Life Cycle Analysis of Plastic: 
Case Study of Plastic Carrying Bags 

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“The Philippines is the world’s third-largest ocean polluter next to China and Indonesia.”

Forecast of plastic marine debris in million tons by the year 2025.

Metro Manila alone spends Seven Billion Pesos a year to dispose of waste – garbage that big corporations are making money with.

Source: www.scmp.com
March 07, 2019. According to NGO GAIA, “Filipinos use more than 163 million plastic sachet packets, 48 million shopping bags and 45 million thin film bags daily.”

Source: www.no-burn.org
Single-use plastic carrying bag is commonly made from Polyethylene which consists of long chains of ethylene monomers. Ethylene is derived from natural gas and petroleum. The polyethylene used in most carrying bags is either low-density or, more often, high-density (HDPE). Color concentrates and other additives are often used to add tint to the plastic. Plastic shopping bags are commonly manufactured by blown film extrusion.
What are Plastics?

Plastics are synthetic polymers consisting of carbon, hydrogen, oxygen, chloride and nitrogen. It is derived from fossil sources such as oil, coal and natural gas.

Examples are polyethylene (PE), polyethylene terephthalate (PET),nylons, polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC) and polyurethane (PU). Due to inefficient disposal methods for these materials, they often end up as environment pollutants, posing an ever-increasing ecological threat to all inhabitants of our planet.
Sources of Plastic Material

• Fossil-Based Plastics
  • Fossil- or petrochemical-based plastics utilize fossil feedstock like petroleum and natural gas. About 7% of all petroleum is converted into plastics. Examples of fossil-based plastics are polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET) and polystyrene (PS).

• Bio-Based Plastics/Bioplastics
  • These are defined as “plastics” in which 100% of the carbon is derived from renewable agricultural and forestry resources, such as corn starch, soybean protein and cellulose
Categories of Plastics

• Thermoplastics
  • These are polymers that do not change their chemical composition when heated and can, therefore, undergo molding multiple times. These include the common plastics polyethylene(PE), polypropylene(PP), polystyrene(PS), polyvinyl chloride(PVC) and polytetrafluoroethylene(PTFE) with molecular weights in the range of 20,000 to 500,000 AMU(atomic mass unit).

• Thermoset Plastics
  • These are polymers that remain solid and can not be melted nor modified. The chemical change here is irreversible, and hence these plastics are not recyclable because they have a highly cross-linked structure, whereas thermoplastics are linear. Examples include phenol-formaldehyde, polyurethanes, etc.
Biodegradable Plastics

• Biodegradable
  • Biodegradable materials can be broken down by microorganisms (bacteria or fungi) into water carbon dioxide (CO2) and methane (CH4) and microbial biomass.

• Compostable bioplastics
  • These are bioplastics that are decomposed biologically in a composting process at a similar rate to other compostable materials, without leaving visible toxic remainders. A plastic is designated bio-compostable based on standard measurements of its total biodegradability and disintegration degree, as well as ecological toxicity of its degraded materials.

❖ Clarifications
  • Compostable plastics are a subgroup of biodegradable plastics
  • Not all bioplastics are biodegradable
Global Plastics Production

381 million tons (MT) of plastic was produced in 2015.

Source: Geyer et al. (2017)
Global Plastic Production

7.81 billion tons of plastics was produced cumulatively in the world as of 2015

Source: Geyer et al. (2017)
In 2015, plastics were disposed in the following methods:
- Discarded (55%)
- Incinerated (25%)
- Recycled (20%)
The Fate of Plastics

All the plastics produced from 1950 to 2015 went to the following:

- Straight to landfill (55%)
- Still in use (30%)
- Incinerated (8%)
- Recycled (6-7%)

Only 9% of the plastics no longer in use was recycled.
Disposal Method and Fate of Plastics Summary

**Plastics Disposal Method (2015)**
- Discarded: 55%
- Incinerated: 20%
- Recycled: 25%

**Fate of Plastics (1950 - 2015)**
- Straight to Landfill: 55%
- Still in Use: 30%
- Incinerated: 7%
- Recycled: 8%
Plastic Production by Industrial Sector

Packaging is leading at 146 million tons in 2015.

Primary plastic production by industrial sector, 2015

- Packaging: 146 million tonnes
- Building and Construction: 65 million tonnes
- Other sector: 59 million tonnes
- Textiles: 47 million tonnes
- Consumer & Institutional Products: 42 million tonnes
- Transportation: 27 million tonnes
- Electrical/Electronic: 18 million tonnes
- Industrial Machinery: 3 million tonnes

Source: Geyer et al. (2017)
Plastic Waste Generation by Industrial Sector

Packaging is leading at 141 million tons in 2015 in waste generation.

Source: Geyer et al. (2017)
Global Mismanaged Plastics by Region

East Asia has the biggest share of mismanaged plastics at 60% in 2010.

Global mismanaged plastic by region, 2010

Share of global mismanaged plastic waste by region in 2010. This is measured as the total mismanaged waste by populations within 50km of the coastline, and therefore defined as high risk of entering the oceans. Mismanaged plastic waste is defined as "plastic that is either littered or inadequately disposed. Inadequately disposed waste is not formally managed and includes disposal in dumps or open, uncontrolled landfills, where it is not fully contained. Mismanaged waste could eventually enter the ocean via inland waterways, wastewater outflows, and transport by wind or tides."

Source: OWID based on Jambeck et al. (2015)
The Philippines is among top ocean polluting countries with a total of 1.9 million metric tons of mismanaged plastic wastes and 750,000 metric tons of plastic marine debris.
Plastic Ocean input from Top 20 Rivers

Pasig river is one top 20 polluting rivers around the world.
Pasig river’s annual plastic input to the oceans is around 38,800 tons.

Lebreton et al. (2018)
Other Facts on Plastic Bags

• Around 100,000 marine animals are killed each year due to plastic bags.
• Around 46,000 plastic pieces are found in every square mile of ocean.
• 4.3 billion gallons of crude oil used each year for plastic bag production.
• Around 1 trillion single use plastic bags are used every year.
• It takes around 1000 years for 1 plastic bag to fully degrade.
• Total of 3.5 million tons of plastic bags are discarded every year.

Source: Greener Ideal (2018)
Life Cycle Assessment (LCA)

“LCA is a process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and releases to the environment; and to identify and evaluate opportunities to effect environmental improvements.”

Source: (SETAC, 1993)
Components of LCA

- Goal & Scope Definition (ISO 14041)
- Inventory Analysis (ISO 14041)
- Impact Assessment (ISO 14042)
- Interpretation (ISO 14043)
Product Life Cycle: A Cradle-to-Grave Analysis
A paradigm that provides a holistic picture of an entire product system covering resources extraction, material processing, transportation, manufacturing, distribution, use, disposal and reuse/recycling.
Life Cycle Impact Assessment

• **Classification**: What specific impacts (e.g., global warming, acid rain) do the material and energy flows contribute to?

• **Characterization**: How much do the M&E flows contribute to these impacts?

• **Valuation**: How much does each impact category contribute to overall damage?
Define Scope & System Boundary

Model Processes & Activities

Build Model

Life Cycle Inventory

Inputs:
Raw Materials, Energy Carriers, Water

Outputs:
Airborne & Waterborne Emissions, Solid Wastes

Life Cycle Impact Assessment

Global Warming Potential
Acidification
Ozone Depletion
Human Toxicity
Eutrophication
Photochemical Ozone Creation
Ecotoxicity
Fossil Energy Use
Flooding
Landfill Volume

Weighing and Interpretation
<table>
<thead>
<tr>
<th>Impact Area</th>
<th>Reference Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming</td>
<td>kg CO$_2$-eq</td>
<td>This impact is related to the continued rise in the average temperature of the earth’s climatic system. This is also concerned with climate change and the greenhouse effect.</td>
</tr>
<tr>
<td>Ozone Depletion</td>
<td>kg CFC11-eq</td>
<td>This is the environmental impact related to the thinning of the ozone layer caused by ozone depleting substances emitted by different forms of human activities. The depletion of ozone in the stratosphere makes it ineffective to screen out much of the UV rays from the sun and can cause serious damages to plants, animals, and humans.</td>
</tr>
<tr>
<td>Acidification</td>
<td>m$^2$</td>
<td>This impact is associated with the apparent decrease in the pH level of terrestrial and aquatic ecosystems caused by releases of hydrogen cations (or protons) from acidifying substances which leads to damages in ecosystem populations. This is measured in terms of the land area of an ecosystem with exceeded limits of acidification.</td>
</tr>
<tr>
<td>Ozone Formation</td>
<td>person.ppm.h</td>
<td>This impact category is related to the photochemical ozone creation potential. In the ground level, ozone acts as a secondary pollutant formed by a highly-complex reaction between sunlight, NOx and volatile organic compounds (VOCs) including methane. At certain concentrations, ozone causes damages to vegetation and human health.</td>
</tr>
<tr>
<td>Impact Category</td>
<td>Unit</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------</td>
<td>------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>kg N-eq</td>
<td>This impact category covers the negative effects of excess nutrients, particularly Nitrogen present in soil (terrestrial eutrophication) or turbidity-causing nutrients in water (aquatic eutrophication) which are, in turn, caused by present atmospheric input of nutrients, from human and industrial activities. These imbalances in nutrients cause changes in species composition as adaptation becomes advantageous to a limited number of species.</td>
</tr>
<tr>
<td>Human Toxicity</td>
<td>person</td>
<td>This is the impact to the level of functional state of a person to adequately cope with his/her daily activities by the absence of diseases and impairment. This is also the impact factor which can represent the social aspect of sustainable production.</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td>m³</td>
<td>A combination of the words ecology and toxicity, this impact factor refers to the potential for physical stressors (whether biological, chemical or physical) to affect ecosystems.</td>
</tr>
<tr>
<td>Fossil Energy Use</td>
<td>MJ</td>
<td>This impact factor quantifies the fossil fuel used in terms of energy equivalent.</td>
</tr>
</tbody>
</table>
Life Cycle Interpretation

- What do the results mean?
- Have high-impact areas or *hot spots* been identified?
- Has a *best environmental option* (BEO) been identified?
- Is further in-depth evaluation necessary?
Interaction of LCA Components
Why is LCA important?

- LCA gives an indication of total environmental impacts
- LCA can reveal environmental impacts that are overlooked in conventional assessments
- LCA gives a true measure of environmental performance
- Rationalizes the structure of a decision-support mechanism that considers the interaction of both environmental and productivity parameters.
Life Cycle Analysis of Plastic: Case Study of Plastic Carrying Bags
To determine the environmental performance of the production of plastic carrying bags. The bag is made of high density polyethylene (HDPE).

Functional Unit: 1000 kg of carrying plastic bags produced.
LCA Framework
Cradle-to-grave approach
<table>
<thead>
<tr>
<th>Output Product</th>
<th>Crude Oil Extraction</th>
<th>Petroleum Refining</th>
<th>Natural Gas Extraction</th>
<th>Natural Gas Processing</th>
<th>Ethylene Production</th>
<th>Polyethylene Production</th>
<th>Plastic Bag Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Flow</td>
<td>kg</td>
<td>kg</td>
<td>kg</td>
<td>kg</td>
<td>kg</td>
<td>kg</td>
<td>kg</td>
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<tr>
<td>Crude oil</td>
<td>1035</td>
<td>1018</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Natural Gas</td>
<td>-</td>
<td>-</td>
<td>1000</td>
<td>1000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Refined Petroleum Products</td>
<td>kg</td>
<td>-</td>
<td>-</td>
<td>186</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Processed Natural Gas</td>
<td>kg</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Olefins (Ethylene)</td>
<td>kg</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>830</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Water</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1005</td>
<td>-</td>
</tr>
<tr>
<td>Polyethylene resins</td>
<td>kg</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1005</td>
</tr>
<tr>
<td>Ink</td>
<td>Kg</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>65</td>
</tr>
<tr>
<td>colorants</td>
<td>kg</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>60</td>
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<tr>
<td>Process Energy Input</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>kWh</td>
<td>39</td>
<td>143</td>
<td>39</td>
<td>21.3</td>
<td>78.8</td>
<td>178</td>
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<tr>
<td>Natural gas</td>
<td>cu.m.</td>
<td>32.8</td>
<td>11.1</td>
<td>32.8</td>
<td>34.6</td>
<td>142</td>
<td>35.5</td>
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<tr>
<td>Residual oil</td>
<td>liters</td>
<td>0.80</td>
<td>27.2</td>
<td>0.80</td>
<td>0.050</td>
<td>-</td>
<td>6.01</td>
</tr>
<tr>
<td>Distillate/Diesel oil</td>
<td>liters</td>
<td>1.29</td>
<td>-</td>
<td>1.29</td>
<td>0.050</td>
<td>0.079</td>
<td>-</td>
</tr>
<tr>
<td>Gasoline</td>
<td>liters</td>
<td>0.68</td>
<td>-</td>
<td>0.68</td>
<td>0.048</td>
<td>0.091</td>
<td>-</td>
</tr>
<tr>
<td>LPG</td>
<td>liters</td>
<td>-</td>
<td>1.15</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.038</td>
</tr>
<tr>
<td>Recovered Energy</td>
<td>MJ</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>29</td>
<td>-</td>
</tr>
<tr>
<td>Maintenance oil</td>
<td>Kg</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.0075</td>
</tr>
<tr>
<td>Lube oil</td>
<td>kg</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
</tr>
<tr>
<td>Transportation Energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel Combination truck</td>
<td>liters</td>
<td>-</td>
<td>1.2</td>
<td>-</td>
<td>0.44</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Diesel Rail</td>
<td>liters</td>
<td>-</td>
<td>0.18</td>
<td>-</td>
<td>0.10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Diesel Barge</td>
<td>liters</td>
<td>0.0025</td>
<td>0.49</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Residual Oil Barge</td>
<td>liters</td>
<td>0.0083</td>
<td>1.64</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Diesel Ocean Freight</td>
<td>liters</td>
<td>2.33</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Residual Oil Ocean Freight</td>
<td>liters</td>
<td>21.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Natural Gas Pipeline</td>
<td>cu.m.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>21.5</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Life Cycle Impact Assessment

Inputs:
- Raw Materials
- Energy Carriers
- Water

Outputs:
- Airborne & Waterborne Emissions
- Solid Wastes

Global Warming Potential
Acidification
Ozone Depletion
Human Toxicity
Eutrophication
Photochemical Ozone Creation
Ecotoxicity
Fossil Energy Use
Flooding
Landfill Volume

Define Scope & System Boundary
Model Processes & Activities
Build Model

Weighing and Interpretation
Ozone depletion

- Raw Material Extraction
- Raw Material Preparation
- Production
- Utilization
- Disposal
Single score allows you to easily compare the environmental impact of different products or scenarios, or stage in the life cycle. It is much easier to explain a single score for environmental impact than it is to explain 3 to 18 different scores per product or scenario.

All environmental impact scores are converted with a single unit and then added to determine a single score amount.
Raw Material Extraction
Raw Material Preparation
Production
Utilization
Disposal
• Production stage has the biggest damage among the life cycle stages of producing single-use plastic carrying bags.
• It is encouraged to adapt to reusable bags.
Based from a study (Biona, 2017), **Reusable bags** has considerably less environmental impact compared to plastic bags and paper bags.
Sources


