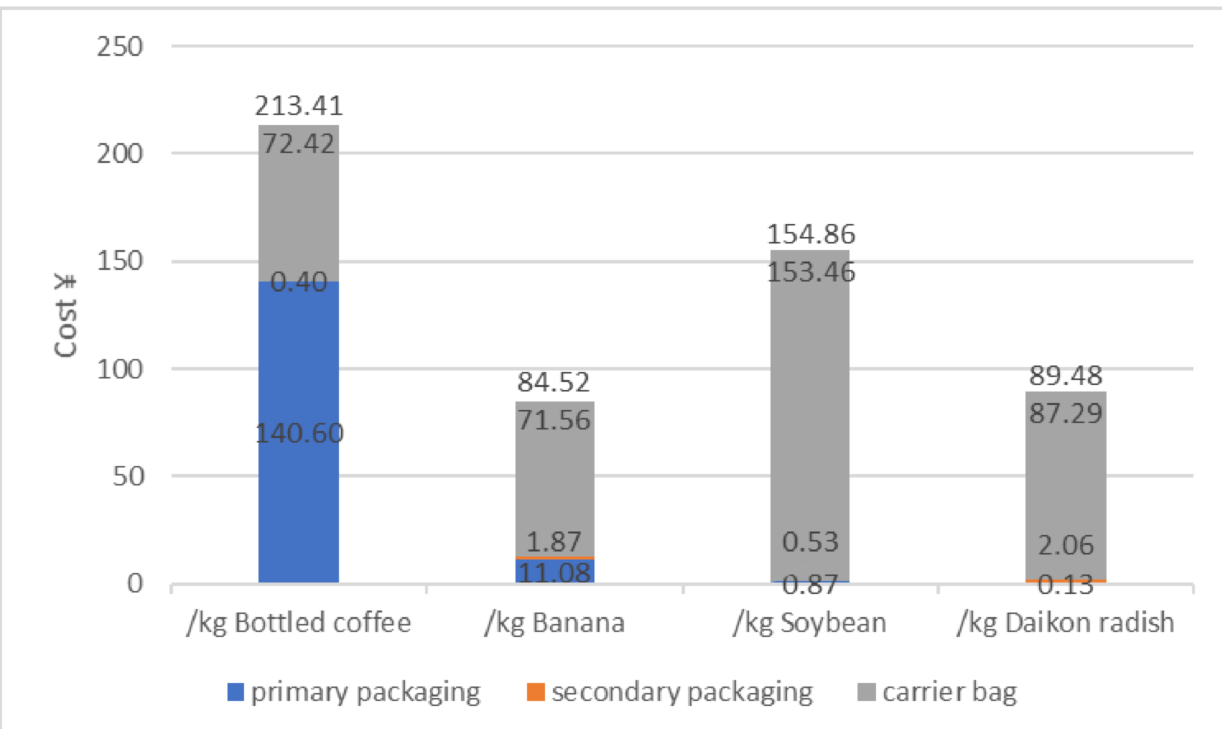

Figure 14:Costs of the different types of packaging

3.3 Zero Packaging Prioritization (ZPP) Indicator

As was mentioned in Chapter 2.7, a ZPP indicator was proposed for this study with the said indicator being derived from two other indicators that were published in separate studies [27,30]. ZPP is expected to help department stores prioritize the products to implement zero-packaging practices. The ZPP indicator is proposed to be as follows:

$$ZPP_i = w_1 \frac{\text{CFP−PACKAGING}_{,i}}{\text{CFP−FOOD}_{\,i}} + w_2 \frac{\text{Cost−PACKAGING}_i}{\text{Cost−UNIT PRODUCT}_i} + w_3 \text{PS}_i \ , \qquad (3)$$

i : food product ; Coffee = 1, Banana = 2, Soybean = 3, Daikon = 4

3.3.1 Potential Score (PS)

Most of the components in the ZPP indicator were already worked out for all four case studies in the prior sections with the exception of PS, or Potential Score. PS is a measure of the potential of the particular product to adopt zero-packaging practices from the perspective of stakeholders across the supply chain, including the consumers.

For this study, the PS values were obtained from a study that was published by the National Zero Waste Council, an initiative of Metro Vancouver, Canada [64]. A survey was conducted in the study and one of the derivatives of the survey was the potential of certain food products to be sold loose (bulk) versus prepackaged. The survey was conducted with respondents hailing from different industries with the list of industries being listed in Figure 15 below.

Industry Classification	Responses
Packaging Industry	17
Food Industry	46
Retail/Consumer	31
Foodservice (HRI)	7
Waste Management/Recycler	22
Government	45
NGO/Non-Profit	10
Other	22
Total	**200**

Figure 15:List of industries where respondents of online survey came from [64]

Respondents were asked for their opinion on each of the 12 foods' potential to be sold loose (bulk) versus prepackaged and their responses can be found in figure 16 below. Respondents were told to rate using a Likert scale of 1 to 5 with 1 = None, 3 = Moderate and 5 = Significant.

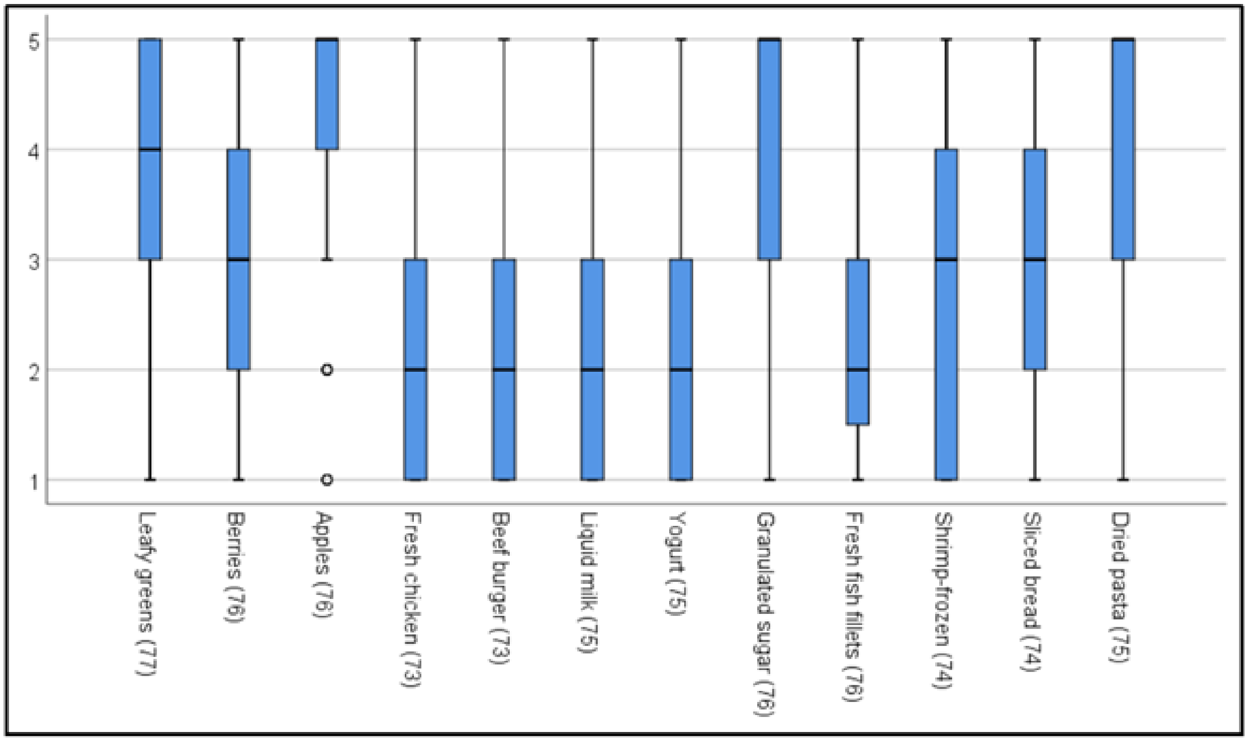

Figure 16:Potential to increase bulk/not packaged sales [64]

As shown in Figure 16 above, the specific food products studied in the research report published by the National Zero Waste Council are not a direct match with the food products chosen for the four case studies presented in this study. However, similarities can be found in the food categories that the specific food products belong to. For our case study of bottled coffee, liquid milk, which was the only liquid beverage found in the study published by National Zero Waste Council, is chosen to be its counterpart. Similarly, the potential score of apples were chosen for our case study of bananas. Even though berries are also part of the fruit category, apples were chosen instead for their similarity in size and ease of bruising with bananas. For our case study of soybeans, the potential score of dried pastas was used for their shared food category of dried foods. Lastly, for the case study of daikon radish, leafy greens were chosen for they both belong to the food category of vegetables.

3.3.2 Prioritization list

The median of the potential scores were taken and the data input for the ZPP indicators for each of the case studies can be found in the following Table 7:

i	$\text{CFP} - \text{PACKAGING}_i$	$\text{CFP} - \text{FOOD}_i$	$\text{Cost} - \text{PACKAGING}_{,i}$	$\text{Cost} - \text{UNIT PRODUCT}_i$	$\mathbf{PS}_i$
Bottled coffee = 1	0.7	0.22	5	178	2
Bananas = 2	0.6	0.46	4.6	290	5
Soybeans = 3	1.3	0.27	3.7	220	5
Daikon radish = 4	0.7	0.14	4.4	91	4

Table 7: Data input for the different components of ZPP indicators

The maximum values for each sub-function were identified for each of the case study and displayed in table 8 below. The weightage for each sub-function is shown in Table 8 below as well. These weightages were obtained from a separate email exchange with Tokyu department store, Hiyoshi and they were based on Tokyu department store's perspective on carrier bags.

i	$\frac{\text{CFP} - \text{PACKAGING}_i}{\text{CFP} - \text{FOOD}_i}$	$\frac{\text{Cost} - \text{PACKAGING}_i}{\text{Cost} - \text{UNIT PRODUCT}_i}$	$\mathbf{PS}_i$
Weights	$w_1 = \mathbf{0.2}$	$w_2 = \mathbf{0.3}$	$w_3 = \mathbf{0.5}$
Bottled coffee = 1	3.17	0.028	2
Bananas = 2	1.33	0.016	5 **(max)**
Soybeans = 3	4.80	0.017	5 **(max)**
Daikon radish = 4	5.15 **(max)**	0.048 **(max)**	4

Table 8: Simplified table with the maximum value and weightage of each sub-function identified

The values of the sub-functions for each of the case study are then normalized to the maximum value identified. This is in accordance with the weighted sum method. The weighted sum method was chosen over more complex multi-objective optimization methods even though it might be biased is because it is one of the most widely used and easy to understand method. Since the purpose of the ZPP indicator here is just to prioritize, the weighted sum method is sufficient in our case. At the same time, it would be easier for other department store managers who has no scientific training to use this indicator. The normalized values are shown in Table 9 below:

i	$\frac{\text{CFP} - \text{PACKAGING}_i}{\text{CFP} - \text{FOOD}_i}$	$\frac{\text{Cost} - \text{PACKAGING}_i}{\text{Cost} - \text{UNIT PRODUCT}_i}$	$\mathbf{PS}_i$
Weights	$w_1 = \mathbf{0.2}$	$w_2 = \mathbf{0.3}$	$w_3 = \mathbf{0.5}$
Bottled coffee = 1	0.62	0.58	0.4
Bananas = 2	0.26	0.33	1
Soybeans = 3	0.93	0.35	1
Daikon radish = 4	1	1	0.8

Table 9: Normalized values of the sub-functions for each case study

The sub-functions for each case study are then multiplied by the weightages identified for each sub-function and added together to derive the final ZPP indicator score for each of our case study according to Equation (3) shown above. The ZPP indicator scores shows us the food products that should be prioritized for zero-packaging and according to the ZPP indicator scores, daikon radish and soybeans should be prioritized for zero-packaging over coffee and bananas as can be seen in Table 10 below.

i	$\frac{\text{CFP} - \text{PACKAGING}_i}{\text{CFP} - \text{FOOD}_i}$	$\frac{\text{Cost} - \text{PACKAGING}_i}{\text{Cost} - \text{UNIT PRODUCT}_i}$	$\mathbf{PS}_i$	$\boldsymbol{ZPP_i}$
Weights	$w_1 = \mathbf{0.2}$	$w_2 = \mathbf{0.3}$	$w_3 = \mathbf{0.5}$	
Bottled coffee = 1	0.62×0.2	0.58×0.3	0.4×0.5	0.50
Bananas = 2	0.26×0.2	0.33×0.3	1×0.5	0.65
Soybeans = 3	$\mathbf{0.93 \times 0.2}$	$\mathbf{0.35 \times 0.3}$	$\mathbf{1 \times 0.5}$	**0.79**
Daikon radish = 4	$\mathbf{1 \times 0.2}$	$\mathbf{1 \times 0.3}$	$\mathbf{0.8 \times 0.5}$	**0.90**

Table 10: ZPP indicator scores for each case study

3.4 Sensitivity Analysis

Since assumptions were made when using secondary data collected, there is a need to see how sensitive the end result is due to the uncertainties introduced from the assumptions for the secondary data collected. Hence, sensitivity analysis is commonly performed at the end of most published LCA studies and this study shall be no exception.

For the four case studies presented above, 3 types of uncertainties have been selected for further study and they are: emission factor of banana production (

+/-10% from base case of 0.22 kgCO2e/kg), emission factor of container transportation of bananas (+/- 20% from base case of 1.12E-05 kgCO2e/kg.km) and PS of bananas (+/- 1 from base case of 5).

For the emission factor of banana production, +/-10% was chosen as the range because there is an approximate 20% difference between the productivity yield of Cavendish banana production in Costa Rica (45.78 tons/ha) [40] as compared to the productivity yield in the Philippines (55 tons/ha) [65].

For the emission factor of container transportation of bananas, +/- 20% was estimated to be the range as it was mentioned in the study published by Svanes et. al. [40] that if a larger sized container ship was assumed to be used for transportation of the bananas, it would make the carbon footprint differ by 45%.

For the potential scores of banana, +/- 1 was estimated to be the range after taking into consideration the difference in public outlook of plastic packaging between the two countries. For Canada, where the potential score data was collected from, a published study regarding consumer behavior and perceptions of single-use plastic packaging showed that the vast majority of Canadians (93.7%) were personally motivated to reduce consumption of single-use plastic food packaging [66]. Whereas for Japan, a published report indicates that the packaging industry of Japan is expected to grow and cited the cause to be an increase in demand for on-the-go packaging format for easy consumption fueled by the prevalent busy lifestyle [67].

As seen in the tornado plot shown in figure 17 below, the values shown on the blue side of the plot depict the difference between the actual ZPP from the assumed ZPP (also known as the baseline ZPP) when the actual values for the PS of banana (4 instead of 5), emission of container transport of bananas (9E-6 $kgCO_2e/kg.km$ instead of 1.12E-05 $kgCO_2e/kg.km$) and emission of banana production (0.20 $kgCO_2e/kg$ instead of 0.22 $kgCO_2e/kg$) vary from the assumed values. The values shown on the orange side of the plot depicts the difference in ZPP values when the actual values for emission of container transport of bananas (1.345E-5 $kgCO_2e/kg.km$ instead of 1.12E-05 $kgCO_2e/kg.km$) and emission of banana production (0.24 $kgCO_2e/kg$ instead of 0.22

kgCO2e/kg) vary from the assumed values. The maximum for PS is 5, which is why actual value for the PS of banana in this situation remains the same at 5.

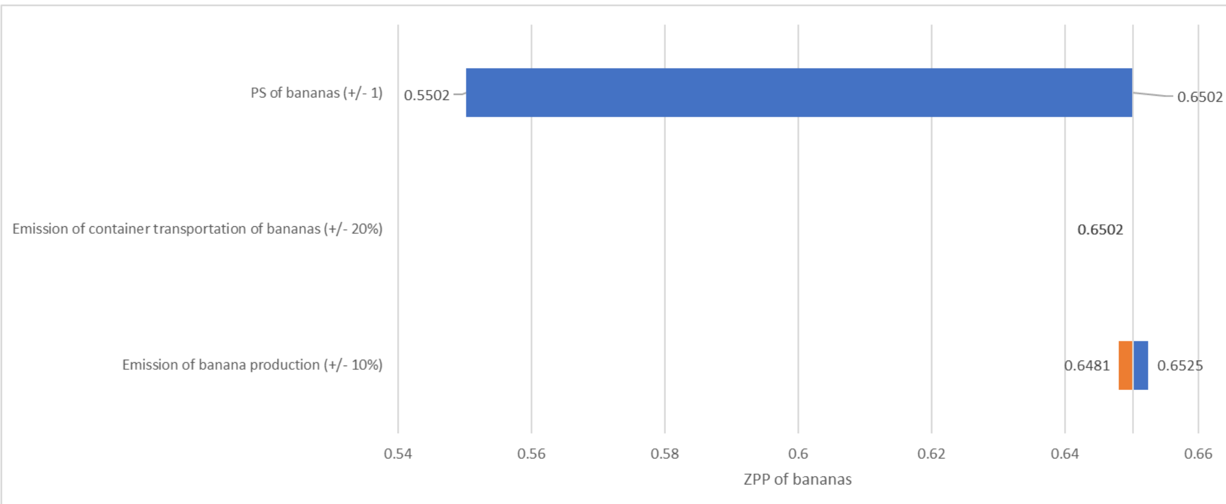

Figure 17:Tornado plot showing the difference in ZPP indicator for bananas for each of the three types of uncertainties and ranges

With the help of the tornado plot as shown in Figure 17 above, we can see that the ZPP is the most sensitive to changes in the potential score with a swing range of 0.1. This is followed by the changes in the emission of banana production which has a swing range of 0.01. For the changes in emission of container transportation of bananas, we see no actual changes in the ZPP value.

From this, we note that the potential score is a crucial component of the ZPP indicator as the swing range is the widest.

However, one good point to note is that although PS is indeed an important factor, the swing is not so wide that it upsets the prioritization list completely. If the ZPP of banana is taken to be 0.5502, it maintains its position of second last on the prioritization list.

4. Discussion

4.1 Comparing ZPP indicator with and without PS

Since PS was determined to be the data introducing the most uncertainty in our results, we will proceed to compare the ZPP indicator using the same dataset with and without the PS sub-function in order to gather some more insights as to how this might affect our end results.

The following Table 11 shows the results of ZPP indicator with the PS sub-function removed by setting $w_3 = 0$. w_1 and w_2 are changed according to ensure that the total proportion is equal to 1.

i	$\frac{\text{CFP} - \text{PACKAGING}_i}{\text{CFP} - \text{FOOD}_i}$	$\frac{\text{Cost} - \text{PACKAGING}_i}{\text{Cost} - \text{UNIT PRODUCT}_i}$	$\mathbf{PS}_i$	$\boldsymbol{ZPP_i}$
Weights	$w_1 = \mathbf{0.4}$	$w_2 = \mathbf{0.6}$	$w_3 = \mathbf{0}$	
Bottled coffee = 1	0.62×0.4	0.58×0.6	0.4×0	0.60
Bananas = 2	0.26×0.4	0.33×0.6	1×0	0.30
Soybeans = 3	0.93×0.4	0.35×0.6	1×0	0.58
Daikon radish = 4	1×0.4	1×0.6	0.8×0	1

Table 11: ZPP indicator without PS

i	$\boldsymbol{ZPP_i}$ (WITH PS)	$\boldsymbol{ZPP_i}$ ($\boldsymbol{WITHOUT\ PS}$)
Bottled coffee = 1	*0.50*	0.60
Bananas = 2	0.65	0.30
Soybeans = 3	0.79	0.58
Daikon radish = 4	0.90	1

Table 12: Comparison of ZPP results with and without PS

	ZPP_i (WITH PS)	$ZPP_i(WITHOUT\ PS)$
Highest priority	Daikon	Daikon
↓	Soybeans	Bottled Coffee
	Bananas	Soybeans
Lowest Priority	Bottled Coffee	Bananas

Table 13: Comparison of prioritization list derived from ZPP with and without PS

The results from the ZPP indicator without PS looks slightly different from the results from the ZPP indicator with PS as shown in Tables 12 and 13. For the case of bottled coffee, since it received the lowest PS score out of the four case studies, removing the PS score significantly altered its ranking as shown in Table 13 where bottled coffee is seen to shift from being the last in the priority list to be the second. In this case, the uncertainty introduced by the PS data is significant.

Fortunately, it remains coherent in the fact that there is no change to the highest priority (i.e. Daikon remains at the top of the list despite the removal of PS). This shows that for food products that environmentally and economically made sense to have their packaging removed, they will still be given highest priority despite not including the social perspective. In this case, the uncertainty introduced by the PS data is negligible because what needs to be prioritized is still properly prioritized. However, it remains a fact that the PS data used in this study does indeed introduce uncertainty. Hence, it would be extremely helpful if future studies would be able to collect more accurate data to represent the social perspective of Japan.

4.2 Comparing ZPP indicator with other quantitative measures

There exist numerous studies published with indicators looking at packaging alternatives for food products. One example is the study published by Šerešová and Koˇcí where they created an indicator, as shown in Equation (1), assessing the environmental impacts of all the packaging involved (primary, secondary and tertiary) together with the corresponding product [30]. Their study looked at case studies where they consider alternative packaging systems for each of the food products as well as different EoL scenarios. Another example is a study by Heller and Selke where they created an indicator, as shown in Equation (2), that illustrates both the importance of considering food waste when comparing packaging alternatives, and the potential for using packaging to reduce overall system impacts by reducing food waste [27]. However, they mainly focus on the perspective of carbon emission for the different potential packaging systems and EoL scenarios and do not provide the perspectives needed for our context, namely Japanese department stores.

For the sake of comparison, the same dataset used in this study for the ZPP indicator are used for both indicators shown in Equations (1) and (2) and the results are compared with the results derived from the ZPP indicator as shown in Table 14 below:

i	ZPP_i	PTP_{CC-i}	FTP_{E-i}
Bottled coffee = 1	*0.50*	75%	0.32
Bananas = 2	0.65	*52%*	*0.75*
Soybeans = 3	0.79	70%	0.21
Daikon radish = 4	**0.90**	**82%**	**0.19**

Table 14: Comparison of the different indicators using the same dataset

	ZPP_i	PTP_{CC-i}	FTP_{E-i}

Highest priority	Daikon	Daikon	Daikon
	Soybeans	Bottled Coffee	Soybeans
	Bananas	Soybeans	Bottled Coffee
Lowest Priority	Bottled Coffee	Bananas	Bananas

Table 15:Difference in the priority lists derived from the indicators

Interestingly, daikon radish remains at the top of the priority list for the implementation of zero-packaging measures despite the use of different indicators as can be seen in Table 15 above. This could be due to the fact that the CFP sub-function and cost sub-function were both the highest for daikon radish out of the four case studies for the ZPP indicator. Hence, despite the fact that the potential score was not the highest for daikon radish, daikon was still the top priority. As for the other two indicators, since CFP is the only consideration for both, it made sense for daikon to come out as top priority for both indicators. This shows the coherence of the ZPP indicator with the two existing indicators.

The rest of the priority list for the three indicators turn out different. Bottled coffee appeared as the last in the priority list for ZPP indicator, however it is second and third for the PTP and FTP indicators respectively. This is interesting since it shows that after taking into consideration the economic and social perspectives, something that was previously considered to be highly favorable for packaging removal turns out to be not. It remains a fact that the social perspective is indeed significant and should definitely be included in future indicators.

4.3 Comparing with other qualitative measures

A global standard for packaging known as the Global Protocol on Packaging Sustainability 2.0 was published by the Consumer Goods Forum where all the possible lifecycle indicators like Cumulative energy demand, freshwater consumption, land occupation, global warming potential etc., as well as attributes of the products like packaging to product weight ratio, recycled content, chain of custody, packaging reuse rate, etc., that can be used to study packaging systems are listed [68]. It is a protocol that gives a detail list and description of the different indicators, heavily referencing on the LCA methodology in order to help users assess packaging sustainability. In this case, it could be intimidating for businesses like Japanese department stores to take up especially if they lack the sustainability expertise.

There are also more business oriented publications focusing on best practices and environmental impact that food business can pick up if they want to study the packaging systems used in their current business. For example, there is Walmart's Sustainable packaging playbook where it uses a sustainability index and preset questionnaire to optimize the design of the packaging, source for packaging materials sustainably and support recycling [69]. There is also a study published in the context of Italian supermarkets where it analysed supermarket waste management systems to identify more sustainable and circular processes using the Lean Six Sigma methodology [70]. However, both studies are qualitative and not in the Japanese context, which makes it difficult to be applied in our context of Japanese department stores. There is a publication in the Japanese context where the carbon footprint of the different types of packaging for different products being sold currently in Japanese supermarkets were studied [46]. This document provided a very detailed outlook of the environmental performance of the different packaging that can be found in Japanese supermarkets, however, only the carbon footprints were studied.

4.4 Limitations of this study

For our study this time round, due to the situation of COVID-19, we were unable to gather data from the Japanese people with respect to their perspective on zero-packaging. Instead, we used data from a published study done in Vancouver, Canada. For future studies, primary data collected from the Japanese consumer market would add valuable inputs into this study especially since PS was found to introduce a significant amount of uncertainty.

As mentioned in the study published by Molina-Besch [28], there is a general lack in current food LCA when it comes to indirect environmental impact of packaging. Namely, there is a general lack in perspective to what happens to FLW rates when we reduce packaging. For future studies, it will be valuable to add in the perspective of FLW into consideration. Erik Pauer's study is a great example of food packaging LCA practice where he not only looked at the environmental impact but also packaging related FLW as well as circularity [26].

Furthermore, since this indicator was created for Japanese department store managers to help Japanese department stores cut down on plastic packaging usage, it would be extremely helpful for future studies to gather feedback from the managers to find out the possibility of implementing this indicator in real life and what sort of problems they might face during implementation. Similarly, since we could only gather information from Tokyu department store, Hiyoshi for this study, future studies would need to approach other department stores in Japan in order to determine the effectiveness of this indicator in other department stores.

4.5 Future Research

For future research directions, it would be efficient to have the government on board to introduce some form of guidelines or regulations incorporating this indicator for department stores, or even supermarkets in Japan to reduce their plastic packaging usage. From the example of the recent carrier bag levy imposed on most shops here in Japan, it is evident that having the government push for policies would be the fastest and have the widest reach.

In addition, since this study was mainly focused in the context of Japan, it would be interesting and helpful for future research to see if this indicator can be applied in an overseas context. If it cannot be completely duplicated and applied in an overseas setting, it would be interesting to see which points are impossible to duplicate, why is that so, and how should we tweak the indicator so it can fit the overseas context.

5. Conclusion

With marine plastic waste wreaking havoc on our marine biodiversity and environment, plastic packaging usage reduction has emerged as the forefront of our concerns in recent year. In particular, single-use plastic packaging has been increasingly banned around the world, which shows the urgency of the issue for governments to take such extreme measures.

Plastic waste is being shipped to less developed countries that simply do not have sufficient waste management capacity to properly dispose of the waste. Thus, it is critical to look at the reduction of the consumption of plastic packaging to attempt to kill off the source.

In recent years, the zero-waste concept has garnered attention as a means to solve our waste problem, particularly in the European countries where it is easier to come across zero-waster supermarkets. In Japan, zero-waste markets are less common and serves only a niche consumer market, hence not achieving the desired wide-spread effect of reducing packaging in the Japanese consumer market. This study takes into account the perspectives that are lacking from previous studies, namely economic and social perspectives, and combine them together with the environmental perspective into an indicator that would aid department stores in Japan to incorporate zero-waste concept into their current operations, which would ultimately lead to zero-waste being more wide-spread in the daily lives of the Japanese people since department stores are more common in Japan.

This study provides Japanese department store with the first step required to start reducing packaging in their operations by providing a list of food products derived from the indicator proposed in this study. Japanese department stores would ultimately go down this list of food products starting from the food product with the highest score to start looking at ways to reduce packaging.

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Appendix

Appendix 1: Matrix calculation for bottled coffee

	Units	Raw material extraction						Distribution	
	Units	Electricity production	Primary packaging production (PET bottle)	Coffee production	Secondary packaging production (cardboard box)	Secondary packaging production (plastic film)	Carrier bags production	Transport	Retail
Electricity	kWh	1	0	0	0	0	0	0	0
Primary packaging (PET bottle)	kg	0	1	-0.019	0	0	0	0	0
Bottled coffee	kg	0	0	0.519	0	0	0	-1	0
Secondary packaging (cardboard box)	kg	0	0	0	1	0	0	-0.0044	0
Secondary packaging (plastic film)	kg	0	0	0	0	1	0	-0.0029	0
Delivered product	kg	0	0	0	0	0	0	1.0073	-0.519
Carrier bags	kg	0	0	0	0	0	1	0	-0.068
Sold product	kg	0	0	0	0	0	0	0	0.587
CO2	kgCO2e	0.464	3.993843421	0.13	0.553930818	2.060325	4.819	0.01309	0.0016290
Cost	¥	21.87	4375.364184	0	27.12884711	63.78990297	625.1198649	0	0.0767791
							593.1372549		
		FU		**kgCO2e/kg product sold(bottled coffee)**	0.928097529				
Electricity	kWh	0		**¥ for packaging/kg sold product (bottled coffee)**	213.4092015				
Primary packaging (PET bottle)	kg	0		$CFP_{packaging/kg\ product\ sold}$	0.696743394				
Bottled coffee	kg	0		$CFP_{food\ production/kg\ product\ sold}$	0.219860098				
Secondary packaging (cardboard box)	kg	0		$Cost_{packaging/unit\ product}$	5				
Secondary packaging (plastic film)	kg	0							
Delivered product	kg	0							
Carrier bags	kg	0							
Sold product	kg	1							
		Scaling Vector							
Electricity production		0							
Primary packaging production(PET bottle)		0.032133399							
Coffee production		1.691231523							
Secondary packaging production (cardboard box)		0.003862096							
Secondary packaging production (plastic film)		0.002545473							
Carrier bagsproduction		0.115843271							
Transportation		0.87774916							
Retail		1.703577513							
		Process Balance							
Electricity	kWh	0	0	0	0	0	0	0	0
Primary packaging (PET bottle)	kg	0	0.032133399	-0.032133399	0	0	0	0	0
Bottled coffee	kg	0	0	0.87774916	0	0	0	-0.87775	0
Secondary packaging (cardboard box)	kg	0	0	0	0.003862096	0	0	-0.00386	0
Secondary packaging (plastic film)	kg	0	0	0	0	0.002545473	0	-0.00255	0
Delivered product	kg	0	0	0	0	0	0	0.88416	-0.884157
Carrier bags	kg	0	0	0	0	0	0.115843271	0	-0.115843
Sold product	kg	0	0	0	0	0	0	0	1
CO2	kgCO2e	0	0.128335764	0.219860098	0.002139334	0.005244501	0.558248722	0.01149	0.0027751
Cost	¥	0	140.5953228	0	0.10477422	0.162375448	72.41592984	0	0.1307992

Electricity	1	0	0	0	0	0	0	0
Primary packaging (PET bottle)	0	1	0.0366	0	0	0.0363	0	0.0321
Bottled coffee	0	0	1.9268	0	0	1.9128	0	1.6912
Secondary packaging (cardboard box)	0	0	0	1	0	0.0044	0	0.0039
Secondary packaging (plastic film)	0	0	0	0	1	0.0029	0	0.0025
Delivered product	0	0	0	0	0	0	1	0.1158
Carrier bags	0	0	0	0	0	0.9928	0	0.8777
Sold product	0	0	0	0	0	0	0	1.7036

Appendix 2: Matrix calculation for bananas

	Units	Raw material extraction: Electricity production	Primary packaging pro	Secondary packaging (cardboard b	Secondary packaging (LDPE liner) production	Carrier bags production	Banana Production	Processing: Banana Processing	Banana Ripening	Distribution: Transportation (processing plant to ripening plant)	Transportation (ripening plant to retail)	Retail
Electricity	kWh	1	0	0	0	0	0	0	0	0	0	0
Primary packaging	kg	0	1	0	0	0	0	0	-0.005736138	0	0	0
LDPE liner	kg	0	0	0	1	0	0	-0.0014	0	0	0	0
Cardboard boxes	kg	0	0	1	0	0	0	-0.0709	0	0	0	0
Raw bananas	kg	0	0	0	0	0	1	-1	0	0	0	0
Packed bananas	kg	0	0	0	0	0	0	1.0013	0	-1	0	0
Unripen bananas	kg	0	0	0	0	0	0	0	-1	1	0	0
Ripen bananas	kg	0	0	0	0	0	0	0	1.005736138	0	-1	0
Bananas	kg	0	0	0	0	0	0	0	0	0	1	-0.526
Carrier bags	kg	0	0	0	0	1	0	0	0	0	0	-0.068
Sold Products	kg	0	0	0	0	0	0	0	0	0	0	0.594
CO2	kgCO2e	0.464	4.679	0.553930818	1.530325	4.819	0.22	0.017	0.286	0.096587351	0.01625	0.0015
Cost	¥	21.87	2194.156203	27.12884711	49.53756396	625.1198649	0	0	0	0	0	0.07047
			2163.333333		18.71469396							

1	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0.01	0.01	0	0.01
0	0	0	1	0	0.07	0.07	0.07	0.07	0	0.06
0	0	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	0.11
0	0	0	0	1	1	1	0.99	0.99	0	0.88
0	0	0	0	0	1	1	0.99	0.99	0	0.88
0	0	0	0	0	0	0	0.99	0.99	0	0.88
0	0	0	0	0	0	1	0.99	0.99	0	0.88
0	0	0	0	0	0	0	0	1	0	0.89
0	0	0	0	0	0	0	0	0	0	1.68

	Units	FU
Electricity	kWh	0
Primary packaging	kg	0
LDPE liner	kg	0
Cardboard boxes	kg	0
Raw bananas	kg	0
Packed bananas	kg	0
Unripen bananas	kg	0
Ripen bananas	kg	0
Bananas	kg	0
Carrier bags	kg	0
Sold Products	kg	1

kgCO2e/kg sold product (banana)	1.173884403
¥ for packaging/kg sold product (bananas)	84.51508689
$CFP_{packaging/kg\ product\ sold}$	0.614236663
$CFP_{food\ production/kg\ product\ sold}$	0.460215611
$Cost_{packaging/unit\ product}$	4.6

Distance from Mindanao International Container Terminal to Tokyo Harbor	3,376	km
GHG emissions large container ship, operator 1. Average	115.8	g CO2/TEU*km
GHG emissions large container ship, operator 2. Average	105.7	g CO2/TEU*km
Average of the above 2	110.75	g CO2/TEU*km
Refrigerant emissions, large container ship, operator 2	0.08	g CO2-eq per kilogram banana
Net load per TEU	9.88	tonnes bananas
GHG emissions from large container ship	1.12095E-05	kg CO2/km kg
GHG emissions from refrigerated cargo truck in JP	9.83202E-05	kg CO2/km.kg
distance from osaka to tokyo	506	km
average distance from harbor to ripening plant	200	km

ant emissions, small container ship, op

0.096587351

	Scaling Vector
Electricity production	0
Primary packaging production (PP)	0.005050505
Secondary packaging (cardboard boxes) p	0.062344373
Secondary packaging (LDPE liner) product	0.00123106
Carrier bagsproduction	0.114478114
Banana Production	0.879328254
Banana Processing	0.879328254
Banana Ripening	0.88047138
Transportation (processing plant to ripeni	0.88047138
Transportation (ripening plant to retail)	0.885521886
Retail	1.683501684

Yield for costa rica	45.78	tons/ha
Yield for Philippines	55	tons/ha
	20.13979904	%

Process Balance

	Units	Electricity production	Primary packaging pro	Secondary packaging (cardboard b	Secondary packaging (LDPE liner) production	Carrier bags production	Banana Production	Banana Processing	Banana Ripening	Transportation (processing plant to ripening plant)	Transportation (ripening plant to retail)	Retail
Electricity	kWh	0	0	0	0	0	0	0	0	0	0	0
Primary packaging	kg	0	0.005050505	0	0	0	0	0	-0.005050505	0	0	0
LDPE liner	kg	0	0	0	0.00123106	0	0	-0.00123106	0	0	0	0
Cardboard boxes	kg	0	0	0.062344373	0	0	0	-0.062344373	0	0	0	0
Raw bananas	kg	0	0	0	0	0	0.879328254	-0.879328254	0	0	0	0
Packed bananas	kg	0	0	0	0	0	0	0.88047138	0	-0.88047138	0	0
Unripen bananas	kg	0	0	0	0	0	0	0	-0.88047138	0.88047138	0	0
Ripen bananas	kg	0	0	0	0	0	0	0	0.885521886	0	-0.885521886	0
Bananas	kg	0	0	0	0	0	0	0	0	0	0.885521886	-0.8855
Carrier bags	kg	0	0	0	0	0.114478114	0	0	0	0	0	-0.1145
Sold Products	kg	0	0	0	0	0	0	0	0	0	0	1
CO2	kgCO2e	0	0.023631313	0.03453447	0.001883921	0.551670034	0.193452216	0.01494858	0.251814815	0.085042399	0.014389731	0.00252
Cost	¥	0	11.08159699	1.691330969	0.060983691	71.56254346	0	0	0	0	0	0.11863

Appendix 3: Matrix calculation for soybeans

assuming bulk cargo	Units	Raw material extraction: Electricity production	Primary packaging production (LDPE)	Soybean production	Secondary packaging (cardboard boxes) production	Carrier bags production	Processing: Soybean Processing	Distribution: Transportation (farm to processing facility)	Transportation (processing facility to retail)	Retail
Electricity	kWh	1	0	0	0	0	0	0	0	0
Primary packaging (LDPE)	kg	0	1	0	0	0	-0.024509804	0	0	0
Raw Soybeans	kg	0	0	1	0	0	0	-1	0	0
Secondary packaging (cardboard box)	kg	0	0	0	1	0	-0.0273	0	0	0
Delivered soybeans	kg	0	0	0	0	0	-1	1	0	0
Packed soybeans	kg	0	0	0	0	0	1.051809804	0	-1	0
Delivered product	kg	0	0	0	0	0	0	0	1	-0.209
Carrier bags	kg	0	0	0	0	1	0	0	0	-0.068
Sold product	kg	0	0	0	0	0	0	0	0	0.277
CO2	kgCO2e	0.464	4.719	0.371	0.553930818	4.819	0	0.39	0.012025	0
Cost	¥	21.87	49.53756396	0	27.12884711	625.1198649	0	0	0	0

Inverse matrix

1	0	0	0	0	0	0	0	0
0	1	0	0	0	0.02	0.02	0	0.02
0	0	1	0	1	0.95	0.95	0	0.72
0	0	0	1	0	0.03	0.03	0	0.02
0	0	0	0	0	0	0	1	0.25
0	0	0	0	0	0.95	0.95	0	0.72
0	0	0	0	1	0.95	0.95	0	0.72
0	0	0	0	0	0	1	0	0.75
0	0	0	0	0	0	0	0	3.61

	Units	FU
Electricity	kWh	0
Primary packaging (LDPE)	kg	0
Raw Soybeans	kg	0
Secondary packaging (cardboard box)	kg	0
Delivered soybeans	kg	0
Packed soybeans	kg	0
Delivered product	kg	0
Carrier bags	kg	0
Sold product	kg	1

kgCO2e/kg sold product (soybean)	1.83179528
¥ for packaging/kg sold product (soybeans)	154.8612792
$CFP_{packaging/kg\ product\ sold}$	1.276821178
$CFP_{food\ production/kg\ product\ sold}$	0.266135747
$Cost_{packaging/unit\ product}$	3.7

	Scaling Vector
Electricity production	0
Primary packaging production (LDPE)	0.017582035
Soybean production	0.717347027
Secondary packaging (cardboard boxes) production	0.019583574
Carrier bags production	0.245487365
Soybean Processing	0.717347027
Transportation (farm to processing facility)	0.717347027
Transportation (processing facility to retail)	0.754512635
Retail	3.610108303

Process Balance

	Units	Electricity production	Primary packaging production (LDPE)	Soybean production	Secondary packaging (cardboard boxes) production	Carrier bags production	Soybean Processing	Transportation (farm to processing facility)	Transportation (processing facility to retail)	Retail
Electricity	kWh	0	0	0	0	0	0	0	0	0
Primary packaging (LDPE)	kg	0	0.017582035	0	0	0	-0.017582035	0	0	0
Raw Soybeans	kg	0	0	0.717347027	0	0	0	-0.717347027	0	0
Secondary packaging (cardboard box)	kg	0	0	0	0.019583574	0	-0.019583574	0	0	0
Delivered soybeans	kg	0	0	0	0	0	-0.717347027	0.717347027	0	0
Packed soybeans	kg	0	0	0	0	0	0.754512635	0	-0.754512635	0
Delivered product	kg	0	0	0	0	0	0	0	0.754512635	-0.7545
Carrier bags	kg	0	0	0	0	0.245487365	0	0	0	-0.2455
Sold product	kg	0	0	0	0	0	0	0	0	1
CO2	kgCO2e	0	0.082969623	0.266135747	0.010847945	1.18300361	0	0.27976534	0.009073014	0
Cost	¥	0	0.870971182	0	0.53127978	153.4590282	0	0	0	0

Appendix 4: Matrix calculation for daikon radish

	Units	Raw material extraction Electricity production	Primary packaging production (LDPE film)	Daikon production	Secondary packaging production	Carrier bags production	Distribution Transportation	Retail							
Electricity	kWh	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Primary packaging	kg	0	1	0	0	0	0	-0.001	0	1	0	0	0	0	0
Daikon	kg	0	0	1	0	0	-10	0	0	0	1	0	0.91	0	0.78
Secondary packaging	kg	0	0	0	1	0	-0.97	0	0	0	0	1	0.09	0	0.08
Delivered product	kg	0	0	0	0	0	10.97	-0.418	0	0	0	0	0	1	0.14
Carrier bags	kg	0	0	0	0	1	0	-0.068	0	0	0	0	0.09	0	0.08
Sold product	kg	0	0	0	0	0	0	0.487	0	0	0	0	0	0	2.05
CO2	kgCO2e	0.464	5.249	0.18	0.553930818	4.819	0.213915	0							
Cost	¥	21.87	63.78990297	0	27.12884711	625.1198649	0	0							

		FU		
Electricity	kWh	0	**kgCO2e/kg sold product (daikon)**	0.883270602
Primary packaging	kg	0	**¥ for packaging/kg sold product (radish)**	89.4756564
Daikon	kg	0	$CFP_{packaging/kg\ product\ sold}$	0.725697592
Tertiary packaging	kg	0	$CFP_{food\ production/kg\ product\ sold}$	0.140835843
Delivered product	kg	0	$Cost_{packaging/unit\ product}$	4.4
Carrier bags	kg	0		
Sold product	kg	1		

	Scaling Vector
Electricity production	0
Primary packaging production (LDPE film)	0.002053388
Daikon production	0.782421351
Tertiary packaging production	0.075894871
Carrier bags production	0.13963039
Transportation	0.078242135
Retail	2.05338809

		Process Balance						
Electricity	kWh	0	0	0	0	0	0	0
Primary packaging	kg	0	0.002053388	0	0	0	0	-0.0021
Daikon	kg	0	0	0.782421351	0	0	-0.782421351	0
Tertiary packaging	kg	0	0	0	0.075894871	0	-0.075894871	0
Delivered product	kg	0	0	0	0	0	0.858316222	-0.8583
Carrier bags	kg	0	0	0	0	0.13963039	0	-0.1396
Sold product	kg	0	0	0	0	0	0	1
CO2	kgCO2e	0	0.010778234	0.140835843	0.042040508	0.67287885	0.016737166	0
Cost	¥	0	0.130985427	0	2.058940353	87.28573062	0	0