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HE3011 - Cost Benefit Analysis

Cost Benefit Analysis of Replacing Plastic Bags with Biodegradable Bags

(HDPE VS PLA)

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CONTENTS

EXECUTIVE SUMMARY

This paper aims to quantify the cost and benefits associated with replacing plastic bags (HDPE) with biodegradable bags (PLA). The motivation of this research stems from efforts to reduce the environmental effects of plastic bags. Considering the use of biodegradable plastic as an alternative to tackle the issue of plastic waste has been widely discussed amongst researchers. This motivation has also been backed by The Singapore Green Plan 2030; a national movement aimed to propel Singapore's goal of sustainable development. With an aim to solidify Singapore's commitments under the United Nations 2030 Sustainable Development Agenda and the Paris Agreement, Singapore is looking to lower net emissions to zero in the long term (SG Green Plan, 2021). This justifies a 10-year time period for our research. Additionally, a time period of 10 years allows us to control and quantify uncertainties to ensure accuracy in quantitative measure as much as possible.

Singapore uses about 2.5 billion plastic bags a year, which is equivalent to each person using about 452 plastic bags a year. As such, the accounting stance employed will be all 'consumers' of plastic bags in Singapore. In this paper, we have used the contingent valuation method to quantify the benefits and costs of HDPE and PLA plastic bags using a payment card valuation and damage schedule approach. Two surveys were conducted to reveal consumers' willingness to pay (WTP) for 24 plastic bags (a week's worth). Our findings revealed a consumer's WTP value of $0.247 and $0.218 and a weighted WTP value of $0.153 and $0.130 for HDPE and PLE plastic bags respectively. Benefits and costs that are not captured in the pairwise comparison will be assigned a value monetary based on available data.

To tackle the issue of time period differences and discounting, we used a uniform series present worth regime to calculate the net present worth of consumer surplus of HDPE and PLA plastic bags. For the benefits and cost that have been assigned a monetary value, we conducted the same uniform series present worth discounting as well. To account for uncertainty, we assign weights to each cost and benefit according to the probabilities obtained from the results of the damaged schedule approach in our questionnaire. The product of each weight with its corresponding cost / benefit is then summed up to provide the expected net benefit.

Additionally, using a time period of 10 years and a discount rate of 2.00%, results show that the discounted net present value of using HDPE bags is -$2.655 x 10^{13} while the net present value of using PLA is -$2.847 x 10^{13}. The results are repeated for discount rates of 1.90% and 2.10%, both of which yield consistent results where net benefits of HDPE outweigh those of PLA because they are less negative. Therefore, it can be reasonably concluded that HDPE provides a larger net benefit than PLA. Using Net Present Value (NPV) as our investment decision criterion, the paper concludes that it is unwise for Singapore to be pushing towards the goal of replacing HDPE bags with PLA bags, in order to reap the environmental benefits of PLA.

1. INTRODUCTION

1.1 TYPES OF PLASTIC BAGS

There are typically 2 main types of plastic bags that are commonly manufactured and used globally. The first type of plastic is High Density Polyethylene (HDPE). It is the most widely used plastic bag due to its variety of qualities. HDPE is lightweight, waterproof, and most importantly it has high tensile strength (Poly, 2015). Most of these plastic bags are used for storage of items and manufactured to be carriers. However, there is an increasing demand to replace HDPE with a greener alternative, due to its negative impacts on the environment. Globally, the most common commercial biodegradable polymers which could replace HDPE are PLA polymers. PLA is derived from renewable sources such as corn starch, sweet potatoes, and sugarcane. Hence, we will be comparing HDPE to PLA for our research to ascertain if a replacement of all HDPE bags with PLA provides a larger benefit to consumers in Singapore.

PLA VS HDPE

HDPE (High Density Polyethylene) is a polymer derived from the polymerisation of petrochemical monomers. It is widely used for plastic bags because it has a relatively high tensile strength for its given density, making it useful for creating thin and durable plastic bags. Plastic bags need to be highly flexible, light, strong, and disposable, all of which are properties of HDPE sheets. HDPE is also exceedingly cheap because large petrochemical plants allow for the exploitation of economies of scale. Due to the high durability of HDPE, it does not naturally degrade and often persists in the environment for centuries if it is not incinerated. Thin sheets of HDPE are especially damaging to the environment when released into the sea, where it is often consumed by or injures sea life. Furthermore, flue gases from incineration release toxic substances into the air, which are detrimental to the ozone layer and to human respiratory health, such as phthalates, furans, and dioxins. From the initial oil extraction to its incineration, the Global Warming Potential (GWP) to produce 1kg of HDPE is one of the highest GWP values out of all the plastics. However, due to its high durability, a single HDPE bag could be recycled and thus justify its carbon emissions over several lifetimes.

PLA (Polylactic Acid) is a biodegradable polymer that is derived from fermented plant starch. Due to it being made from renewable sources and its ability to degrade naturally over time, as well as its properties of strength, durability, and flexibility (with specific processing parameters), it is considered to be a viable, eco-friendly material for the replacement of HDPE for the production of plastic bags. PLA takes roughly 80 years to fully biodegrade, compared to most conventional petrochemical-derived plastics which take at least 450 years before starting to break apart from natural stresses or UV degradation. Since it is based on biological plant matter, a considerable amount of CO_2 is absorbed from the environment for every kilogram of PLA. Replacing "fossil carbon" with "renewable carbon" also means less dependence on the fossil fuel industry which is responsible for most carbon emissions and environmental disasters such as oil spills. After complete biodegradation, the GWP of PLA is less than HDPE. However, ensuring the proper disposal of PLA for biodegradation at the intended rate is often complex and does not follow Singapore's standards of waste incineration. Industrial composting facilities require additional infrastructure, management, and utility costs. Without these facilities, PLA can take as long as HDPE to biodegrade, even if it does not form microplastics or release toxic substances into the environment. PLA will not release toxic fumes upon incineration, and its resultant GWP after incineration is less than HDPE. However, it requires significantly more energy to combust for a longer period and at a higher temperature, meaning higher energy costs for its incineration. At the end of its usable life cycle, PLA cannot be recycled unlike HDPE, meaning its use-life is only a fraction of HDPE.

Product Manufacturing

The cost of production of PLA ranges from US$1.47 to US$2.42 per kilogram (Permpoonwiwat, 2011). The consumer-facing price of PLA ranges from US$3.04-4.69 (Permpoonwiwat, 2011). HDPE is significantly cheaper, primarily due to the highly established industrial production standards and economies of scale. The cost of production of HDPE is US$0.67 per kilogram (Authors, 2018). The consumer-facing price of HDPE ranges from US$0.82-1.21 (Statista, 2021).

PLA production and manufacturing still experiences significant problems with standards of durability and as such not all PLA bags can replace all the functional capabilities of HDPE. In particular, toughened blends are still not able to measure up to HDPE's durability, which is necessary in applications such as containment of heavy waste. PLA also has a lower tolerance for water permeability, which is necessary for many plastic bag applications. Ensuring total water resistance requires thicker PLA material, which may not be feasible for the flexibility and lightness required. The 6 main stages in the life cycle of carrier bags are raw materials acquisition, product manufacturing, retailer to end-user, disposal and incineration, and eventually landfilling. At the same time, transportation occurs from every stage in the life cycle to the next. **Refer to appendix A for plastic bags' life cycle illustration.**

1.2 RATIONALE FOR REPLACING PLASTIC BAGS WITH BIODEGRADABLE BAGS

Raw material acquisition and manufacturing of carrier bags in Singapore
The data of constituting raw materials were chosen per the International Trade Centre data and knowledge exchanged within the respective industries. To the best of our ability, inputs and outputs were measured according to the percentage of constituting materials used.

Sellers
HDPE is sold as part of the more significant petrochemical-based plastic industry, which is highly competitive and not mainly monopolised compared to most chemical and energy production industries. 100 companies control 90% of global production. China is the largest single producer

of raw HDPE material, often sent to processing plants outside of China to manufacture the final plastic bag form. On the other hand, PLA production is much flatter across the globe because the production process has multiple stages. Firstly, starchy crops' planting, harvesting, and fermentation is often based in agricultural production hubs such as Thailand, China, and the Philippines. The processing of starches to produce lactic acid, and PLA polymerisation is often conducted in more developed industrial hubs such as the US, Italy, Germany, the Netherlands, and China.

<u>Total amount of plastic bags used in a year</u>

Carrier Bag Type	Considerations	Flow of bags (no. of bags)
HDPE Plastic Bags	These bags have a 12-litre volume, further not considering that items would be "double bagged" at point of purchase.	1,248
PLA Plastic Bags	For PLA Plastic Bags, it is considered to be slightly weaker where it can carry up to 10-litre volume comfortably.	1,498

A study by NEA measured the average number of carrier bags a family of four would buy over a year, based on the volume of grocery items. The assumption was that a family unit was two adults and two children, with all meals prepared at home and shopping for groceries made weekly. The average number of grocery items per family was derived empirically by averaging the number of items bought by two families that fit the assumed criteria. The study found that, on average, 50 grocery items were purchased by each family. The study further found that the 50 grocery items weekly translated into 24 carrier bags. Furthermore, due to the weaker strength and durability of PLA plastic bags, translating the amount of bags used would be at 28 bags weekly for the same 50 grocery items. Based on these numbers, it would be estimated that families using HDPE Bags would use about 1,248 yearly, while substituting the use with PLA plastic bags would be about 1,498 bags used yearly.

1.3 ACCOUNTING STANCE

The consumer's perspective is being employed for this project's accounting stance. Consumers have various sub-groups with differing circumstances and situations, giving them different opinions on replacing plastic bags with biodegradable bags, even though they are considered a group. The various sub-groups are the lower and upper-income groups, environmentalists, and business organizations. In this case, these sub-groups overlap and may take on more than one category. Lower-income groups may be more price-sensitive towards switching from plastics to biodegradable bags because of the possible increased cost incurred. For these lower-income groups, an increase in plastic bag cost would take up a higher proportion and margin of their income. Contrary to the higher-income group, who are less price-sensitive due to the lesser percentage that the increase in the plastic bag cost would take from their income. Environmentalists, being active towards saving the environment, would most likely be supportive of changes that appear to head towards a greener world, in this case, switching from plastic to biodegradable bags. Business organizations have a vested interest in keeping costs low, and thus, any increase in cost would contradict this goal. For this case, this switching of plastic to biodegradable bags would increase the cost for the organization. To sum up, the varying sub-groups bring about different consumer categories. For this purpose, these categories will be grouped under the umbrella of 'consumers'.

2. COSTS AND BENEFITS

Price

HDPE bags are far cheaper than PLA bags. Consumers pay an average of US$0.67/kg which is SGD$0.90/kg for HDPE plastic bags (Statista, 2021), which is only a fraction of the cost of PLA, which ranges between US$0.82-1.21/kg (Permpoonwiwat, 2011) or SGD$1.107-1.64/kg, averaging SGD$1.37/kg. Three factors account for the much lower price. Firstly, HDPE polymers are derived from petrochemical compounds; usually the lighter fractions refined from bulk amounts of crude oil. Heavier fractions are often sold at considerable profit margins, justifying a low materials cost for the fractions which produce plastics like HDPE. In contrast, PLA is derived from organic starches, which require relatively high costs to produce. Every unit of starch is processed from a larger plant, which requires water, fertiliser, land and a significant amount of time to grow. Furthermore, the conventional plastics industry is much more developed than the biodegradable materials market, meaning prices are low due to high competition between firms. Lastly, process chains between each stage of production are highly established in the production of conventional plastics, with individual firms taking over multiple stages of processing, such as compounding, film-blowing and thermosetting the plastic in the same factory, reducing the need for transport costs and gaining the benefits of economies of scale. Conversely, PLA requires processes often divided across many different firms located in many different countries, thus requiring additional costs for transportation and logistics.

Energy expenditure during incineration

During incineration, an initial amount of energy must be applied to a plastic to raise its temperature to its point of pyrolysis, which begins the thermal decomposition process. More energy is then released during thermal decomposition, resulting in a net gain of energy, known as the heat of combustion. For standardisation, the initial input of energy for pyrolysis is referred to in this paper as the Heat of Pyrolysis, or ΔH_p, although it is also sometimes referred to as the Heat of Gasification. The heat of pyrolysis provides a reasonable estimate of energy expenditure used to incinerate PLA and HDPE. ΔH_p values from experimental literature are provided in the table below:

Plastic	Heat of Pyrolysis @ 400°C, ΔH_p (kJ/kg)	Energy Cost of combustion (SGD/kg)
HDPE	920	11978.40
PLA	1370	17837.40

The cost of energy required can then be calculated using average energy prices in Singapore for 2021, which is SGD 0.217/kWh = SGD 13.02/kJ. Therefore, PLA requires a higher utilities cost to incinerate.

Standards of durability and water resistance

HDPE is known to have a high strength to density ratio and tensile strength compared to other materials for similar applications such as PLA. HDPE is also water-resistant, whereas only some varieties of PLA can be fully water-resistant, often requiring additives that reduce the plastic bag's biodegradability. Below is a summary of quantified physical properties of PLA and HDPE which are relevant to the functions of a plastic bag

Physical properties	HDPE	PLA
Water absorption	0.016%	1.00%
Ultimate tensile strength	22.2 MPa	12.5MPa

Therefore, while PLA may be able to functionally replace HDPE for applications such as carrying groceries with loads up to 10kg, its lower tensile strength and significant moisture absorption makes it unsuitable for certain applications, such as throwing waste or wet food, carrying heavier loads or packaging in high-pressure conditions (such as vacuum sealing). It must also be noted that PLA degradation over several years causes these properties to worsen, while time effects on the physical properties of HDPE are not as significant.

Recyclability

HDPE can be recycled at least 10 times, allowing for a longer lifespan before being permanently retired or incinerated. This could mean a significant reduction in the carbon cost within the lifespan of a single plastic bag, distributing this cost 10 times its average duration of use. The physical lifespan of a HDPE plastic bag is 500 years. PLA, however, cannot be recycled and must be disposed of once it reaches the end of its useful lifespan, which is 15 years. On average, consumers dispose of plastic bags 12 minutes after initial use. Thus, recycling the same material over several iterations can considerably reduce the amount of plastic disposed of.

Biodegradability

The main benefit of PLA over HDPE is its ability to biodegrade over time. Under a controlled composting environment, PLA takes 80 years to biodegrade with the help of enzymes into non-toxic substances, which is significantly shorter than the amount of time that HDPE takes to photodegrade (upon exposure to UV light), which ranges from 500 to 1000 years. However, PLA must be processed under specific composting compositions, requiring additional infrastructure (Zaaba, 2020). This is elaborated upon more in the following section.

Infrastructure Costs

For PLA to fully biodegrade, it must be processed and treated under specific conditions, which require establishing specialised infrastructure. PLA cannot biodegrade at its optimal rate without the availability of enzymes produced by mesophilic bacteria, actinomycetes in the presence of organic waste and dairy manure. The processing facility must also be kept at humidity levels of 60-70% and a temperature level of 60^{o}C, which leads to further energy cost expenditure. These conditions are customised only to PLA waste, which means that PLA bags must be sorted out of general waste, requiring additional costs and energy expenditure. The costs of infrastructure can be estimated using the land property price and opportunity cost methods, which are further elaborated upon in our paper’s quantitative measures of cost and benefits.

Microplastics

A major area of concern surrounding the widespread use of disposable plastics involves the release of microplastics into the environment, chiefly the pervasive spread of microplastics in the ocean. Microplastics are small pieces of plastic less than 5mm long that are harmful to aquatic life and humans upon consumption of seafood that has ingested it (National Ocean Service, 2021). Most microplastics are released into the environment due to the physical breakdown of larger plastic sheets or pieces through abrasion and environmental forces. This occurs because plastic is the most prevalent type of marine debris in the ocean, and microplastics are often too small to be removed via conventional filtration systems. HDPE films of thickness 0.1mm (similar to that of conventional plastic bags) has been shown to fragment into microplastics upon a cumulative luminance of 5.3 x 106 lux d, and at an even faster rate with the application of mechanical stress, such as being in water, stretched or poked. HDPE is estimated to account for roughly 22.3% of microplastics in all of the world's water bodies due to its sensitivity to UV light, the effects of which are amplified in bodies of water. Microplastics have shown to cause potential health concerns due to cumulative ingestion from eating seafood or even exposure to plastic heated in potable water. A recent study aimed at quantifying the costs of plastic pollution has also identified its impacts on fisheries, aquaculture, and recreational activities (Hodal, 2020).

Release of Toxic Substances upon Incineration

During the incineration of HDPE, toxic substances are released into the environment, such as phthalates, furans, and dioxins. These factors cause both health concerns and environmental damage. An overwhelming majority of chemical and biological literature has demonstrated that plastic combustion's toxic byproducts can be carcinogenic and cause severe respiratory illness. Even advanced flue gas absorption systems that aim to reduce the toxic fumes released do not produce a significant change because these substances are not soluble in industrial solvents. However, PLA does not produce toxic fumes upon incineration.

Global Warming Potential

The Global Warming Potential (GWP) of different materials seeks to quantify the impact a particular product has on the environment by quantifying the equivalent mass of CO2, which corresponds to the heat trapped by all emissions released into the environment from the start of its life cycle until it's incineration. From the initial oil extraction to its incineration, the Global Warming Potential (GWP) to produce 1kg of HDPE is equivalent to 2.38kg of CO2, one of the highest GWP values out of all conventional plastics. However, after complete biodegradation, the GWP of PLA is considered only 0.5kg of CO2 per kilogram of PLA. This significantly lower quantity is due to the absorption of CO2 during the cultivation of organic feedstock used to produce starch, the base component of PLA. GWP is useful because it can indirectly provide us with a monetary cost associated with global warming due to each plastic bag. This is done by multiplying the GWP value with the rate of carbon taxation set by the NEA, which is $5 / tonne CO2, or $0.005 / kg CO2.

Material	GWP (kg CO_2/kg)	Cost ($/kg)
PLA	0.50	0.0025
HDPE	2.38	0.0119

Dependence on Petrochemical Industry

Given the rising levels of environmental awareness in Singapore, as well as repeated calls by environmental advocacy groups and the government to reduce carbon emissions, Singapore’s dependence on the petrochemical industry is often brought into question. Environmental groups such as Singapore Climate Rally, Students for a Fossil Free Future and Activism in Crisis have highlighted the need for divestment from fossil fuel companies to meet targets set by the international community such as the Paris Climate Agreement or the United National Climate Change Conference. Wide-ranging studies such as the Intergovernmental Panel on Climate Change have shown that an integral part of reducing carbon emissions is decoupling consumption from high-emission industries, especially the petrochemical industry. As such, a significant advantage of replacing HDPE, which is considered “fossil carbon”, with PLA, which is “renewable carbon” is a reduction in reliance on the petrochemical industry, and thus a reduction in demand for petrochemical feedstocks.

Renewable carbon vs Fossil carbon

Beyond the harmful effects of carbon emissions, the non-renewability of fossil fuel sources is also an area of concern. One solution to rapidly depleting petrochemical resources in manufacturing products is based on "renewable carbon" sources. Renewable carbon entails all carbon sources that avoid or substitute the use of any additional fossil carbon from the geosphere. Renewable carbon can come from the biosphere, atmosphere, or technosphere – but not from the geosphere. Its ability to circulate allows for the establishment of a carbon-neutral instead of a carbon-emissive economy. PLA is produced by extracting fermented starch from crops such as corn, cassava, sugarcane, or sugar beet pulp, which produce the polymerised lactic acid used as a base material. These crops can be regrown after harvesting and are often genetically modified to produce optimally efficient amounts of starch, reach maturity quickly, and require less water to grow.

Refer to appendix B to view the table showing costs and benefits of HDPE plastic bags.

Refer to appendix C to view the table showing costs and benefits of PLA plastic bags.

3. METHODOLOGY

3.1 APPROACHES

Our group will be conducting two surveys: (1) preliminary survey and (2) secondary survey comprising the same sample size. Convenience sampling will be used due to the time savings and ease of conduct. Our target audience are Singapore residents who are above the age of 20. This allows us to obtain accurate data in terms of valuation as young people may not completely grasp the value of things. For questions on ranking benefit and cost in the secondary survey, the average ranking will be calculated using a weighted average formula $\frac{X_1W_1 + \ldots + X_nW_n}{Total\ Responses}$, where w_i = weight of the ranked position and x_i = response count for answer choice.

3.2 PRELIMINARY SURVEY

Our preliminary survey comprises three primary focuses: (1) socioeconomic profiling of participants; (2) awareness of environmental issues related to the usage of plastic bags; (3) frequency of plastic bag usage. We included the demographics of participants of the survey to ensure that we considered their characteristics. Given that each participant's income and habits are different, it might affect our survey results, making it skewed. Thus, we can run a regression to determine the correlation between the various variables with their demographics.

3.3 SECONDARY SURVEY

Our secondary survey mainly utilises two different methods to determine our results. We used the pairwise comparison method for our first question and the contingent valuation method for our second question.

Pairwise comparison method

The pairwise comparison method is a way to help us understand the importance of several options relative to one another concerning the customer's preferences. Using this method, we chose the top 3 most significant costs and benefits to the participant. With that, we found out their willingness to pay for regular plastic bags and biodegradable plastic bags.

Pairwise comparison is the best method for our project as objective judgments are difficult to obtain. We are unable to measure their preferences or observe them to make our final decision. This comparison method is ideal as we are comparing very subjective variables towards each individual (*Paired Comparison Analysis: Working Out Relative Importances*, 2020). For example, one might think that a particular benefit of using PLA bags outweighs another, but another individual might think otherwise. By finding out how they perceive each factor, we can rank all the factors accordingly. The pairwise comparison also helps to present the discrete choices that consumers prefer in this situation. There is a need to further define the goods into specific situations of benefits and cost, not just public goods like the environment, as the definition of environmental cost and benefits vary with individuals.

Developing the Damage Schedule

We utilised the damage schedule approach to uncover the scale of the relative importance of the cost and benefits of using HPPE and PLA plastic bags, based on the perception of the participants of the survey. By allowing participants to rank the options presented by assigning monetary values to them from a budget of $100 each for benefits and costs, they can then convey how much they value the choices through values they have assigned. In the secondary survey, participants are assigned a budget of $100 and asked to allocate varying amounts that they feel are needed to choices provided in the survey. In this case, it will be the amount needed to alleviate costs from using HDPE and PLA plastic bags and the benefits of using HDPE and PLA.

Contingent Valuation Method (CVM)

We used closed-ended questions to attain the consumer's willingness to pay (WTP) for HDPE plastic bags and PLA bags. Before the survey, we ensured that the consumers understood the various costs and benefits by reading the hypothetical scenario. In the hypothetical scenario, participants were made aware of the time period of the project, the benefits and cost of both PLA and HDPE plastic bags, and the aim of the survey to prevent strategic bias and ensure the honesty of participants of the survey.

Using the payment card method, we can elicit the willingness to pay for the plastic bag levy by using a hypothetical situation in this study. Based on the factsheet on findings from life-cycle assessment study on carrier bags conducted by the National Environment Agency and Ministry of the Environment and Water Resources (National Environment Agency, 2018), an average household used 24 HDPE plastic bags per week and 28 PLA bags per week, this is because PLA bags has lower tensile strength. In the survey question of this report, considering that the surveyee representing her household absorbs the cost of the lower tensile strength of PLA bags, we did not include a question involving the willingness to pay for 28 PLA bags. In our survey question, we asked participants how much they were willing to pay for 24 bags. An average household uses 24 bags per week, as mentioned above. The payment card technique had been applied to estimate the maximum willingness to pay to obtain HDPE and PLA bags. Given the hypothetical situation, the types of plastic bags were explained before the respondents were prompted with the willingness to pay. The payment card in this study provides values between S$0.10 – S$0.50 for both HDPE and PLA plastic bags. According to (Joe, 2021), after The Plastic ACTion Retail Bag Charge was launched in 2019, retailers reported a decrease in plastic bag usage by 60%, which was equivalent to a decrease in 300,000 plastic bags used monthly. The Plastic ACTion Retail Bag Charge was a charge imposed on plastic bags on major retailers that increased the price of plastic bags. The average price of 1 Kilogram of HDPE plastic bags is SGD$0.9045. Taking the weight of 1 biodegradable bag to be 5 grams, the average price of 24 biodegradable bags is $\frac{SGD\$0.09045}{1000}(5)(24) = SGD\$0.10854$. This meant that the initial plastic bag usage before the charge was imposed was 6,000,000 per year. It decreased to 2,400,000 after the charge was imposed. Using these two prices and quantities, we plotted a demand curve to get the gradient of the graph, $(3.015)10^{-8}$, to find out the y-intercept of the graph.

Gradient = $\frac{(0.10854-0.00)}{(6{,}000{,}000-2{,}400{,}000)}$

$= (3.015)10^{-8}$

Y = $(3.015)10^{-8}$(2,400,000) + 0.10854

= $0.1809 ~ $0.20

Refer to Appendix D for the demand curve of HDPE plastic bags.

Given that we found the value of the maximum price that consumers are willing to pay to be S$0.1809, we gave a range of values for the price of plastic bags to be between S$0.10 to S$0.50 to account for some differences in price due to each individual's difference in personal values towards plastic bags. We also accounted for the possibility that plastic bags might increase in price. Thus, the range of values that we provided the surveyees ranged from S$0.10 to S$0.50.

For PLA bags, the average price of 1 Kilogram of PLA biodegradable plastic bags is SGD$1.374. Taking the weight of 1 biodegradable bag to be 5 grams, the average price of 24 biodegradable bags is $\frac{SGD\$1.374}{1000}$(5)(24) = SGD $0.16488. As mentioned above, the average use of plastic bags decreased from 6,000,000 bags a year to 2,400,000 bags. Using the 2 sets of price and quantity, we plotted the demand curve to get the gradient of the graph to find the y-intercept.

Gradient = $\frac{(0.16488-0.0)}{(6{,}000{,}000-2{,}400{,}000)}$

= $(4.58)10^{-8}$

Y = $(4.58)(10^{-8})$(2,400,0000) + 0.16488

= $0.2728 ~ $0.30

Refer to Appendix E for the demand curve of PLA plastic bags.

We offered participants of the survey a range of prices to choose from, including \$0.50, as the usage of biodegradable bags are not largely adopted by retailers in Singapore yet, and consumers may not be as familiar with biodegradable bags as with regular HDPE plastic bags. Additionally, offering the ranges of value similar to those offered for HDPE plastic bags in the question before will provide a more structured approach for both surveyors and surveyees.

4. RESULTS OF METHODOLOGY

From the findings of our preliminary survey, a regression is conducted to validate and explore the profiles of individuals that might have a higher WTP for each of the plastic bags. Variables such as *Gender*, *Familiar with benefits*, and *BYOB* will be encoded as binary variables. In contrast, variables such as *Age*, *Household Income*, *No. of Household Members*, and *Awareness* will be encoded as categorical variables. Our ordered probit regression model is as follows:

$WTP_i = \beta_0 + \beta_1 Y_i + \beta_2 Z_i + \beta_3 \pi_i + \varepsilon_i$

WTP_i is the maximum price that respondent i is willing to pay for a week's worth of normal biodegradable (PLA) plastic bags or biodegradable (PLA) plastic bags (24 bags)

Y_i is the monthly household income of respondent i (Captured by Q2)

Z_i is vector of household socio demographics characteristics of respondent i (Captured by Q1,3)

π_i is vector of attributes perceptions of respondent i of the environmental attributes of the plastic bags (Captured by Q4,5,6)

4.1 ANALYSIS OF PRELIMINARY SURVEY

From the secondary survey, we found out that the mean WTP for HDPE plastic bags and PLA plastic bags are \$0.247 and \$0.218, respectively. Additionally, we considered a weighted WTP approach, where we assign a probability based on the individual's response to Q6, with 1 representing a probability of 0.2 and 5 representing a probability of 1.

$Weighted\ WTP_i = Pr(i) * WTP$ where $Pr(i) \epsilon$ [*0.2,0.4,0.6,0.8,1*]

This is to elicit the actual WTP that an individual will have in issues on environmental concerns. From the WTP that we obtained, we can get a weighted mean WTP for HDPE plastic bags and PLA plastic bags to \$0.153 and \$0.130, respectively. By regressing these WTP values, several insights were derived.

(1) The correlation matrix in Appendix L suggests that *Household Income* and *Efforts* are the main drivers for an individual's WTP value. This is evident from the high correlation values seen from both correlation matrices and is further supported by the low p-values of *Household Income* and *Efforts* variables after conducting an ordered probit model regression, indicating that they are both statistically significant.

(2) Findings from the regression are consistent across both HDPE plastic bags and PLA plastic bags. Individuals who have a higher household income, familiar with the benefits and costs

of using biodegradable plastic bags, and those who put in more effort into protecting environmental issues tend to have a higher WTP for both plastic bags. These findings are indicative of the positive sign of the coefficients. They are consistent with the research conducted by Xiong et al. (2018). They state that higher-income households can have more disposable income to protect and improve environmental issues.

(3) On the other hand, individuals who are older and have the practice of bringing their own recycling bags tend to have a lower WTP as indicative of the negative sign of the coefficients. This is intuitive as individuals who bring their recycling bags have less need for plastic bags when checking out, indicating lower WTP values.

Refer to Appendix L for the ordered probit regression results for HDPE and PLA plastic bags using WTP and weighted WTP

4.2 ANALYSIS OF SECONDARY SURVEY

Qualitative Analysis - Pairwise comparison

From figure 1 of appendix K, **since consumers on average chose "**Less expensive", "High standards of durability, strength and waterproof", "Requires less energy to incinerate", "Dependence on petrochemical industry", "Releases toxic substances into air upon incineration" and "Forms microplastics when released into the sea" as important and considered these factors when assigning a value to their willingness to pay, we will assign the monetary value of "can be recycled" and "Higher GWP (more carbon released into air)". This can be done through the revealed preference method.

From figure 2 of appendix K, **since consumers on average chose "**Reduces dependence on petrochemical industry", "Is able to biodegrade over time given proper composting facilities" and "Does not release toxic substances into the air or form microplastics in the environment", "More expensive", "Requires more energy to incinerate", "Lower quality (less durable, waterproof, etc)" as the more important factors when assigning a value to their willingness to pay for PLA plastic bags, we will assign the monetary value to "Lower GWP" and "Requires composting facilities to biodegrade". This will be done using the revealed preference method.

Quantitative analysis - Cost and Benefit

Quantitative measures for cumulative energy savings for recyclability

To understand the benefits associated with recycling (Stanford, 2021), a comparison of the cost spread out over the useful lifetime of 1kg of HDPE bags vs 1kg of PLA bags (Guo & Crittenden, 2011) can be made (I, 2005), with the following assumptions:

1. 1kg of HDPE bags are disposed of in proper recycling bins and following recycling protocol.
2. 100% of HDPE is recovered and restored to its full quality after each iteration of recycling.
3. 100% of the HDPE which is recycled is remade into plastic bags
4. The HDPE is recycled ten times, therefore requiring 9 iterations of recycling processing

5. An average of 76MJ of energy is required to produce 1 kg of HDPE
6. An average of 58.9MJ of energy is required to produce 1kg of PLA
7. The benefit of recycling is quantified in its energy savings cost, because recycling existing plastic instead of producing new materials results in a net reduction in energy usage. According to the EPA, 5744 kWh of energy is saved by recycling 1 ton of plastic.

To find the amount of energy used for one iteration to recycle HDPE, the following equation is used:

$$E_{HDPE} = E_{recycle} + E_{saved} \Rightarrow E_{recycle} = E_{HDPE} - E_{saved}$$

Where E_{saved} is the energy saved in one iteration of recycling, $E_{recycle}$ is the amount of energy required to recycle the plastic, and E_{HDPE} is the amount of energy necessary to produce a unit mass of HDPE.

$$E_{recycle} = 76 \times 10^6 \ \frac{J}{kg\ HDPE} - 5744 \times 10^3 \ \frac{kWh}{1tonne} \times \frac{3600s}{h} \times \frac{1tonne}{1000kg\ HDPE}$$
$$= 55.3 \ \times 10^6 \ J/kg\ HDPE$$

Two useful values can be quantified when evaluating the energy savings associated with recycling. First, is the cumulative energy cost of recycling HDPE after iteration n, $\sum_{i=0}^{n} E_{recycle}$ by summation of $E_{recycle}$ with an initial energy cost for the production of a new bag.

$$\sum_{i=0}^{n} E_{HDPE} - \sum_{i=0}^{n} E_{recycle} = E_{sc,n} \ where\ n \in [0,10]$$

Therefore, 207 MJ/kg of energy is saved after 10 iterations of recycling. Refer to Table 1 under the appendix, to find $E_{sc,n}$, the amount of energy savings after recycling HDPE 10 times.

The calculations to obtain these values are available in Appendix F

The second useful value, $E_{hp,n}$ is the cumulative energy savings of recycling HDPE after each iteration $\sum_{i=0}^{n} E_{recycle}$ compared to $\sum_{i=0}^{n} E_{PLA}$.

$$\sum_{i=0}^{n} E_{recycle} - \sum_{i=0}^{n} E_{PLA} = E_{hp,n} \ where\ n \in [0,10]$$

$\sum_{i=0}^{n} E_{PLA}$ is a cumulative measure of the energy consumed for 10 production cycles to repeatedly produce 1kg of PLA. It is indicative of the costs necessary to produce PLA instead of recycling the same load of HDPE 10 times. $\sum_{i=0}^{n} E_{recycle}$ is a cumulative measure of the energy consumed to recycle the same 1kg load of HDPE 10 times.

The calculations to obtain these values are available in Appendix G

$$\sum_{i=0}^{n} E_{recycle} = \frac{\$13.02}{1000J} \times \frac{629MJ}{kg} \times \frac{10^6 J}{1\ MJ} = \$8.18\ x\ 10^6 / \ kg$$

$$\sum_{i=0}^{n} E_{PLA} = \frac{\$647.9}{1000J} \times \frac{647.9MJ}{kg} \times \frac{10^6 J}{1\ MJ} = \$8.44\ x\ 10^6 /\ kg$$

From the figure in Appendix H, after 10 iterations an energy savings of 18.9MJ can be observed. After 4.75 iterations, a net positive energy savings is produced from recycling HDPE, because the savings from recycling outweighs the lower initial energy of production for PLA. $E_{sc,n}$ and $E_{hp,n}$ can be expressed in monetary values by using average energy prices in Singapore for 2021, which is SGD 0.217/kWh = SGD 13.02/kJ

$$E_{sc,n} = \frac{207MJ}{kg} \times \frac{\$13.02}{1000J} \times \frac{10^6 J}{1\ MJ} = \$2{,}695{,}000/\ kg$$

For purposes of comparison between recycled HDPE and non-recycled PLA, only $\sum_{i=0}^{n} E_{recycle}$ and $\sum_{i=0}^{n} E_{PLA}$ will be used, because it represents the cumulative energy costs HDPE and PLA over 10 production cycles.

Quantitative measures for cost of higher Global Warming Potential

The GWP values of HDPE and PLA respectively are represented below:

$$GWP_{HDPE} = 2.38\ \frac{kg\ CO_2}{kg\ HDPE}$$

$$GWP_{PLA} = 0.50\ \frac{kg\ CO_2}{kg\ HDPE}$$

The cost of GWP can then be calculated by multiplying these values by $\frac{\$0.005}{kg\ CO_2}$, the cost of carbon tax.

$$GWP_{HDPE} = 2.38\ \frac{kg\ CO_2}{kg\ HDPE} \times \frac{\$0.005}{kg\ CO_2} = \$0.0119\ /\ kg\ HDPE$$

$$GWP_{PLA} = 0.50\ \frac{kg\ CO_2}{kg\ PLA} \times \frac{\$0.005}{kg\ CO_2} = \$0.0025\ /\ kg\ PLA$$

Quantitative measures for benefits of being derived from renewable resources

To quantify the benefit of PLA being derived from renewable resources, the comparison between a carbon-neutral system involving PLA bags is made against the carbon-positive system involving HDPE bags. In principle, carbon released into the atmosphere in a carbon-neutral system is recirculated into the re-production of new PLA material during the growth stages of the plants which supply biological matter. As such, this benefit can be quantified by multiplying the mass of CO_2 absorbed during the production process of PLA by $\frac{\$0.005}{kg\ CO_2}$, the cost of carbon tax.

$$1.833\ \frac{kg\ CO_2}{kg\ PLA} \times \frac{\$0.005}{kg\ CO_2} = \$0.009165\ /\ kg\ PLA$$

Quantitative measures for cost of requiring composting facilities

Several factors contribute to the cost of composting facilities for the biodegradation of PLA. Firstly, the opportunity cost associated with revenue from a composting plant instead of a conventional incineration plant (O2Compost, 2021). Second, the price of land that the composting plant takes up (Pinkerton, 2020). Thirdly, the cost of construction, maintenance and utilities supplied to the composting facility. These can be calculated using the following formulae:

$$C_{Opp} = R_{IP} - R_{CP} = \$29.5 \times 10^6 - \$17.6 \times 10^6 = \$27.74 \times 10^6$$

where C_{Opp} is the yearly opportunity cost, R_{IP} is the yearly revenue from a waste-to-energy incineration plant, which comes from the energy produced by the plant (Ong, 2016), and R_{CP} is the yearly revenue from a composting plant, which comes from the sale of compost. R_{IP} is calculated according to the following equation, using the proportion of energy produced by the incineration of plastic bags:

$$R_{IP} = E_{IP}\ x\ \frac{\$13.02}{1000J} = 0.06\ x\ 120\ x \frac{10^6 J}{s} x\ \frac{365\ x\ 24\ x\ 3600s}{year}\ x\ \frac{\$13.02}{1000J} = \$29.5\ x\ 10^6$$

$$C_{land} = LPSM \times A_{CP} = 10.5\ ha \times \$142\ /ft^2\ \times 107639 \frac{ft^2}{ha} = \$160\ \times 10^6$$

where C_{land} is the land cost, $LPSM$ is the cost of land per unit area (URA, 2021) and A_{CP} is the area occupied by the composting facility (NEA, 2018).

$$C_{10} = C_{EAC} \times 10 = (C_{Capital} + C_{O\&M}) = (\$11282 + \$295723)/year = \$307005/year$$

where C_{EAC} is the equivalent annual cost of owning, operating and maintaining the plant, $C_{Capital}$ is the equivalent annual capital cost and $C_{O\&M}$ is the equivalent annual cost to maintain and operate the plant (JICA, 2002).

Quantitative Analysis - CVM

	Total WTP by all HDPE bags consumers in 1 year	Total WTP by all PLA bags consumers in 1 year
Mean WTP * Total number of households * Number of weeks in a year = Benefits	$0.247 * 1,370,000 * 48 = $16,242,720	$0.218 * 1,370,000 * 48 = $14,335,680

The total number of households in Singapore is 1.37 million (Statista, 2021).

5. TIME PERIOD DIFFERENCES AND DISCOUNTING

Plastic bags are considered market goods. As such, the social opportunity cost of capital could be considered due to the fact that it utilises a higher discount rate. However, accounting for stakeholders affected in the time period of this project, the price increase of both HDPE and PLA bags are absorbed by the consumers (Phneah, 2020). This is because there exists an intergenerational transfer of the cost of using plastic bags. Due to the increase in price of plastic bags the present generation has to contribute to the pool of funds to compensate future generations, resulting in less personal disposable income for current consumers. As consumers bear more of the cost compared to the government, there is a tradeoff between current consumption and future consumption.

Additionally, to evaluate the net present worth, a time period 10 years is selected, using a discount rate based on the 10-year Singapore Bond, which at a timestamp of 5th November 2021 is at 1.77%. We will be utilising the discount rate of 2.00% for our project to account for further discrepancies and changes over the 10 years.

<u>Benefits to discount for HDPE</u>

The surveyees' average willingness to pay for 24 HDPE plastic bags is \$0.247. Since the market price of HDPE plastic bag is \$0.10854, the consumers surplus would be

= ½ * 24 * (\$0.247 - \$0.10854) = \$1.66152

\$1.66152 * 1,370,000 * 48 = \$109,261,555.2 is the consumer surplus enjoyed by consumers in Singapore in one year.

Using a uniform series present worth regime, the net present worth of consumer surplus for a period of 10 years is \$54,629,852.42

Refer to appendix H for graph of consumer surplus of consumers' benefits for HDPE plastic bags.

<u>Benefits to discount for PLA</u>

The surveyees' average willingness to pay for 24 PLA plastic bags is \$0.218. Since the market price of PLA plastic bag is \$0.16488, the consumer surplus would be

= ½ * 24 * (\$0.218 - \$0.16488) = \$0.63744

\$0.63744 * 1.370,000 * 48 = \$41,918,054.4 is the consumer surplus enjoyed by consumers in Singapore in one year.

Using a uniform series present worth regime, the net present worth of consumer surplus for a period of 10 years is \$20,958,672.06

Refer to Appendix I for graph of consumer surplus of consumers' benefits for PLA plastic bags.

<u>Discounting for Cost of GWP</u>

$$GWP_{HDPE} = 2.38\ \frac{kg\ CO_2}{kg\ HDPE} \times \frac{\$0.005}{kg\ CO_2} = \$0.0119\ /\ kg\ HDPE$$

$$GWP_{PLA} = 0.50\ \frac{kg\ CO_2}{kg\ PLA} \times \frac{\$0.005}{kg\ CO_2} = \$0.0025\ /\ kg\ PLA$$

These values are multiplied by the total mass of plastic bags used per year (26,334,140kg) to find the total cost of GWP for both HDPE and PLA per year. Then, using the uniform series present worth with a discount rate of 2.00%, the annual cost for 10 years was translated to the following net present worth values:

$$NPW_{GWP,HDPE} = \$156.685 \times 10^3$$
$$NPW_{GWP,HDPE} = \$32.917 \times 10^3$$

Discounting for Recyclability

To account for energy savings from recycling, a uniform series present worth was performed using the values $\sum_{i=0}^{n} E_{recycle}$ to represent the energy cost of 10 iterations of recycling per year and $\sum_{i=0}^{n} E_{PLA}$ to represent the energy cost of 10 product cycles of PLA per year. The total energy cost throughout a year was found by multiplying these values with the total mass of plastic bags used, and then using the uniform series present worth with a discount rate of 2.00% to obtain the net present worth for a period of 10 years.

$$NPW_{Recyc,HDPE} = \$1.077 \times 10^{14}$$
$$NPW_{Recyc,PLA} = \$1.1113 \times 10^{14}$$

Discounting for Cost of Infrastructure

To account for the cost of retaining existing incineration infrastructure compared to building new composting infrastructure for the biodegradation of PLA, yearly EAC costs were discounted for a period of 10 years, with an initial cost of $\$160 \times 10^6$ in year 0. The difference between calculations for PLA and HDPE resulted in the opportunity cost, which was also discounted for a period of 10 years. As such, the following net present worth values were obtained:

$$NPW_{Inf,HDPE} = \$1.60 \times 10^8$$
$$NPW_{Inf,PLA} = \$1.74 \times 10^8$$

A lower cost for incineration is considered a gain, and therefore the values were scaled in the gain direction before being added to get the net benefit

Discounting for Renewability

To account for the cost of renewability, the cost per mass was multiplied by the total mass of plastic bags produced per year. This was then put through a uniform series present worth for 10 years to obtain the following NPW values:

$$NPW_{HDPE} = \$0$$
$$NPW_{PLA} = \$120674.153$$

6. ACCOUNTING FOR UNCERTAINTY

6.1 SENSITIVITY ANALYSIS

Perform an annual worth analysis to find net present value for each cost and benefit. -discounting To find the expected net benefit based on likelihood of each outcome, we use transformed measurements to scale each benefit and costs considered into similar orders of magnitude.

We assign weights to each cost and benefit according to the probabilities obtained from the results of the damaged schedule approach in our questionnaire. The product of each weight with its corresponding cost / benefit is then summed up to provide the expected net benefit.

For example, based on the results of the survey, the average amount participants are willing to pay to enjoy the benefits of PLA being derived from renewable resources is $17.84 out of a budget of $100. From this, we derive the weights of 0.1784 to scale the discounted benefits of PLA being derived from renewable resources, that were quantitatively measured above.

Comparison of net value for HDPE & PLA at different discount rates			
Discount rate	1.90%	2.00%	2.10%
HDPE	-$2.795 x 10^{13}	-$2.655 x 10^{13}	-$2.529 x 10^{13}
PLA	-$2.997 x 10^{13}	-$2.847 x 10^{13}	-$2.712 x 10^{7}

After performing the net benefit calculation with discount rates of 1.90%, 2.00%, and 2.10%, it can be concluded that the net benefits of HDPE outweigh those of PLA for all 3 discount rates, because they are less negative. Therefore, it can be reasonably concluded that HDPE provides a larger net benefit than PLA.

6.2 LIMITATIONS OF METHODOLOGY

Pairwise

Under the use of this method, inconsistent answers and intransitive responses may be obtained. This may be because answers from participants may be inconsistent. Additionally, pairwise comparison does not allow for the possibility of being indifferent in our answers. For example, in the findings of this report, respondents may value the impacts of increasing global warming potential and impacts of plastics on marine life, equally. However, respondents are forced to make a choice and rank these impacts in different orders. This may cause results of the survey to have a high percentage of intransitive answers. To combat this limitation, we came up with an acceptable percentage of transitive answers that we allow for. The percentage of intransitive answers in the survey was lower than 30%. Hence, the results from the pairwise comparison method are reliable and informative.

Additionally, we utilised the damage schedule approach to allow participants to further justify their ranking of choices. For example, if a participant values the increase in global warming potential as much as the impacts of HDPE plastic on marine life, s/he would assign a budget of $30 for alleviating the impacts of global warming potential and $31 for saving marine life. From this, we are still able to distinguish that participants value the two options almost to the same extent. This is something that cannot be done through simple ranking.

Contingent Valuation Method

Using the contingent valuation method, some limitations may arise in the form of biasness. Specifically for our project, there are two main forms of biases that may affect our survey findings as written below.

1. **Payment Vehicle Bias:**

Payment methods might affect the way consumers view the price of plastic bags. For example, an individual who is using cash payment to pay for the bags might value the bag differently from another individual who uses a credit card to make payment. According to Hurd (2020), research has shown that people spend substantially more money when they make purchases on a credit card as compared to cash. When using cash, it is a tangible piece of paper and using more of it has a negative psychological effect on the brain. To put it into context for our project, an individual might value the price of the plastic bag more if he is using cash to make payment as compared to if he uses a credit card. The percentage of answers in the survey when we asked them to choose their most common mode of payment was 50% for cash and 50% for credit card usage. Thus, we managed to take this limitation into consideration and ensure that we have good data collection and accurate information. With a mix of participants who use cash and credit cards, we are hence able to better estimate their average willingness to pay for the plastic bags.

2. **Information Bias:**

Participants may make irrational decisions due to the lack of information. For example, they may value the life of marine animals more than the landfill spaces due to their own personal morals. However, in terms of cost benefit analysis, the cost of losing the marine animals and landfill spaces may be different from what they perceive it to be. To mitigate this problem, we provided them with all the information they needed in the hypothetical situation so that they are able to better allocate the portion of their income for various choices presented to them. This helps us ensure that participants are fully aware of the situation and have full knowledge before answering the questions.

3. **Problem of double counting:**

We need to take into consideration that consumers might face the problem of double counting as they do not consider other factors when making a decision on their rankings. In general, consumers may have different preferences individually and value different costs and benefits to various extents. Hence, our first question in the secondary survey is designed to find out on average what are the costs and benefits that value most when they consider their willingness to pay and to sieve out the cost and benefits that are not valued as much by participants. This will provide a more accurate cost and benefit analysis of the consumer's preferences.

7. EQUITY CONSIDERATIONS

The most feasible solution to increase energy expenditure for the incineration of PLA, or to implement new infrastructure for the establishment of new industrial composting facilities is to introduce a tax on PLA bags. This is a form of indirect taxation which impacts consumers and businesses.

When considering taxation for goods as widespread in consumption as plastic bags, matters of equity must be considered. Two distributional goals are considered in the pursuit of tax fairness, namely vertical and horizontal equity. Horizontal equity involves the principle of similar treatment for similar individuals, even if they make different economic choices. Horizontal equity would not be the goal behind the implementation of this tax, because it is specifically aimed at reducing PLA bag usage, which is an economic choice that individuals make. Vertical equity considers the equity across groups of different income and wealth levels, and is motivated by utilitarian social welfare, so that those who have more resources pay more taxes.

The redistribution effects of vertical equity become clear when considering that research has shown the effects of climate change often impact low-income groups disproportionately. As such, a progressive tax could be implemented, where the average tax rate rises with income. However, indirect taxation does not allow for effective vertical equity to be enacted in taxation policy, because the tax incidence falls on any individual or business using PLA bags. As such, an alternative could be a direct tax on income, with taxation revenue channeled towards the cost of new incineration / waste facilities to process PLA bags. However, this may sacrifice the quantity reduction of PLA consumption which indirect taxation offers.

To evaluate these two proposals, the tax incidence and tax efficiency of each must be considered, and the alternative which provides the highest social net benefit should be chosen. Tax incidence involves distinguishing between the statutory and economic incidence of the tax. While statutory incidence shows, on paper, who pays the tax to the government, the economic incidence is an actual indication of who is actually impacted by a change in resources due to the tax. They are independent of each other. While companies may be paying more for a taxed shipment of PLA bags, the real economic incidence may lie on consumers due to inelastic demand. Therefore, evaluating the burden of consumer and producer taxation requires an analysis of demand and supply rates, as well as an understanding of market elasticity.

An evaluation of tax efficiency involves the actual calculation of how much social efficiency is sacrificed due to the tax, as well as effects of quantity changes on society. Three parameters for tax efficiency for the two alternatives can be defined:

1. To what extent is PLA consumption reduced?
2. How much tax revenue is collected?

3. How much is redistributed in the form of net benefits to lower income groups with reduction in climate change?

The resulting quantity and price changes must be evaluated along the lines of tax shifting, whereby taxes may be shifted backward or forward, towards the factor of labor or to consumers respectively. The deadweight loss due to the tax can be evaluated by measuring the behavioral changes to an increase in price. Similar to the principle of economic incidence, tax efficiency is also affected by the elasticity of demand and supply. To evaluate the exact amount of taxation, the Ramsey tax rule can be applied, taking reference from similar taxation regimes such as the additional tax on tobacco products. The Ramsey tax rule states that the optimal tax ensures the ratio of marginal deadweight loss to marginal revenue for a certain good is equal to that of a good with similar elasticity. As such, there is a tradeoff between the equity and efficiency of the tax. Further market research into demand and supply patterns will allow for these to be pursued.

8. CHOSEN INVESTMENT DECISION CRITERIA

To decide whether to make the switch from HDPE to PLA bags, we have decided to use Net Present Value (NPV) as the investment decision criterion

Net present value (NPV)

For our project, it is considered to be a public investment as we surveyed a random pool of 100 people as a representation of the overall population in Singapore. After considering how the benefits and costs of switching from HDPE to PLA bags affects individuals in the society, we then managed to find the overall social welfare. To determine if a switch to PLA is beneficial, we had to ascertain the potential future benefits as well as costs. As the time period of the project is 10 years, it is necessary to factor in the uncertainty and any opportunity cost as well as the cost of capital. Most importantly, the motivation of the report was to provide an informative analysis to determine which type of plastic bags to use from now to 10 years later.

Net Present Value = Present Benefit - Present Cost. Therefore, since the net present value of HDPE bags is less negative (-$\$2.655 \times 10^{13}$) than PLA bags (-$\$2.847 \times 10^{13}$), we can conclude that HDPE bags are the better alternative.

9. DISCUSSION AND CONCLUSION

In this paper, we have identified and quantified the costs and benefits associated with replacing HDPE bags with PLA bags. With a time period of 10 years, the discounted benefit for HDPE amounts to -$\$2.655 \times 10^{13}$ while the discounted benefit for PLA amounts to -$\$2.847 \times 10^{13}$. Therefore, HDPE results in a smaller net cost and is the more beneficial alternative of reusable bags. A variety of factors contributed to this result. While the biodegradability and renewability of PLA may seem like factors which would make PLA the more eco-friendly option, its shorter lifespan, non-recyclability and the higher energy requirement for its incineration actually make it more harmful to the environment, given Singapore's constraints which require PLA to be incinerated.

Through our CVM study conducted for this term paper, the value in which consumers in Singapore place on HDPE and PLA bags is derived. Taking into account the benefits and cost of HDPE and PLA bags, consumers have a higher WTP value for a week's worth of HDPE bags (0.247) and PLA bags (0.218). In retrospect, there is room for improvement for the CVM study conducted for this term paper. Firstly, online surveys were used instead of personal interviews. Self-administered surveys based on a convenience sample frame and a relatively low sample size might cause our data collection to be inaccurate. Secondly, having an initial bid value of $0.10 per weeks' worth of plastic bags has precluded us from directly measuring consumer responses to even lower bid levels e.g at $0.05 or even higher bid levels e.g at $0.60. As a result, we can only conjecture what the consumer surplus might be. Beyond this, the evaluation of costs and benefits could be vastly improved, as many figures were approximated based on values from other case studies or other countries. With more official data from government bodies, as well as a larger sampling pool, our evaluation of costs and benefits could be more accurate. Overcoming these shortcomings is an obvious starting point for future research as well as making our results more robust.

In conclusion, the objective of this study to estimate the value that consumers place on HDPE and PLA bags using CVM has been achieved. We have obtained the total economic value based on our own surveys, with a further differentiation of the results into revealing the socioeconomics profiles of the consumers and the WTP values that they place. With our findings, this term paper can therefore provide invaluable insights into the environmental literature in Singapore and to potentially influence policy making decisions pertaining to plastic bags usage in the future.

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11. REFLECTIONS

Group 2 consists of members of different years as well as different majors. The diversity in our group has provided us the basis of ideas to be exchanged and built upon, by tapping onto each individual's unique skill sets. When working together as a team, it allowed us to share the knowledge we have with one another and this really helped us to speed up the process of understanding the content and the various ways to go about the project. We were also able to see things from each other's point of view and have a broader perspective about things. Putting more heads together to form a cost benefit analysis of the project definitely helped us to save more time as compared to if we did it individually. When we were brainstorming for ideas and methods to carry out our cost benefit analysis, many of us had differing opinions. This took up quite a lot of time during the research. However, it also allowed us to learn not only subject content, but also learn more practical issues from one another. This helped our research to a great extent as we were able to evaluate a variety of suggestions and come up with the best solution.

With Singapore Green Plan 2030 being set in place for the future, there has never been a more pressing need to conduct a cost benefit analysis of environmental issues. However, due to the non-market goods nature of plastics commodity as well as the lack of existing literature regarding biodegradable plastic bags in Singapore, our group has to resort to extrapolating data that is being used in research that is conducted overseas. Additionally, we realised that there are many considerations to take note of when conducting a cost benefit analysis. Researching for the background information on the topic we are doing was the easier part. However, the more challenging part was getting the methodology to be aligned to the basis of our report. We learnt that it may not be the best option to carry out only one survey but have two instead. This was to allow us to have a more accurate representation of our survey results which will lead to the eventual conclusion that we make regarding benefits and costs of the switch from HDPE plastic bags to PLA plastic bags.

Conducting a full cost benefit analysis of any project is difficult, and to accurately answer the 6 questions of cost benefit analysis is even harder. Along the way, our group has faced multiple difficulties in attempting to do so, especially with the topic that we have chosen. Despite the challenges that we faced along the way, our group has managed to produce a term paper that we are proud of. Going forward, with the cost benefit apparatus that we now possess, we will definitely have a greater appreciation of things around us, especially to the simplest common sight objects - plastic bags.

12. APPENDICES

Appendix A

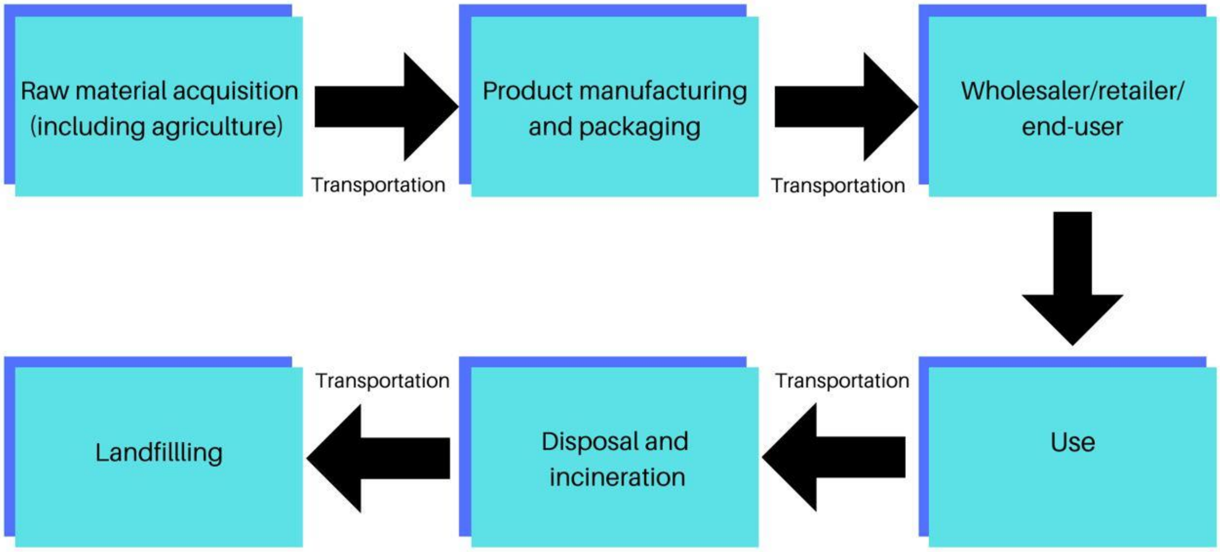


Figure 1: Life cycle of Plastic Bags

Appendix B

HDPE Plastic Bags	
Benefits	Costs
Less expensive	**Dependence on petrochemical industry**
Requires less energy to incinerate	**Releases toxic substances into air upon incineration**
High standards of durability, strength and waterproof	Higher global warming potential
Cumulative energy savings from recycling HDPE	**Forms microplastics when released into the sea**

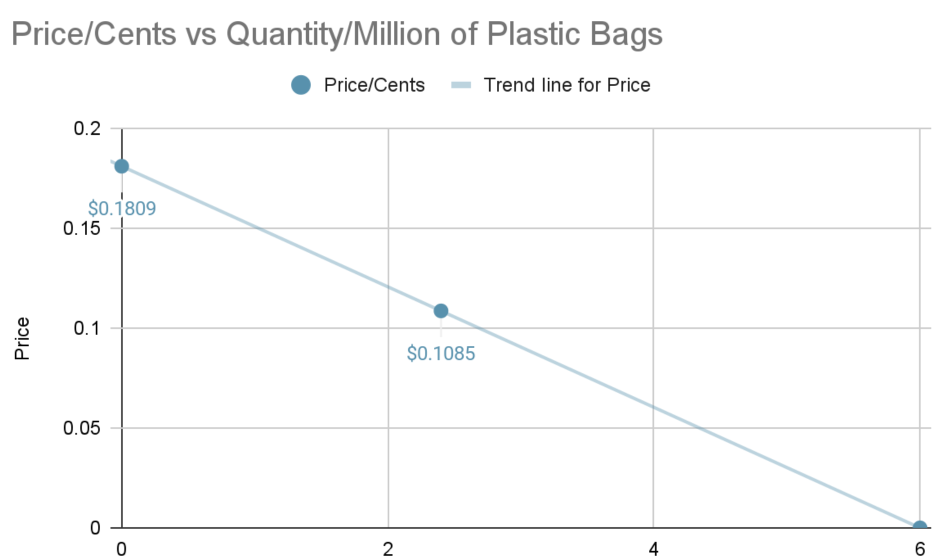
Table 1: Costs and benefits of HDPE plastic bags

Appendix C

PLA Plastic Bags	
Benefits	Costs
Reduces dependence on petrochemical industry	**More expensive**
Able to biodegrade over time given proper composting facilities	**Opportunity cost of composting facilities to biodegrade/ cost to transport waste overseas/ cost to store waste in Singapore**
Lower global warming potential	**Cumulative energy costs from recycling HDPE**
Does not release toxic substances into the air or form microplastics in the environment	Non-recyclability (shorter lifespan)
Derived from a renewable resource	**Lower quality, less durable, less waterproof**

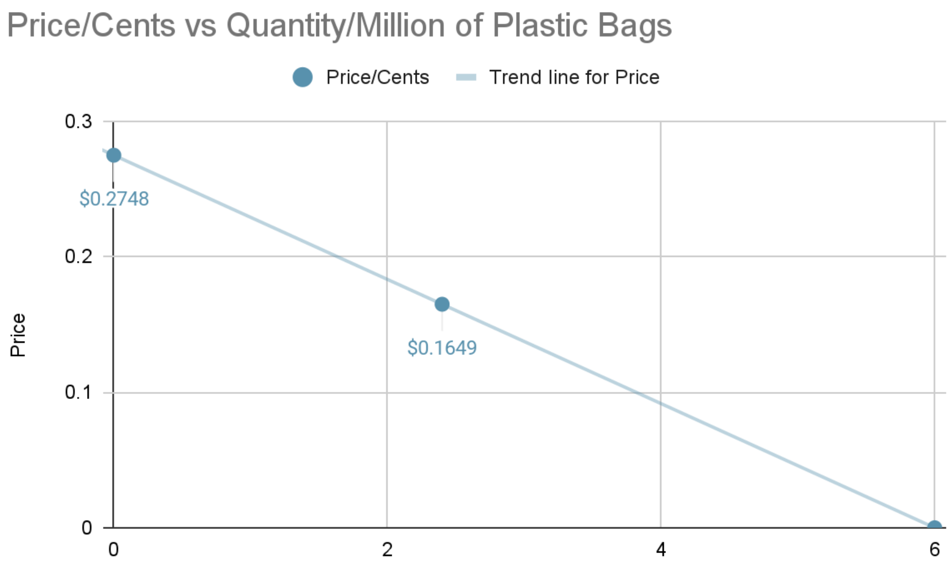
Table 1: Costs and benefits of PLA plastic bags

Appendix D



Graph 1: Demand curve for HDPE plastic bags

Appendix E



Graph 1: Demand curve for PLA plastic bags

Appendix F

Comparison of energy usage after 10 iterations					
n	E_{HDPE} (MJ/kg)	$E_{recycle}$ (MJ/kg)	$\sum_{i=0}^{n} E_{HDPE}$ (MJ/kg)	$\sum_{i=0}^{n} E_{recycle}$ (MJ/kg)	$E_{sc,n}$ (MJ/kg)
0	76	76	76	76	0
1	76	55.3	152	131.3	20.7
2	76	55.3	228	186.6	41.4
3	76	55.3	304	241.9	62.1
4	76	55.3	380	297.2	82.8
5	76	55.3	456	352.5	103.5
6	76	55.3	532	407.8	124.2
7	76	55.3	608	463.1	144.9
8	76	55.3	684	518.4	165.6
9	76	55.3	760	573.7	186.3
10	76	55.3	836	629	207

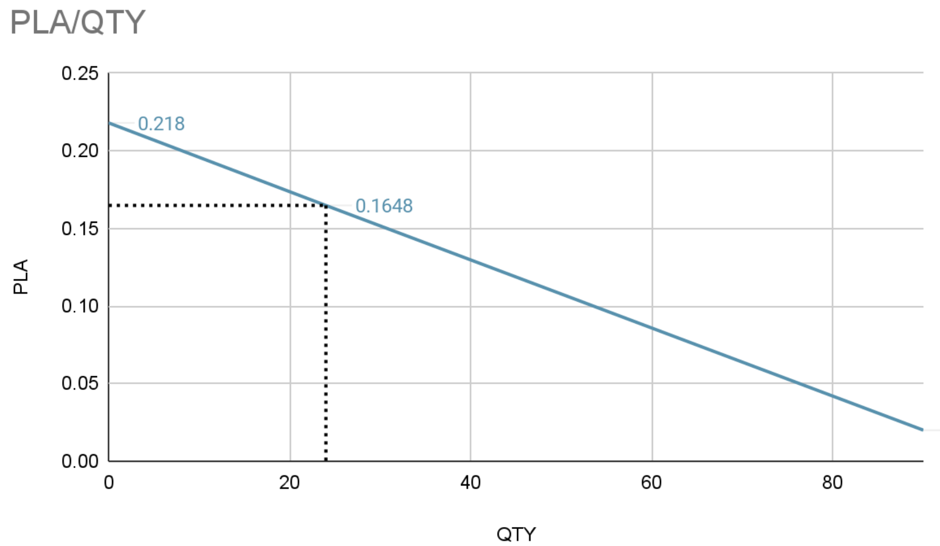
Table 1: Comparison of energy usage after 10 iterations

Appendix G

Comparison of energy usage after 10 iterations					
n	$E_{recycle}$ (MJ/kg)	E_{PLA} (MJ/kg)	$\sum_{i=0}^{n} E_{recycle}$ (MJ/kg)	$\sum_{i=0}^{n} E_{PLA}$ (MJ/kg)	$E_{hp,n}$ (MJ/kg)
0	76	58.9	76	58.9	-17.1
1	55.3	58.9	131.3	117.8	-13.5
2	55.3	58.9	186.6	176.7	-9.9
3	55.3	58.9	241.9	235.6	-6.3
4	55.3	58.9	297.2	294.5	-2.7
5	55.3	58.9	352.5	353.4	0.9
6	55.3	58.9	407.8	412.3	4.5
7	55.3	58.9	463.1	471.2	8.1
8	55.3	58.9	518.4	530.1	11.7
9	55.3	58.9	573.7	589	15.3
10	55.3	58.9	629	647.9	18.9

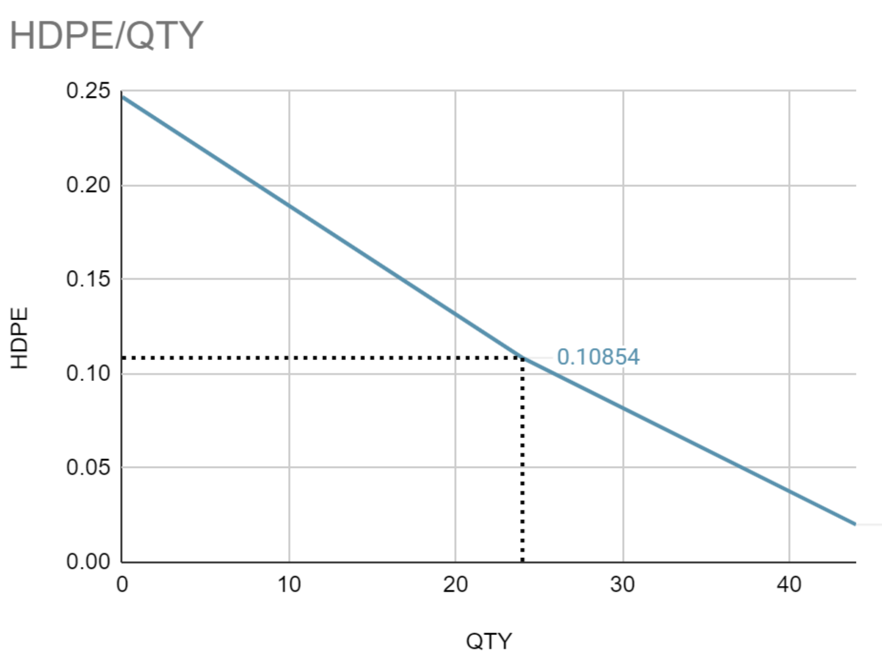
Table 2: Comparison of energy usage after 10 iterations

Appendix H



Graph 1: Consumer surplus of consumers' benefits from PLA plastic bags.

Appendix I



Graph 1: Consumer surplus of consumers' benefits from HDPE plastic bags.

Appendix J

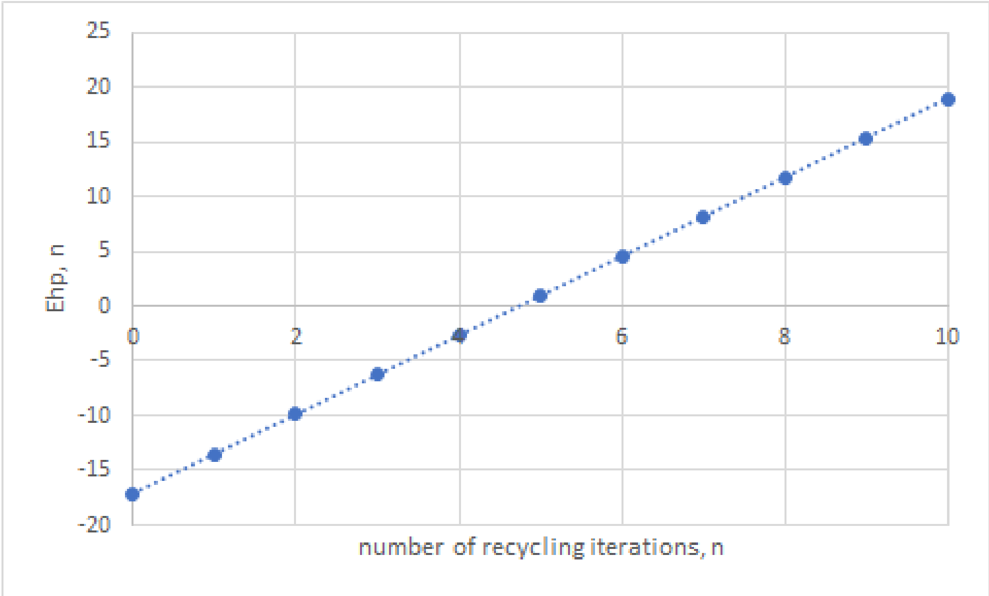


Figure 1: Graph of energy savings for recycled HDPE compared to PLA vs number of recycling iterations, n

Appendix K

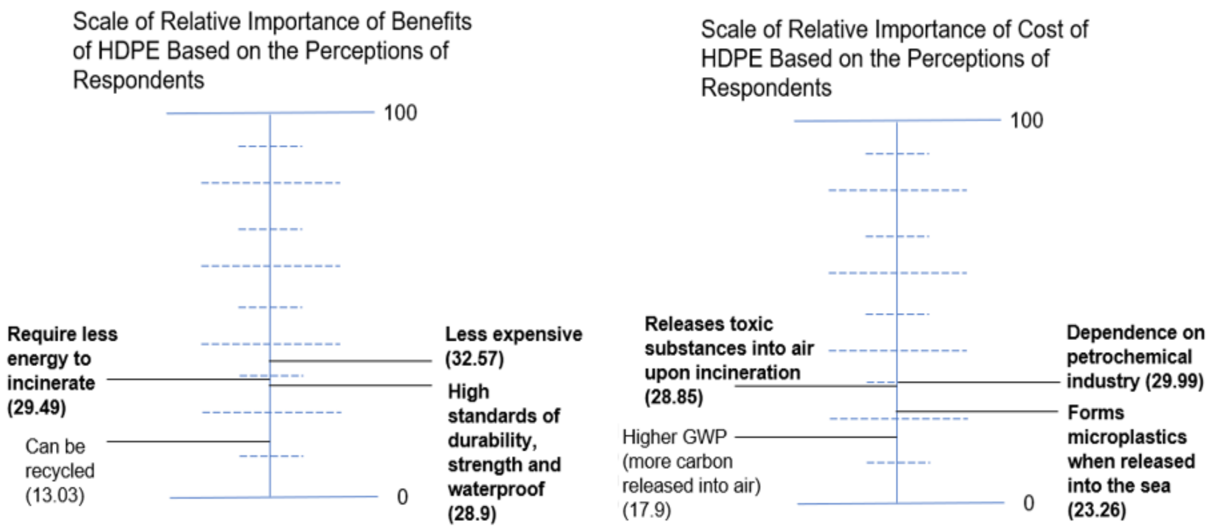


Figure 1: Pairwise comparison of benefits and cost of HDPE plastic bags

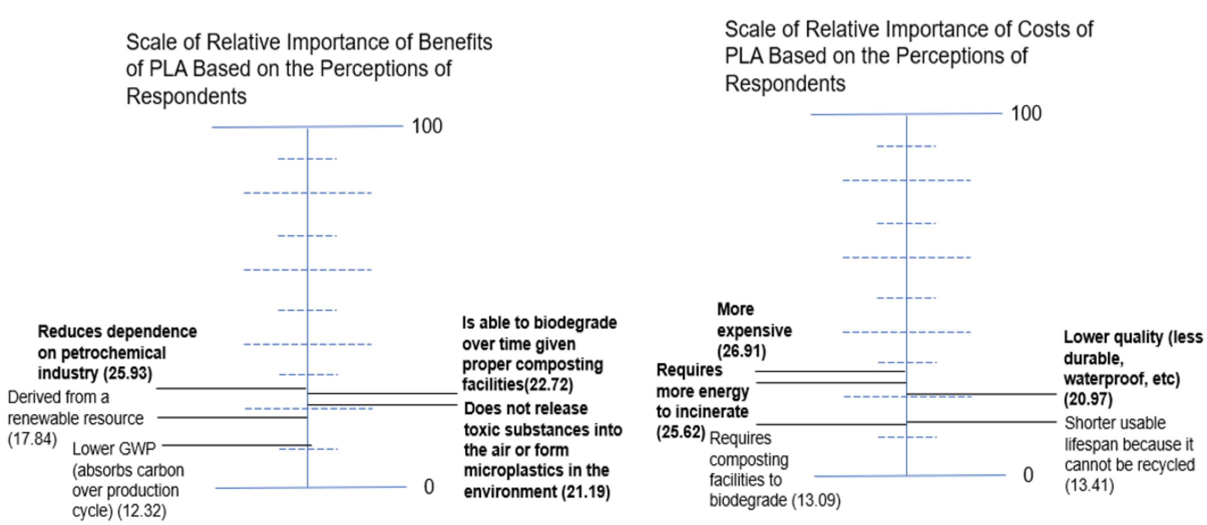


Figure 2: Pairwise comparison of benefits and cost of PLA plastic bags

Appendix L

Preliminary Survey

Cost and Benefit Analysis of changing HDPE plastic bags (the normal bags used as carriers in most places) to PLA biodegradable bags.

Dear Participant,

We are a group of undergraduate students from Nanyang Technological University, seeking the help of the general public to complete a survey as part of a study for our assignment. This study seeks to understand the consideration of costs and benefits with regards to replacing plastic bags with biodegradable plastic bags. During this study, there will be a demographics survey and a questionnaire requiring you to indicate the consideration that is more important to you as an individual in determining the usage of biodegradable (PLA) plastic bags instead of conventional (HDLP) plastic bags.

Demographics

1) What is your age range?
    - 20-29
    - 30-39
    - 40-49
    - 50-59
    - 60 and above

2) What is your monthly household income?
    - <$2000
    - $2000 to $3999
    - $4000 to $5999
    - $6000 to $7999
    - $8000 to $10000
    - > $10000

3) How many people are there living in your household in total?
    - 1-2
    - 3-4
    - 5-6
    - > 6

<u>Questionnaire</u>

4) Are you familiar with the benefits and costs of using biodegradable plastic bags?
    - Yes
    - No

5) Do you usually bring your own recycling bag when checking out during grocery shopping?
    - Yes
    - No

6) On a scale of 1-5, with 1 being the putting in minimal effort and 5 being putting in maximum effort, please rank your efforts that you have done to help on environmental causes?
    - 1
    - 2
    - 3
    - 4
    - 5

Appendix M

Ordered Probit Regression Results for HDPE Plastic Bags

Variable	Obs	Mean	Std.Dev.	Min	Max
WTP	100	0.247	0.118	0.10	0.40
Age	100	2.710	1.438	1	5
Gender	100	0.460	0.501	0	1
Household	100	3.560	1.321	1	6
NoofHouse	100	2.440	0.978	1	4
Familiarwi·	100	0.480	0.502	0	1
BYOB	100	0.600	0.492	0	1
Efforts	100	2.730	1.651	1	5

Table 1: Descriptive statistics for HDPE plastic bags

	WTP	Age	Gender	Househ~e	NoofHo~s	Famili~s	BYOB	Efforts
WTP	1							
Age	-0.139	1						
Gender	0.0575	-0.0654	1					
Household	0.4370*	-0.0360	-0.0727	1				
NoofHouse	0.0813	-0.2820*	-0.0256	0.2062*	1			
Familiarwi·	0.194	0.0549	0.0369	0.0932	-0.126	1		
BYOB	-0.0208	0.0485	-0.0246	0.0839	0.180	0.172	1	
Efforts	0.4685*	-0.2036*	-0.0315	0.3528*	0.0493	-0.0371	0.0771	1

* Significant at 5% level

Table 2: Correlation Matrix for HDPE plastic bags

Variable	Obs	Mean	Std.Dev.	Min	Max
WTP	100	0.218	0.0845	0.10	0.30
Age	100	2.710	1.438	1	5
Gender	100	0.460	0.501	0	1
Household	100	3.560	1.321	1	6
NoofHouse	100	2.440	0.978	1	4
Familiarwi·	100	0.480	0.502	0	1
BYOB	100	0.600	0.492	0	1
Efforts	100	2.730	1.651	1	5

Table 3: Descriptive statistics for PLA plastic bags

	WTP	Age	Gender	Househ~e	NoofHo~s	Famili~s	BYOB	Efforts
WTP	1							
Age	-0.148	1						
Gender	0.0649	-0.0654	1					
Household	0.4426*	-0.0360	-0.0727	1				
NoofHouse	0.0743	-0.2820*	-0.0256	0.2062*	1			
Familiarwi·	0.2227*	0.0549	0.0369	0.0932	-0.126	1		
BYOB	-0.0194	0.0485	-0.0246	0.0839	0.180	0.172	1	
Efforts	0.3971*	-0.2036*	-0.0315	0.3528*	0.0493	-0.0371	0.0771	1

* Significant at 5% level

Table 4: Correlation Matrix for PLA plastic bags

VARIABLES	(1) HDPE WTP	(2) PLA WTP	(3) HDPE Weighted WTP	(4) PLA Weighted WTP
Age	-0.06445	-0.06980	-0.05383	-0.06953
	(0.08071)	(0.08966)	(0.07799)	(0.08148)
Gender	0.19766	0.21215	0.19415	0.27929
	(0.22208)	(0.24042)	(0.21478)	(0.21573)
HouseholdIncome	0.31139***	0.36397***	0.30026***	0.31530***
	(0.10505)	(0.10419)	(0.10172)	(0.10083)
NoofHouseholdMembers	0.03540	0.06484	0.02735	0.02874
	(0.13654)	(0.16052)	(0.13606)	(0.14672)
Familiarwithbenefits	0.53262**	0.61693**	0.53049**	0.43630*
	(0.25438)	(0.28047)	(0.25274)	(0.26114)
BYOB	-0.32409	-0.31909	-0.30522	-0.23397
	(0.23335)	(0.25231)	(0.23265)	(0.22348)
Efforts	0.27316***	0.24072***	1.20039***	1.53200***
	(0.07777)	(0.08189)	(0.10854)	(0.22248)
Constant cut1	1.15025**	1.34796**	1.71640***	2.09373***
	(0.46519)	(0.57963)	(0.51757)	(0.62164)
Constant cut2	2.03784***	2.24235***	3.07445***	3.48472***
	(0.49797)	(0.61779)	(0.54786)	(0.65951)
Constant cut3	2.65501***		4.32097***	5.86923***
	(0.52323)		(0.67225)	(1.06455)
Constant cut4			4.90803***	6.21271***
			(0.70081)	(1.12764)
Constant cut5			5.21531***	6.51899***
			(0.65695)	(1.05218)
Constant cut6			5.54140***	6.82516***
			(0.70753)	(1.10149)
Constant cut7			5.66246***	7.29303***
			(0.69510)	(1.10461)
Constant cut8			5.72377***	7.37592***
			(0.70135)	(1.11456)
Constant cut9			6.44428***	8.57704***
			(0.73971)	(1.26003)
Constant cut10			6.65144***	
			(0.74386)	
Constant cut11			7.25945***	
			(0.76376)	
Observations	100	100	100	100

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 7: Ordered probit regression results for HDPE and PLA plastic bags

<u>Appendix M</u>

Secondary Survey

Hypothetical scenario:

Singapore uses about 2.5 billion plastic bags a year, which is equivalent to each person using about 452 plastic bags a year. Over the years, several efforts have been carried out to reduce dependency on plastic bag use. Considering the use of biodegradable plastic as an alternative to tackle the issue of plastic waste has been widely discussed. Hence, our group is trying to conduct a cost and benefit analysis of replacing plastic bags (HDPE) with biodegradable bags (PLA) in hopes of influencing policy making decisions regarding plastic bags usage. The time period of the project would be 10 years, which means costs and benefits of the use of PLA and HDPE plastic bags over the course of 10 years will be accounted for.

The cost and benefits that we have identified is as follows:

1. **Price**

Consumer facing price for HDPE bags is lesser compared to PLA bags. This is due to the difference between each stage of production within the production of the plastic bags.

2. **Energy expenditure during incineration**

During incineration, different initial amounts of energy must be applied to HDPE and PLA to raise its temperature to begin thermal decomposition. Therefore, PLA requires a higher utilities cost to incinerate.

3. **Standards of durability and water resistance**

HDPE is known to have a high strength to density ratio and tensile strength in comparison to PLA. HDPE is also water-resistant, whereas only some varieties of PLA can be fully water-resistant

4. **Recyclability**

HDPE can be recycled at least 10 times, allowing for a longer lifespan compared to PLA. The physical lifespan of an HDPE is 500 years. However, PLA cannot be recycled and must be disposed of once it reaches the end of its useful lifespan of 15 years.

5. **Biodegradability**

PLA takes 80 years to biodegrade (with help of enzymes) whereas HDPE takes 500 to 1000 years to photodegrade (upon exposure to UV light).

6. **Infrastructure Costs**

Compared to HDPE, in order for PLA to fully biodegrade, it must be processed and treated under specific conditions, which require the establishment of specialised infrastructure

7. **Microplastics**

Microplastics are small pieces of plastic less than 5mm long which are harmful to aquatic life, and to humans upon consumption of seafood which has ingested it. HDPE is estimated to account for roughly 22.3% of microplastics in all of the water bodies of the world

8. **Release of Toxic Substances upon Incineration**

During incineration of HDPE, toxic substances such as furans and dioxins are released into the environment whereas PLA does not produce toxic fumes upon incineration.

9. **Global Warming Potential (GWP)**

GWP of different materials seeks to quantify the impact a certain product has on the environment by quantifying the equivalent mass of CO_2 which corresponds to the heat trapped by all emissions released into the environment from the start of its life cycle until it's incineration. On average, HDPE has a higher GWP value compared to PLA.

10. **Dependence on Petrochemical Industry**

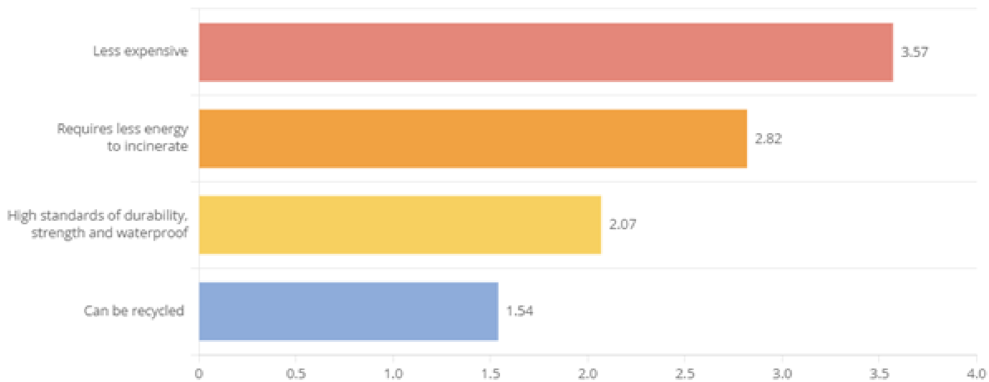
A significant advantage of replacing HDPE, which is considered “fossil carbon”, with PLA, which is “renewable carbon” is a reduction in reliance on the petrochemical industry, and thus a reduction in demand for petrochemical feedstocks.

11. **Renewable carbon vs Fossil carbon**

"Renewable carbon" is a solution to rapidly depleting petrochemical resources. Compared to HDPE, PLA is produced by extracting fermented starch from crops such as corn, cassava, sugarcane or sugar beet pulp. These crops can be regrown after harvesting, and are often genetically modified.

1) With your knowledge from the above hypothetical scenario, please rank the benefits and costs in accordance to your own personal preference, with 1 being most important and 4 being the least important.

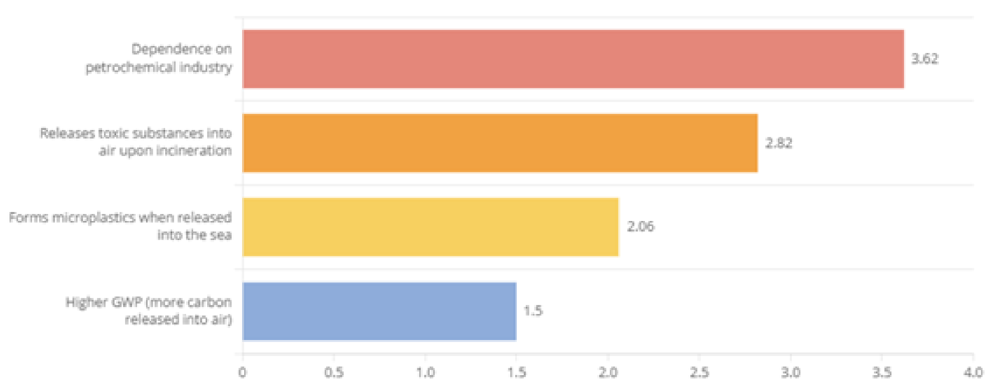
With your knowledge from the above hypothetical scenario, please rank the benefits and costs in accordance to your own personal preference, with 1 being most important and 4 being the least important.



Answers	1st	2nd	3rd	4th	Score
Less expensive	76 (76%)	12 (12%)	5 (5%)	7 (7%)	3.57
Requires less energy t...	15 (15%)	61 (61%)	15 (15%)	9 (9%)	2.82
High standards of dur...	3 (3%)	23 (23%)	52 (52%)	22 (22%)	2.07
Can be recycled	6 (6%)	4 (4%)	28 (28%)	62 (62%)	1.54

Total: **100 responses**

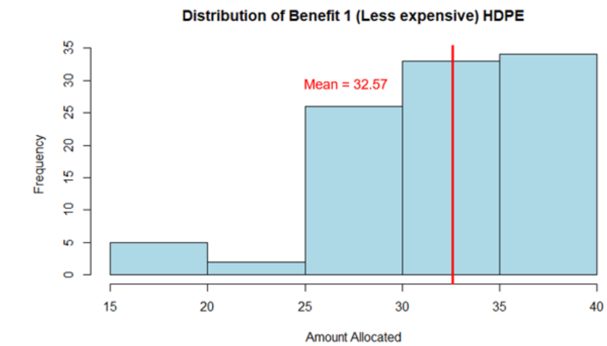
With your knowledge from the above hypothetical scenario, please rank the benefits and costs in accordance to your own personal preference, with 1 being most important and 4 being the least important.

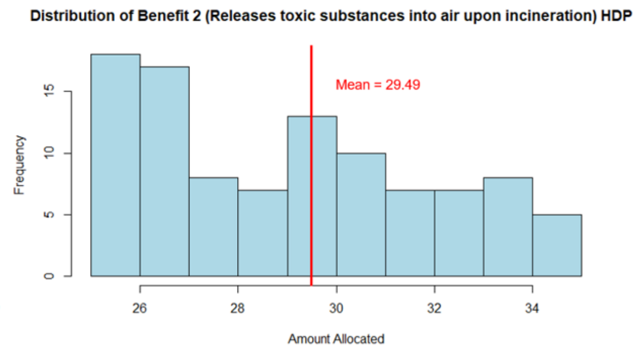


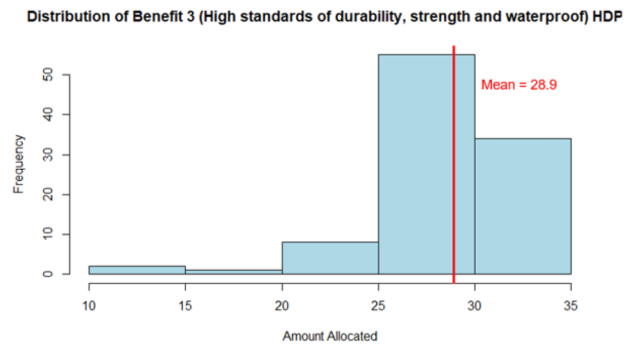
Answers	1st	2nd	3rd	4th	Score
Dependence on petro...	79 (79%)	10 (10%)	5 (5%)	6 (6%)	3.62
Releases toxic substa...	14 (14%)	61 (61%)	18 (18%)	7 (7%)	2.82
Forms microplastics w...	3 (3%)	23 (23%)	51 (51%)	23 (23%)	2.06
Higher GWP (more car...	4 (4%)	6 (6%)	26 (26%)	64 (64%)	1.5

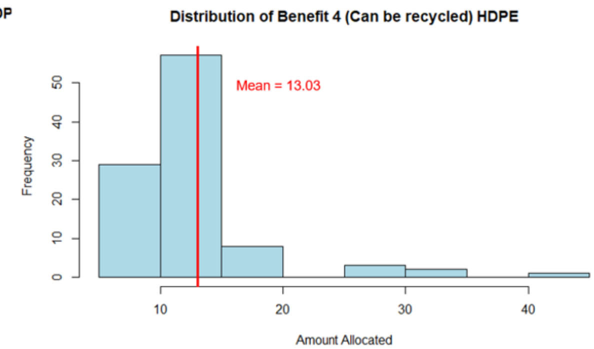
Total: **100 responses**

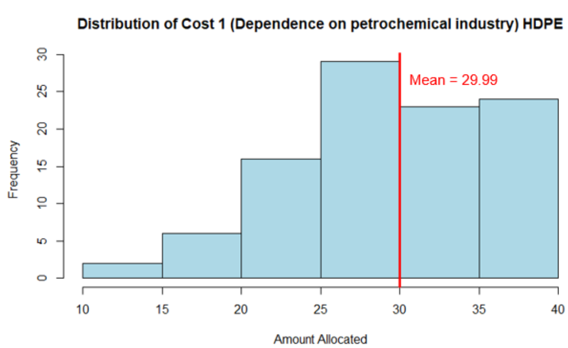
2) Suppose now you have a budget value of $100, kindly assign monetary values to the benefits and costs based on the choices that you have ranked in Q1). The individual values that you have assigned for each cost/benefit should total up to $100.

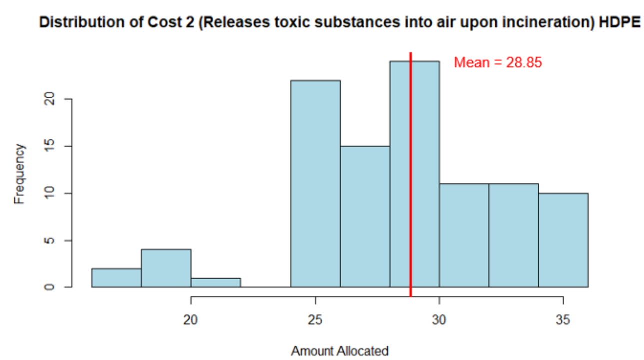


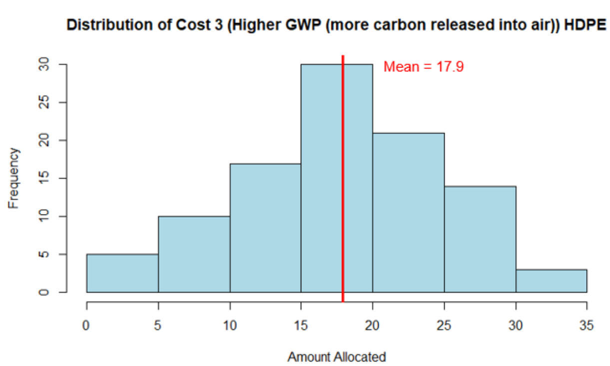


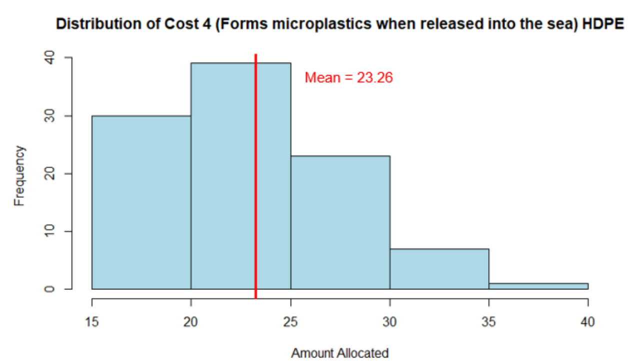




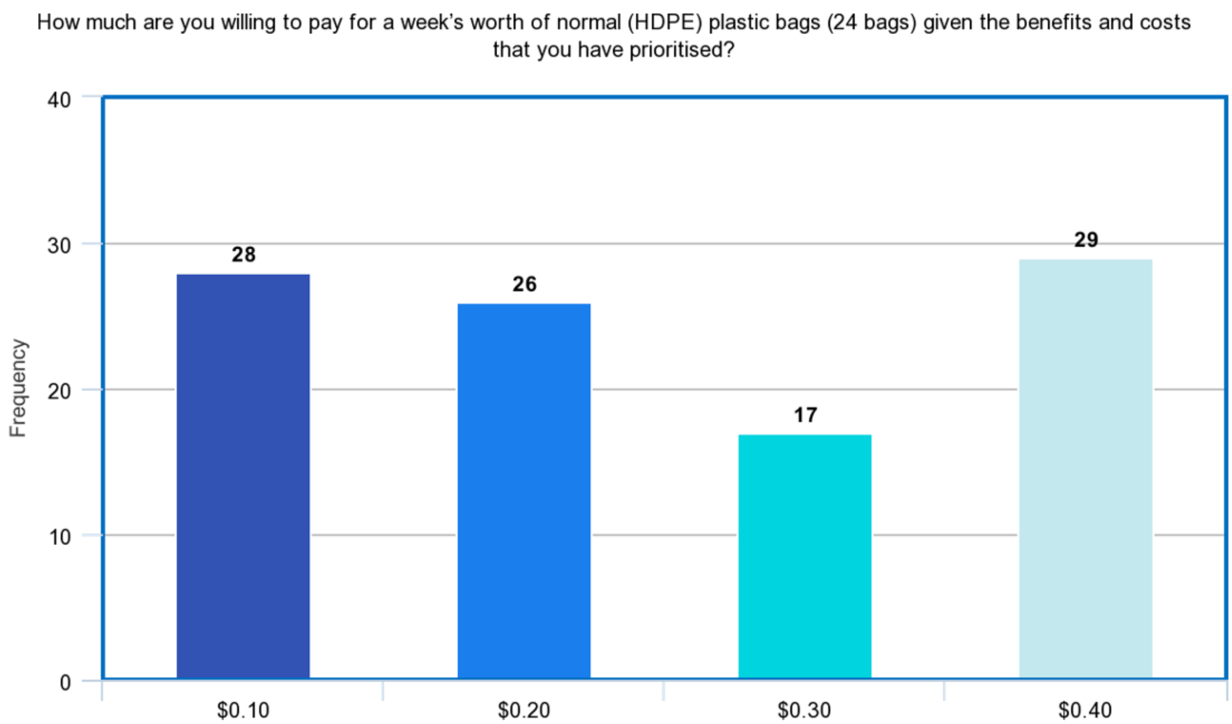






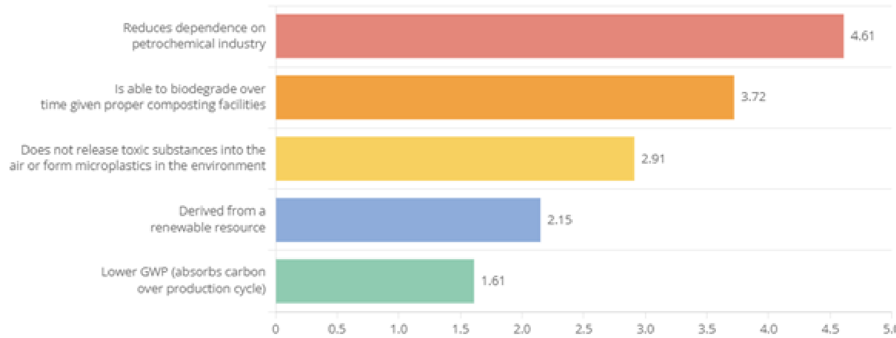


3) How much are you willing to pay for a week's worth of normal (HDPE) plastic bags (24 bags) given the benefits and cost that you have prioritised? (assuming you are representing your household)
    - $0.10
    - $0.20
    - $0.30
    - $0.40
    - $0.50



1) With your knowledge from the above hypothetical scenario, please rank the benefits and costs in accordance to your own personal preference, with 1 being the most important and 5 being the least important.

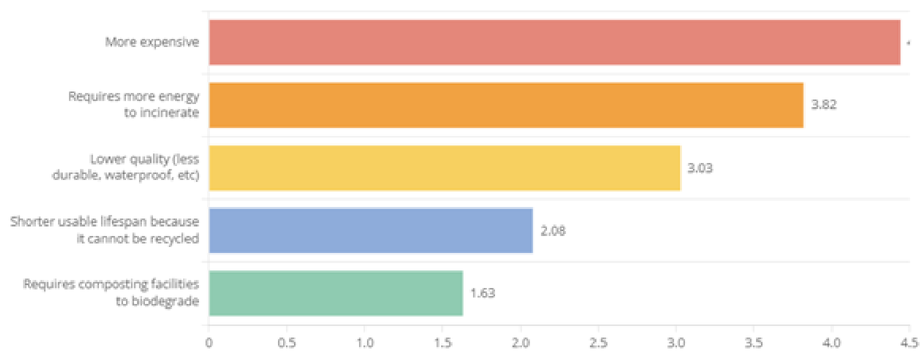
With your knowledge from the above hypothetical scenario, please rank the benefits and costs in accordance to your own personal preference, with 1 being the most important and 5 being the least important.



Answers	1st	2nd	3rd	4th	5th	Score
Reduces dependence ...	79 (79%)	11 (11%)	4 (4%)	4 (4%)	2 (2%)	4.61
Is able to biodegrade ...	12 (12%)	66 (66%)	9 (9%)	8 (8%)	5 (5%)	3.72
Does not release toxic...	3 (3%)	18 (18%)	57 (57%)	11 (11%)	11 (11%)	2.91
Derived from a renew...	3 (3%)	2 (2%)	27 (27%)	43 (43%)	25 (25%)	2.15
Lower GWP (absorbs ...	3 (3%)	3 (3%)	3 (3%)	34 (34%)	57 (57%)	1.61

Total: **100 responses**

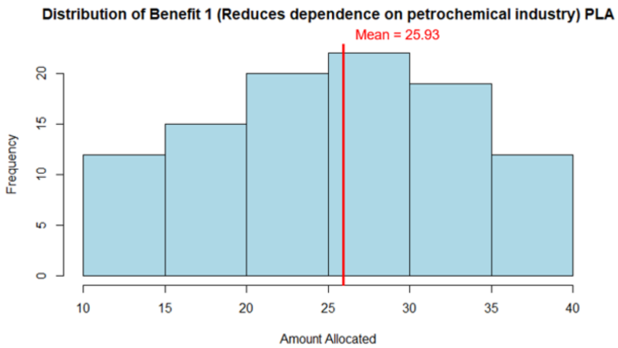
With your knowledge from the above hypothetical scenario, please rank the benefits and costs in accordance to your own personal preference, with 1 being the most important and 5 being the least important.

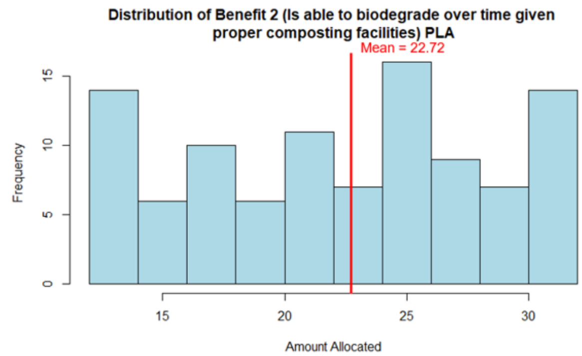


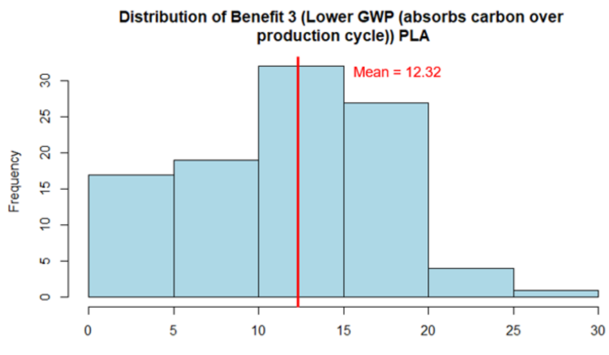
Answers	1st	2nd	3rd	4th	5th	Score
More expensive	78 (78%)	7 (7%)	3 (3%)	5 (5%)	7 (7%)	4.44
Requires more energy...	16 (16%)	66 (66%)	8 (8%)	4 (4%)	6 (6%)	3.82
Lower quality (less du...	4 (4%)	23 (23%)	50 (50%)	18 (18%)	5 (5%)	3.03
Shorter usable lifespa...	0 (0%)	0 (0%)	33 (33%)	42 (42%)	25 (25%)	2.08
Requires composting ...	2 (2%)	4 (4%)	6 (6%)	31 (31%)	57 (57%)	1.63

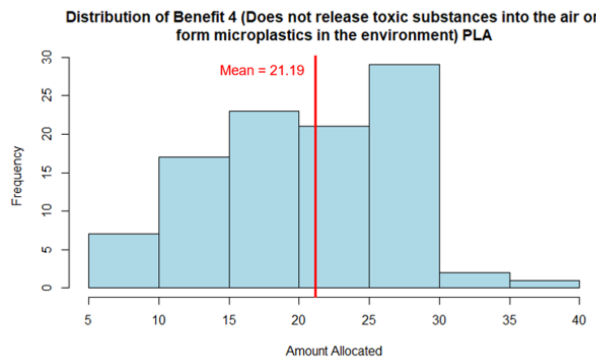
Total: **100 responses**

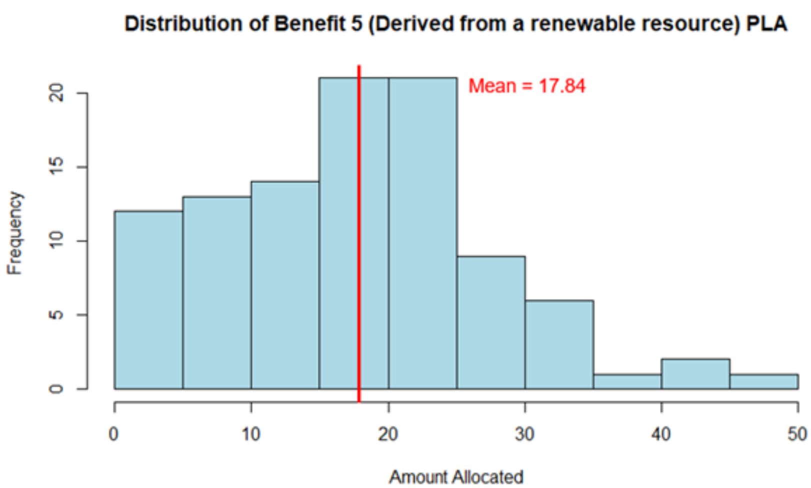
2) Suppose now you have a budget value of $100, kindly assign monetary values to the benefits and costs based on the choices that you have ranked in Q1). The individual values that you have assigned for each cost/benefit should total up to $100.

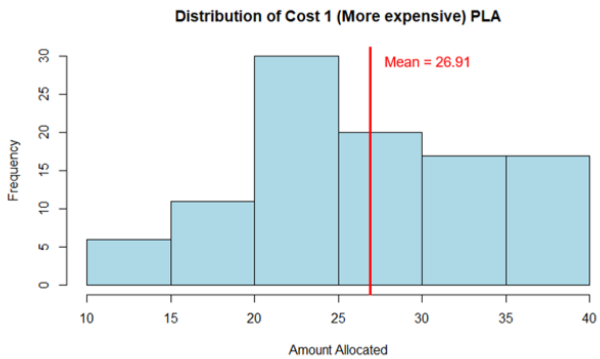


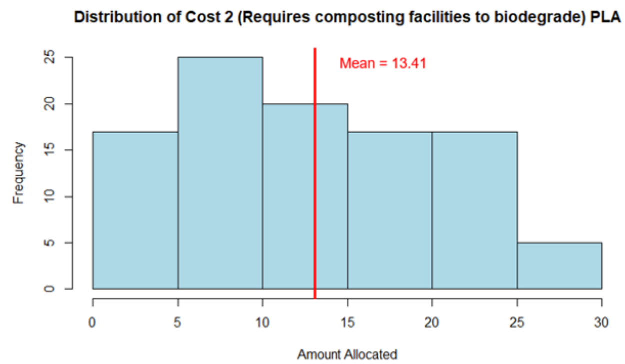


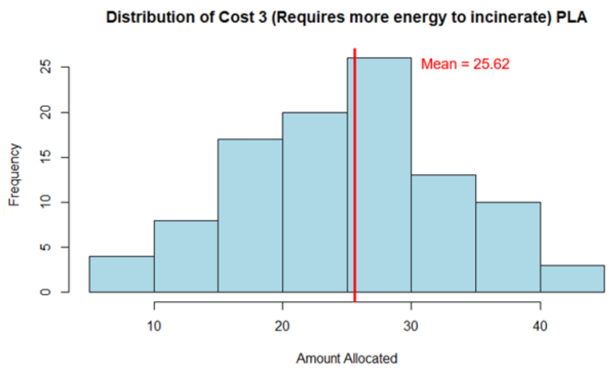


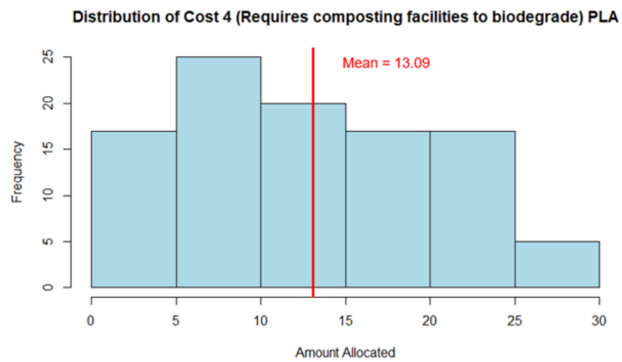


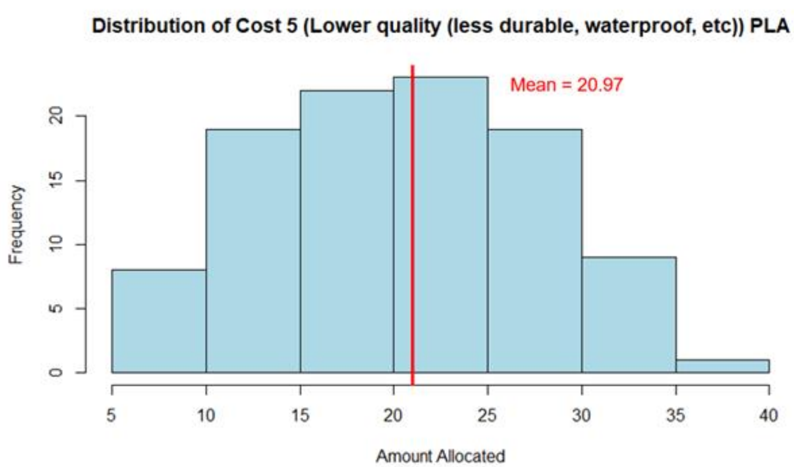



Distribution of Cost 1 (More expensive) PLA
Mean = 26.91
Frequency
Amount Allocated

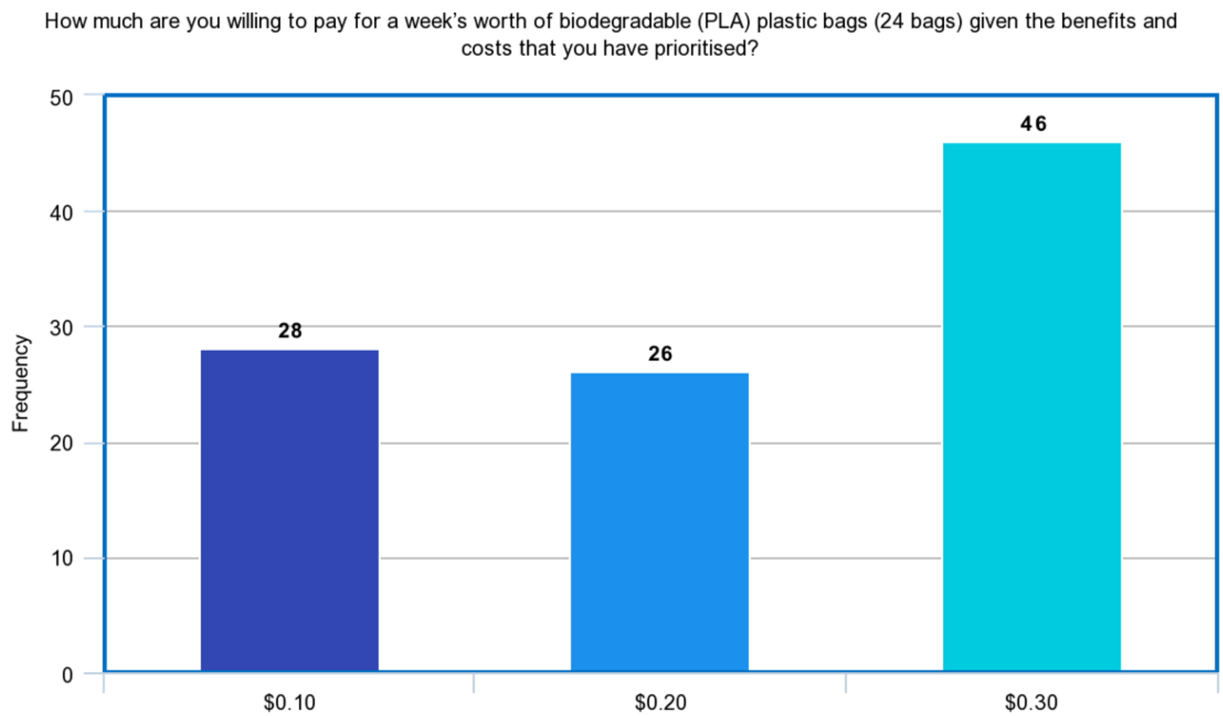

Distribution of Cost 2 (Requires composting facilities to biodegrade) PLA
Mean = 13.41
Frequency
Amount Allocated


Distribution of Cost 3 (Requires more energy to incinerate) PLA
Mean = 25.62
Frequency
Amount Allocated


Distribution of Cost 4 (Requires composting facilities to biodegrade) PLA
Mean = 13.09
Frequency
Amount Allocated


Distribution of Cost 5 (Lower quality (less durable, waterproof, etc)) PLA
Mean = 20.97
Frequency
Amount Allocated

3) How much are you willing to pay for a week's worth of biodegradable (PLA) plastic bags (24 bags) given the benefits and costs that you have prioritised? (assuming you are representing your household)
   - $0.10
   - $0.20
   - $0.30
   - $0.40
   - $0.50



Appendix N

The following screenshots show the excel spreadsheet used to calculate the resultant net value produced at each discount rate.

	Undiscounted yearly costs (with the exception of infrastructure!)							
	Price	Recyclability	Infrastructure	Cons Surplus	GWP	Renewability		
HDPE	23700726	2.1541E+14	174020000	109261555	313376.266	0		
PLA	36077771.8	2.2226E+14	160153500	41918054	65835.35	241352.393		
weight	0.2722	0.2465	0.1309		0.1175	0.1512		
	0.2691	0.2562	0.1309		0.1044	0.1511		
	Discounted costs at 2.1% interest for 10 years							
	212893786	1.077E+14	174020000	54629852.4	156685.479	0		
	324071652	1.1113E+14	160153500	20958672.1	32917.1175	120674.153		
	Weighted costs (red is a negative value, blue is a positive)							
HDPE	57949688.6	2.6549E+13	22779218	54629852.4	18410.5438	0	-2.655E+13	2%
PLA	87207681.6	2.8471E+13	20964093.1	20958672.1	3436.54707	18233.8645	-2.847E+13	

	Undiscounted yearly costs (with the exception of infrastructure!)							
	Price	Recyclability	Infrastructure	Cons Surplus	GWP	Renewability		
HDPE	23700726	2.1541E+14	173360000	109261555	313376.266	0		
PLA	36077771.8	2.2226E+14	160146191	41918054	65835.35	241352.393		
weight	0.2722	0.2465	0.1309		0.1175	0.1512		
	0.2691	0.2562	0.1309		0.1044	0.1511		
	Discounted costs at 2.1% interest for 10 years							
	11285922.3	1.0258E+14	173360000	52028677.2	149224.973	0		
	17179681.7	1.0584E+14	160146191	19960734.6	31349.7842	114928.309		
	Weighted costs (red is a negative value, blue is a positive)							
HDPE	3072028.05	2.5285E+13	22692824	52028677.2	17533.9343	0	-2.529E+13	2.1%
PLA	4623052.35	2.7115E+13	20963136.4	19960734.6	3272.91747	17365.6675	-2.712E+13	

	Undiscounted yearly costs (with the exception of infrastructure!)							
	Price	Energy exp	Infrastructure	Cons Surplus	GWP	Fossil carbon		
HDPE	23700726	2.1541E+14	174760000	109261555	313376.266	0		
PLA	36077771.8	2.2226E+14	160161578	41918054	65835.35	241352.393		
weight	0.2722	0.2465	0.1309		0.1175	0.1512		
	0.2691	0.2562	0.1309		0.1044	0.1511		
	Discounted costs at 2.1% interest for 10 years							
	12473769.8	1.1337E+14	174760000	57504714.8	149224.973	0		
	18987849.6	1.1698E+14	160161578	22061609.3	31349.7842	127024.556		
	Weighted costs (red is a negative value, blue is a positive)							
HDPE	3395360.14	2.7946E+13	22876084	57504714.8	164930.956	0	-2.795E+13	1.9%
PLA	5109630.33	2.9969E+13	20965150.5	22061609.3	34649.3606	19193.4104	-2.997E+13	

A separate spreadsheet was programmed to calculate P/A values using the following formula:

$$\frac{(1+i)^t - 1}{i(1+i)^t}$$

A screenshot of this programme with displayed formulas can be seen below.

	A	B	C
1	from amt	B1	
2	interest (d)	B2	
3	time	B3	
4			
5			
6		DISCOUNTED	
7	F/P	=C7*B1	=(1+B2)^B3
8	P/F	=C8*B1	=(1+B2)^(-B3)
9	A/F	=C9*B1	=B2/(((1+B2)^B3)-1)
10	A/P	=C10*B1	=(B2*(1+B2)^B3)/(((1+B2)^B3)-1)
11	F/A	=C11*B1	=(((1+B2)^B3)-1)/B2
12	P/A	=C12*B1	=(((1+B2)^B3)-1)/(B2*((1+B2)^B3))

In principle, this formatted Excel spreadsheet can calculate many different types of Annual Worth Analysis values, but only the P/A function is relevant.