Fortuna Cools Life Cycle Assessment

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Abstract

Fortuna Cools (Fortuna) was founded in 2018 with the goal of creating an affordable and environmentally sustainable option for coolers for fishermen. To date, they have operated in the Philippines, producing coolers made in large part of coconut husk, a common waste product. The coolers are intended as an alternative for expanded polystyrene (EPS) coolers with usable lives of just two weeks, or as alternatives to reusable polyurethane coolers that are often too expensive to be a feasible option for fishermen. Having created a product to fill this niche, Fortuna Cools hopes to conduct a more formal life cycle assessment to answer the question: are Fortuna coolers truly a more environmentally sustainable option?

For this assessment, the Stanford team conducted interviews with the Fortuna team and one of their partner factories, Juboken, to understand the supply and manufacturing processes. The team then defined a functional unit to compare EPS and Fortuna coolers as one cooler able to hold 35 kg of fish and ice at 32°F for 24 hours. Next, we created a process flow diagram to map out every stage in a Fortuna cooler's life cycle, from raw materials to end of life. Based on interviews, we defined a scope of cradle-to-gate for the life cycle assessment, and cradle-through-use for the life cycle cost analysis, as the use phase has relevant cost differences but only very marginal differences in environmental impact. For our life cycle impact assessment, we conducted a process-based assessment using primary data from SimaPro and Fortuna's partner factory for manufacturing phases of production.

We compared the Fortuna cooler (estimated usable life = 1 year) to one year's worth of EPS coolers with 35 kg-capacity. Due to the two week usable life of an EPS cooler, our comparative assessment considered that 26 EPS coolers are needed to replace one Fortuna cooler. Our impact analysis considered one year's production of Fortuna coolers (3,120 coolers), and the relative impact of producing 26 times as many EPS coolers (81,120 coolers). Additionally, we performed a sensitivity analysis to determine the environmental impact of changes in annual production quantity, the size of the cooler, and the quantity of PVC used in cooler liners.

Ultimately, we determined that the Fortuna cooler life cycle is associated with drastically lower greenhouse gas emissions and is comparable to or has slightly higher emissions than EPS coolers in several impact categories. The capability of coconut husks to be degraded and converted into a biodegradable compost and fertilizer minimizes the energy requirement towards the end-of-life disposal; the ability to compost the Fortuna cooler provides additional benefit over EPS, although this was not included in the scope of our study. Overall, this life cycle assessment study promotes a direction to institutionalize and to regulate the agro-industrial waste market of coconut husks in the Philippines because of the social, economic, and environmental benefits of Fortuna Cools to potentially address the alarming impacts of traditional EPS coolers.

Introduction

Background

Marine fishing in the Philippines has been a prominent industry - and way of life - for a large part of the Filipino population for many generations. There are over 1.6 million Filipinos involved in the fishing industry and depend on it for their livelihood (WCPFC, 2016). With over 22,500 miles of coastline available, the Philippines ranks 5th in the world for longest coastline and access to the ocean. Many fishermen wake at dawn to fish and return late into the evening with their boats filled with coolers of the day's catch. In 2015, these fishermen and women caught over 380,000 metric tonnes of tuna as reported in the 2016 Annual Philippine Fishing Report (WCPFC, 2016). Though fishing is not a major economic sector for exports in the Philippines, the number of individuals involved makes it an essential activity to the Filipino culture.

Another major source of income for many in the Philippines comes from the coconut industry. The agricultural industry is the Philippines' largest economic sector, employing almost 30% of the Filipino workforce in 2014 (World Bank, 2020). A large portion of this is due to the coconut industry, in which the Philippines ranks second in world production after Indonesia. In 2018, it was reported that 14,700,000 tons of coconuts were produced. Coconut production is accountable for about 25% of cultivated land in the Philippines, which demonstrates its essential role in the economy and providing jobs for many farmers. These coconuts are mainly used to produce coconut products, oil, milk, and copra which are then exported globally (Sanchez, 2020).

Significance of Coconut Use

The high level of coconut production in the Philippines is directly proportional to the high level of coconut waste. Currently, 9 billion coconut husks annually are treated as garbage waste and burned in the Philippines. The burning process releases CO_2 into the atmosphere and provides zero economic benefits to coconut farmers. To further compound this negative environmental impact, fishermen typically use expanded polystyrene (EPS) coolers to pack their fish during trips two to three times every week. These coolers have a short life span of two weeks yet take a gruelling 500 years to degrade once discarded in landfills. The waste and lack of longevity in these two industries begs for sustainability efforts at a larger scale to help improve the situation.

Purpose of Study

Start-up company Fortuna Cools (Fortuna) seeks to redirect discarded coconut husks into repurposed fish coolers. Their mission is to eliminate the use of plastic and foam coolers in the fishing industry by replacing them with a more eco-friendly, compostable option. Fortuna Cools was founded in 2018 as a partnership between Stanford graduate students, a local fishing village in the western Philippines, and the non-governmental conservation organization Rare. Their operations take place in the Philippines and all resources are sourced from the region, which is discussed further in this study. Fortuna aims to help tackle global challenges through the UN's Sustainable Development Goals, as noted on Fortuna's website and shown in Figure A.1 (Fortuna Cools, 2020). Fortuna Cools is currently seeking to expand into the North American market.

This study seeks to quantify energy and material inputs for one typical year of production in the Philippines for Fortuna Cools coolers and compares associated emissions to those of EPS coolers. The repurposing of husks into fiber for insulated fish coolers is significant because it decreases the CO_2 emissions released from burning, provides an economic stipend for impoverished coconut farmers, and decreases dependency on environmentally-negative EPS foam coolers. This information is intended to provide comparative data for Fortuna Cools' management team so that they may make informed design and operations decisions about their product materials, processes, and transportation in the future. It is important to note that cooler production data for the past eight months has been scarce due to the economic effects of the novel SARS-CoV-2 virus.

Goal and Scope

Goal of Study

The goal of this research is to evaluate the environmental impacts of the production of coconut husk-based coolers and quantitatively compare these impacts to an EPS cooler. This assessment traces energy and material inputs and outputs, starting from the material acquisition stage of life to the point at which the cooler is sold to consumers. This is also known as a cradle-to-gate analysis. Most of the information on material sourcing, product design, sales, and usage was gained through email and video chat calls directly with the founders of Fortuna Cools and their production managers at associated facilities in the Philippines.

Scope Considerations

It is important to note that the end of life (EoL) phase was not taken into account for the life cycle cost and inventory models. The use phase was not included in the life cycle inventory model for energy and impact assessment. This is because Fortuna was founded in 2018 and has just recently begun to stabilize their production processes; therefore, reliable data is not yet readily available for these phases of the product. During the approximate 1-year lifetime of the cooler, it is assumed that it does not produce or reduce significant amounts of impact category compounds or use a large amount of energy. EoL is not considered because the landfilling and recycling practices of many provinces highly vary in the local level. Being a biodegradable product, it is also assumed that most coconut husk-based coolers would be recycled as a compost for agricultural land.

The use phase was included in the life cycle cost assessment because of its importance to fishermen who could be potential Fortuna product clients. As previously mentioned, there is little data on the usage of the cooler that would suggest significant energy or environmental impact contribution for the life cycle inventory model. However, the weight of the cooler on a small local fisherman's boat, for example, can make a small but not insignificant impact on the cost to a fisherman in the form of gasoline consumption. Further discussion of the inclusion of the use phase is included in the "Life Cycle Cost" section of this report.

Functional Unit Definition

The functional unit used for this project was one cooler capable of carrying 35 kg of fish at 32° F for at least 24 hours (single day fishing trip). The insulation capabilities in Figure A.2 show that both Fortuna and its comparison products are able to maintain this temperature for longer than 24 hours, however our functional unit is restricted to a single day of fishing. The fishing trips were assumed to occur 2-3 times per week. The dimensions of the Fortuna cooler, seen in Figure A.3, were given as 16" x 16" x 22", with each panel being 1" thick.

Brief Overview of Comparison Product

Expanded polystyrene (EPS) is one of the widely used fish packaging coolers because of its lightweight properties and affordability to the local farmers and fish supply owners in the Philippines. Located in Calamba, Laguna, Mega Packaging Corporation manufactures EPS fish pack coolers (23" x 16" x 17.75") at a daily rate of 1,325 units of body and 2,191 units of cover. For the EPS cooler manufacturing, raw materials are imported from other countries and delivered to their warehouse, where quality control is performed before the injection mould process takes place. In the local market, each EPS fish pack cooler is sold for 210.00 PHP (~4.20 USD).

Life cycle assessment studies of EPS fish pack coolers have been extensively compared to alternatives by many environmental organizations such as European Manufacturers of Expanded Polystyrene (EUMEPS) Association – Packaging section (PwC Ecobilan, 2011). However, there have been no publicly available life cycle assessment studies of EPS fish packaging coolers in the Philippines.

As shown in Figure A.4, an EPS fish packaging cooler typically involves the following processes and system boundaries. Starting from the expandable styrene as raw material, the processes will undergo transport, pre-expansion, and moulding. Beyond the system boundary where fish catching takes place, the processes would involve transport and use of diesel. Towards the end, the EPS will be at its end-of-life stage wherein various activities such as recycling, incineration, and landfilling may take place. In this study, we are delimiting the scope of the comparative life cycle assessment of impact category measures within the material processing itself whereas the life cycle cost would consider the fish catching stage.

Impact Assessment Categories

To quantitatively compare the impact of Fortuna and EPS fish packaging coolers, the SimaPro database and Eco-Indicator 95 were used to measure the following five impact categories outlined in Table A.1: greenhouse gases, acidification, eutrophication, summer smog, and heavy metals. Further sensitivity analysis was also performed to determine the effect of changes of varying the size of the cooler, annual production rate, and the amount of polyvinyl chloride material.

Data types, Sources, and Quality

This study applies a process-based LCA approach wherein evaluations are performed for each defined process involved in the production of the functional unit. All data for Fortuna and EPS cooler were gathered by conducting a series of informational interviews with David Cutler and Tamara Mekler of Fortuna Cools, Dr. Justino Arboleda of Juboken Industries, and Praxy Sabiniano of Mega Packaging Corporation.

On one hand, relevant information about Fortuna coolers have been verified in the context of its implementation and manufacturing. It is important to note that the period of time has been considered as a limitation to obtain representative estimates of resources such as diesel and weights. Because Fortuna Cools is in the early stage of implementation and the SARS-CoV-2 (COVID-19) pandemic has disrupted the data coverage, many processes in the defined system boundaries have not been fully observed and measured. However, this report ensures that all data assumes a pre-COVID-19 scenario to minimize any extreme values from the expected average.

On the other hand, relevant information about EPS coolers have been limited to electronic mail correspondences and publicly available information of Mega Packaging Corporation. Specific details such as rate of recycling and time-dependent resources are not included in this report. However, using the estimated weight of the EPS cooler, impact assessment data were obtained in SimaPro and used as a basis of comparison to Fortuna cooler.

This study also considered the life cycle inventory of electricity in the Philippines (see Figure A.5). Using SimaPro, the electricity mix was found to be composed of 37% coal, 30% natural gas, 14% hydroelectric power, 14% geothermal energy, and 5% oil. These values were based on the International Energy Agency (IEA, 2020; IEA, 2019).

Analysis

Process Flow Diagram

The full process flow diagram can be seen in Appendix B. The inputs, outputs, and processes in this section are referenced according to the numeric labels (i.e. in-text bracket numbering) on the process flow diagram in Appendix B. Major sections of the diagram include raw material acquisition, initial transport, manufacturing and construction, secondary transport, final construction, use, and end of life.

Panel Fabrication

Fortuna coolers are composed of six raw materials. The greatest raw material by mass is coconut husk. Coconut shells [1] are a local waste product which Fortuna's partners at the Juboken factory collect locally [7]. In the material processing phase, the Juboken team decorticates the coconut shells [14], which entails removing the coconut husk and fiber from the shell and results in a usable fiber called coir. Meanwhile, polyvinyl acetate, or PVA, [2] is transported via diesel truck from Manila [8] for use as glue. Onsite at Juboken, the PVA is mixed [15] with water [3] sourced locally to create the glue needed for the panels.

In the manufacturing phase, the coir is needle punched [16] to prepare it for panel fabrication, then the glue mixture is applied to both sides as the coir moves through an oven [17]. The panels are then straightened and stacked [18], then pressed to the appropriate thickness using a heat press [19]. They then are air-cooled in the factory [20] before being cut to size [21]. The only step in this phase that produces waste is the panel cutting, and excess cuttings are returned to the pressing phase and incorporated into the next panels to be produced. The completed panels are then transported via diesel truck to Fortuna's warehouse in Manila [26], where they will be assembled.

Liner and Strap Fabrication

Meanwhile, waterproofing and carrying parts need to be created for the cooler. Prefabricated PVC liner [4] is shipped from Guangzhou to Manila [9], then transported via diesel truck [10] to Fortuna's partners at Hagonoy Sports facility. Simultaneously, recycled polyester [5] is sourced domestically, gathered in a warehouse in Laguna, then transported via diesel truck to Hagonoy Sports facility [11]. Finally, polyester thread [6] is produced in Zhejiang and transported via ocean freight to Manila [12] then by diesel truck to Hagonoy [13].

Once the materials arrive at Hagonoy, they need to be assembled into complete waterproof liners with carrying straps. A cutting machine is used to cut the PVC liner to the appropriate size [22] and to cut the webbing to the correct size for straps [24]. The PVC liner then goes through a heat press [23] to waterproof it before the polyester thread is used to sew the straps to the liner and to sew the liner sections together [25]. The completed liners are then transported via diesel truck to Fortuna's warehouse in Manila [27] for final cooler assembly.

Assembly, Use, and End of Life

The panels are inserted into the liner by hand at the Manila warehouse [28]. They then are distributed in one of two methods: customers pick up their orders from the warehouse directly [29], or a courier service picks up the coolers and delivers them to clients [30]. The coolers can be delivered in flattened form, which decreases the amount of space needed for delivery vehicles.

Use and end of life/disposal were excluded in the scope of this life cycle assessment as there is a lack of significant energy difference in use phase between the Fortuna cooler and other coolers on the market; the amount of associated gasoline is comparable.

Despite this being excluded from the analysis, the process flow diagram includes some general information about use and end of life. The expected lifetime for the use phase is one year of 2-3 trips per week [32], with approximately 35 kg of fish and ice loaded into the cooler per use [31]. While there is no confirmed data regarding disposal, there are some options available. The coconut components are considered biodegradable, and the PVC liner and polyester components may be recyclable [34]. That said, the anticipated end of life includes landfills [33] until more robust recycling programs are easily accessible to Fortuna cooler users.

<u>Life Cycle Cost</u>

To make the life cycle cost analysis more concise, the process flow diagram is simplified into Figure A.6 (i.e. in-text brace numbering). Different from the detailed process flow diagram mentioned above, this diagram is a result of subtotals. For example, {11} represents the cost of the transportation of nylon thread, which is the raw materials of straps. In reality, the nylon thread is transported by ocean freight from China to Manila and then is transported by trucks from Manila to Hagonoy. However, for the sake of clarity the separate costs of these two parts are calculated together. Similarly, costs related to the manufacturing process of a specific component are packed, such as {12} and {13}. Additionally, the cost of landfill will not be calculated for reasons previously mentioned.

In practical production, different processes have different statistical measurement standards. For the sake of making the costs of each process more intuitive, the cost of each process is converted to the expense that is used to produce one final cooler.

Raw material acquisition

The raw materials needed to make a cooler are {1} to {6} in the flow diagram, and the mass of each item is collected from Juboken factory data. Because of the different origins of raw materials, we use the average factory prices in China as unit price of PVC and Recycled polyester, then use the average price in Philippines as the unit price of other raw materials. Then the cost of each material can be calculated with Formula A.1. Thus, the cost of raw materials are shown in Table A.2, and the cost relationship of different raw materials is shown in Figure A.6.

Manufacturing and Construction

There are three parts related to manufacturing and construction. The first is producing panels from raw insulation materials. This part includes many processes, such as decortication, punching, etc. To complete all these processes, laborers and equipment are needed. Based on this, labor costs and electricity costs from the Fortuna manufacturing partner were used to roughly represent the cost in manufacturing and construction. According to the information provided by the factory, there are 38 permanent workers in the factory able to produce a cumulative 3,120 coolers per year. It is assumed that one employee works 7.5 hours daily for 312 days per year (6 day work week). The average salary of an industrial worker is 63.93 Philippine peso (PHP) per hour (National Wages and Productivity Commission, 2020). Based on the above data, we can calculate the labor costs with Formula A.2.

Use and service

By local fishman's experience, reasonable assumptions were used to calculate the cost in use phase as shown in Table A.3. Note that the only transportation cost is gasoline used on each fishing trip because the cooler is used by individual fishermen.

Using the data in Table A.3 the daily transportation costs for both the Fortuna cooler and a typical EPS cooler were calculated with Formula A.3. It was assumed that the weight of a Fortuna cooler is 5 kg and the weight of a normal EPS cooler is 1 kg. Thus, the cost to transport a fully-loaded Fortuna cooler is 1.98 USD/day, while the cost to transport a fully-loaded EPS cooler is 1.80 USD/day. According to Fortuna, the retail price is 33 USD for a Fortuna cooler and 4.2 USD for an EPS cooler. The average lifetime of a Fortuna cooler can be one year whereas the EPS cooler can only last for 2 weeks. We integrate the data obtained into Table A.4, which illustrates that the Fortuna Cooler will help fishermen save money in the long term.

Transportation

The bracketed numbers in this section reference the numeric processes from the process flow diagram in Appendix B. To produce one cooler, six raw materials are needed. The transportation cost is an essential cost in this production consideration. Coconut shells are transported from local areas to the factory by trucks. The cost of the transportation is around 0.2 PHP per coconut husks. Producing a cooler will require about 40 coconut husks. So, {7} can be calculated using Formula A.4. The PVA used for bonding is transported from Manila to the Juboken factory by trucks. From a freight trucking company's website (Transportify Philippines, n.d.), the freight cost of trucks in Manila has a base of 1,850 PHP with 50 PHP per unit kilometer. The distance from Manila to Juboken factory is 284.9 miles. The amount of glue per trip is 595 kg, but only 0.4 kg is needed to produce one cooler. So, {8} can be calculated with Formula A.5. The PVC used for waterproof liner is transported from the Chinese city of Guangzhou to Manila by ocean freight and then transported from Manila to the Hagonoy factory. The weight of liner per trip is 1500 kg and the cost of one trip will cost about 24 USD (Logistics Baba, n.d.). The weight of liner material used to make one cooler is 0.75 kg. For truck transportation, calculation is comparable to {8}. So, {9} can be calculated with Formula A.6.

Similar to the calculation of {9}, {10} and {11} can be calculated in the same way. The cost of {10} is 0.09 USD/cooler and the cost of {11} is 0.0135 USD/cooler. {14} and {15} are the costs of transporting the finished components from the factory to the Manila assembly point. According to data provided by Juboken Industries, the cost per trip from factory to Manila is 15,000 PHP and the shipping weight per trip is about 10,000 kg. The distance from the factory to Manila is 311 miles. To produce one cooler, 4 kg panels are needed to be transported. So, {14} can be calculated with Formula A.7. The distance of transporting the finished liner to Manila is 31.5 miles and only 1 kg of finished liner will be used in the final cooler. So, {15} can be calculated in proportion to {14} with Formula A.8.

The costs mentioned above have been summed and used to calculate their respective proportional cost of the product. Figure A.7 shows the cost proportion of each process. From the figure we can see that the cost of processing {12}, which includes manufacturing and construction of coconuts panels, is the greatest cost among all process costs. All of the processes were put into four categories (raw materials, labor, equipment -- electricity, and transportation) and the percentage of cost per category was calculated. Figure A.8 displays the cost of each category. From the chart, it can be deduced that the cost of raw materials and equipment are the major parts that contribute to the final cost of the product.

Life Cycle Inventory Analysis

To quantify the energy and material inputs and outputs to this system over its lifecycle, a spreadsheet model was created in Excel to track energy and material flows throughout the lifecycle processes. The processes, as shown in the process flow diagram, include raw material acquisition, transportation of materials to factories, material processing, manufacturing and construction, transportation to the final assembly point, and transportation to the customer. The inventory analysis and subsequent impact assessment are cradle-to-gate in their scope. The use phase of the product was not included in the scope because no additional energy or material inputs are required to use the product; although a customer may use energy to catch fish and create ice for the cooler, this is not in the scope because these inputs do not vary significantly from comparison products. The disposal of the product was also not included in the system boundary, because the disposal method has not yet been determined by Fortuna. The amount of energy spent on disposal would vary depending on whether the liner is landfilled or recycled, whether the coconut is composted, recycled, or landfilled, and which type of recycling or composting would be used.

The primary data used to create this model were provided by Fortuna in conjunction with the Juboken factory. When primary data were not available, secondary data were gathered using SimaPro or other published literature (see Table A.5). The annual cooler production was calculated using production data from the Juboken factory, assuming machines run continuously during a 7.5 hour work day, 6 days per week, 52 weeks per year. It is estimated that Fortuna will produce 3,120 coolers per year at current production rates. Using this information, the amount of raw materials acquired per year to produce 3,120 coolers was estimated given the product specifications provided by Fortuna. These raw material amounts can be seen in Table A.6.

The energy inputs for the transportation processes were calculated using information from Fortuna on the travel distances and frequency. All trucks were assumed to have 5.2-L diesel engines, which is common for freight trucks in the Philippines; the ocean liners were assumed to be the Panamax ocean freighters. The weight of material transported was either provided by Fortuna or was calculated using the raw material amounts found previously. Once the weight of material and distance transported were known, the energy required for transportation was calculated using the energy content (in Btu/ton-mile) of the fuel (diesel for trucks, fuel oil for ocean liners). Given the frequency of trips provided by Fortuna, the energy required per year was calculated.

Total energy for the polyvinyl chloride (PVC) liner was calculated using three main energy inputs from three sub processes using a previous academic study (Ye et al., 2017). The electricity usage in kilowatts per hour for 1 ton of material was noted for both the purification and molding processes. To convert the yearly electricity consumption to an energy consumption value, a life cycle inventory of the electricity grid in the Philippines from SimaPro was used to determine that 3.6 MJ of fossil fuel energy are required to generate 1 kWh of electricity. This yielded the energy equivalents for 1 ton of material for the purification and molding processes. Energy for the vinyl chloride monomer (VCM) production process required 1.06 GJ to produce 1 ton of PVC. This energy input was simply converted to MJ for ease of calculation. The energies for these three sub processes were summed for a total energy input for 1 ton of PVC liner. The weight of PVC per cooler provided by the sponsor was multiplied by the number of coolers manufactured in one year to get the total weight of PVC used by Fortuna in one year. This was converted to tons of PVC per year and multiplied the MJ per one ton rate to yield the energy input for one year.

The glue is a mix of polyvinyl acetate (PVA), trucked from Manila to the Juboken factory, and water, sourced directly at the factory. The PVA and water are mixed onsite at Juboken in a 2:1 ratio, and each cooler ultimately uses 0.400 kg of the mixed glue. This breaks down to 0.267 kg PVA and 0.133 kg water per cooler for the glue mixture. To determine the impact of transporting the PVA each week from Manila to Camalig, where the Juboken factory is located, the mass of PVA used annually was calculated by multiplying the per-cooler mass by coolers per year. This was then converted to tons, and the energy and emissions from the 5.2-L engine diesel truck used for transport were calculated. We assumed no impact from the water, as it is available onsite at the factory and no machinery is used to mix the PVA and water. Finally, for the energy content and impact factors for polyvinyl acetate itself, previous life cycle assessment of polymer dispersions was used as reference for impact factors and energy data for polyvinyl acetate, as these were not available in SimaPro (European Polymer Dispersions and Latex Association, 2017). These impact factors were multiplied by the annual PVA used in production of the coolers.

The energy input to the coconut decortication process, fiber stitching and heat press processes, and cutting process were calculated using electricity consumption data from Juboken. Yearly electricity consumption was calculated using the known amount of 3.6 MJ of fossil fuel energy required to generate 1 kWh of electricity. The energy input to the liner manufacturing process was calculated using information provided by Fortuna: the process uses a 0.9 kW cutting machine, 250 W sewing machine, and 5 kW heat press, which were assumed to operate 7.5 hours per day.

Finally, the total energy used per year was calculated by summing the energy inputs from each process, and was normalized to energy used per cooler by dividing by the initial estimated cooler production of 3,120 coolers per year. These values can be seen in Table A.7.

Life Cycle Impact Assessment

The environmental impact of the Fortuna cooler was determined using process-based LCA for five impact categories that have a relevant local impact to the Philippines. These categories are greenhouse gases (kg of CO_2 equivalents), acidification (kg of SO_2), eutrophication (kg of PO_4), summer smog (kg of C_2H_4), and heavy metals (kg of Pb). Greenhouse gases and summer smog were chosen because of the impact they have on the local climate and air quality, and acidification, eutrophication, and heavy metals were chosen because of the impact they have on water quality and marine life, which is important to the fishers who will be using the coolers. The impact of this product was quantified using the inventory analysis and data from SimaPro. Once we had determined the energy and material flows in our system from the inventory analysis, we used conversion values from SimaPro to determine the environmental impact for our chosen impact categories.

As mentioned previously, we did not include the end of life cycle in our system boundary, therefore we did not quantify the impact on the environment this cooler would have when it is disposed of. The environmental impact per cooler was estimated to be 127.72 kg of CO_2, 2.13 kg of SO_2, 0.20 kg of PO_4, 1.72 kg of C_2H_4, and 0.0014 kg of Pb. The total impact of annual cooler production was estimated assuming that 3,120 coolers are being produced by Fortuna per year (overall impact illustrated in Figure A.9).

Greenhouse gases were found to be the largest resulting impact of the cooler. For greenhouse gases, the process with the largest yearly impact is the transportation of the completed liner and fiber insulation to Manila, which produces 182,847 kg of CO_2 equivalents per year. The transportation to Manila also accounted for the largest yearly impact on heavy metals (2.28 kg of Pb), whereas the largest yearly impacts on acidification and eutrophication were from raw material acquisition (2,908 kg of SO_2 and 400 kg of PO_4, respectively) and the largest yearly impact on summer smog was from material processing (4,603 kg of C_2H_4).

As shown in Figure A.10 in Appendix A, there is no single process that is primarily responsible for the largest environmental impacts of the cooler. The transportation to Manila does produce a non-negligible amount of pollution across impact categories, as does raw material acquisition.

A comparative assessment of the annual environmental impact of the production of EPS and Fortuna cooler was also performed. Because of high replacement rate and short useful life of EPS cooler, the estimated 3,120 units of Fortuna cooler in one year would require 26 times higher or 81,120 EPS cooler to perform the equivalent annual operation.

The greenhouse gases of the equivalent annual number of 81,120 EPS coolers were found to have the highest relative impact with respect to 3,120 Fortuna coolers (see Figure A.11). This shows that the EPS cooler would be expected to have a greenhouse effect 23 times higher than the Fortuna cooler does in one year. The acidification potential, eutrophication, and heavy metals of the equivalent annual number of EPS coolers were found to be two to seven times lower than the Fortuna cooler. A slight difference was observed for the summer smog between the EPS and the Fortuna coolers. These findings could possibly change because EPS would require processing energy to recycle and to reuse whereas the coconut husks can be converted in a form of biodegradable compost and fertilizer with less energy requirement. For overall impact values of the EPS coolers and Fortuna cooler for one year, see Table A.8.

Sensitivity Analysis

A sensitivity analysis was performed to determine the impact of several possible adjustments to the team's assumptions (see Table A.9).

The first category assessed was cooler production quantity, which was tested by increasing and decreasing the annual production of 3,120 coolers by 20%. The next category was the size of the cooler. The current cooler size is 16" x 16" x 22". For this comparison, we compared the impact of hypothetically producing a smaller cooler and a larger cooler. In calculating the impact, the number of coconuts per square meter of panel was used to determine the number of coconuts needed for the new cooler size, and the ratio of new panel area to original panel area was used to calculate the new amount of PVC needed for the liner, assuming a linear relationship between liner size and cooler panel total area. The final category assessed was an increase or decrease in the PVC quantity used for the liner. Alternative materials are under consideration for the liner, so the team hoped to determine the overall impact that replacing or blending the PVC with a less impactful material may have.

Each of these categories was then reviewed for impact on annual energy consumption as well as the five impact indicators we used in our impact assessment, as shown in the tornado diagrams in Appendix A (Figures A.12 through A.17).

The sensitivity analysis shows that the size of the cooler tends to have the greatest influence on overall environmental impact, followed by annual cooler production. Increasing PVC used has a small effect on environmental impact, especially on heavy metals emissions, but decreasing the PVC used has very little effect on overall impact. This suggests that seeking to make small adjustments to the PVC content of the liner may not be the best use of resources if decreasing environmental impact of production is the goal. It is worth noting here that this analysis excludes disposal, so decreasing PVC content in the coolers may have a larger impact in the landfill and recycling stage than is apparent in these diagrams.

Conclusions

This report has applied a process-based life cycle assessment that evaluated and compared the environmental impacts of the production of coconut husk-based Fortuna coolers and expanded polystyrene (EPS) coolers. Being a newly introduced material in the Philippine market, the process flow and system boundary of Fortuna coolers have been identified. An editable spreadsheet toolkit that measures life cycle impact was also developed to observe the effect of any operational changes done by Fortuna Cools.

Compared to traditional EPS coolers that have been used more often in the Philippine market for years, the Fortuna cooler has been found to emit as much as 23 times lower greenhouse gases annually in terms of production. The capability of coconut husks to be degraded and converted into a biodegradable compost and fertilizer minimizes the energy requirement towards the end-of-life disposal. This promotes a direction to institutionalize and to regulate the agro-industrial waste market of coconut husks in the Philippines because of the social, economic, and environmental benefits of Fortuna Cools to potentially address the alarming impacts of traditional EPS coolers.

Through the sensitivity analysis, this report has determined that the cooler size greatly influences the overall environmental impact. The replacement of PVC with other alternatives may not have a significant effect on environmental impact within the production system boundary; however, the disposal should be extensively studied in the future work to account for the recyclability and landfilling potential.

Because of its early stage of implementation that explains the limited data of end-of-life stage of a Fortuna cooler, it is recommended to conduct further life cycle studies that explicitly take into account the rates of landfilling, recycling, and incineration in the current setting. A full understanding of mass and energy balances across the system boundary could be used to formulate informed decisions to control the upstream and downstream of the processes.

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Appendices

Appendix A: Report Reference Formulas, Figures and Tables

Formulas

Formula A.1

$$\text{Cost (USD)} = \text{Unit price (USD/kg)} \times \text{Mass (kg)}$$

Formula A.2

$$0.021\frac{USD}{PHP} \times \frac{63.93\ PHP/hour \times 7.5hours/day \times 312days/year}{3120\ coolers} = 1.20\ USD$$

Formula A.3

$$\frac{2.5trips}{week} \times \frac{1week}{7day} \times \frac{5L}{trip} \times \frac{load+cooler\ weight}{36kg} \times \frac{1USD}{L}$$

Formula A.4

$$0.021\ USD/PHP \times 0.2PHP = 0.16\ USD$$

Formula A.5

$$0.021\frac{USD}{PHP} \times \frac{1850PHP + 284.9miles/trip \times 1.61km/mile \times 50PHP/km}{595kg/trip} \times 0.4kg = 0.35\ USD$$

Formula A.6

$$\frac{24\ USD/trip}{1500\ kg/trip} \times 0.75\frac{kg}{cooler} + 0.021\frac{USD}{PHP} \times \frac{1850PHP + 284.9\ miles/trip \times 1.61\ km/mile \times 50\ PHP/km}{1500\ kg/trip} \times 0.75\frac{kg}{cooler} = 0.27\ USD/co$$

Formula A.7

$$0.021\frac{USD}{PHP} \times \frac{15{,}000\ PHP/trip}{10{,}000\ kg/trip} \times 4\frac{kg}{cooler} = 1.2\ USD/cooler$$

Formula A.8

$$1.2\ USD/cooler \times \frac{1kg}{4kg} \times \frac{31.5miles}{311\ miles} = 0.003\ USD/cooler$$

Figures

Figure A.1: Target Sustainable Development Goals (source: https://www.fortunacools.com/).

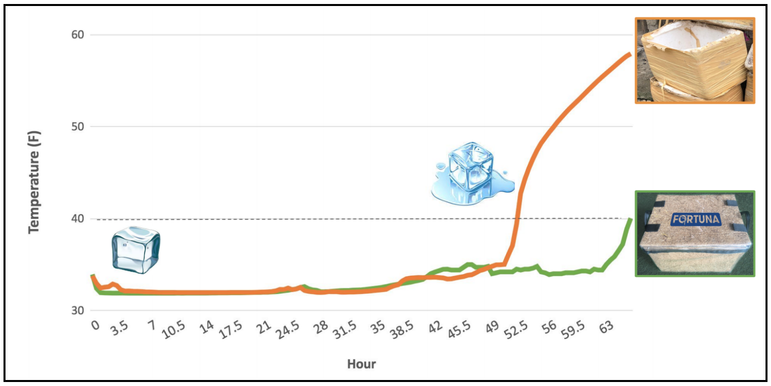


Figure A.2: Insulation capabilities of Fortuna vs. comparison product (source: Fortuna)

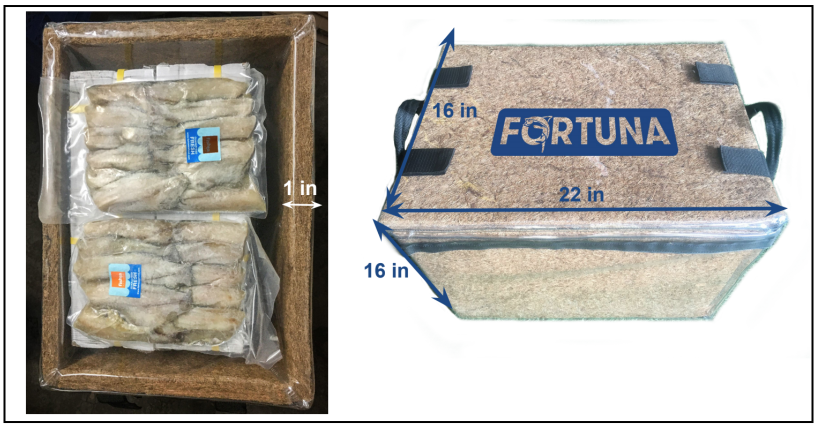


Figure A.3: Dimensions of the Fortuna cooler (source: Fortuna)

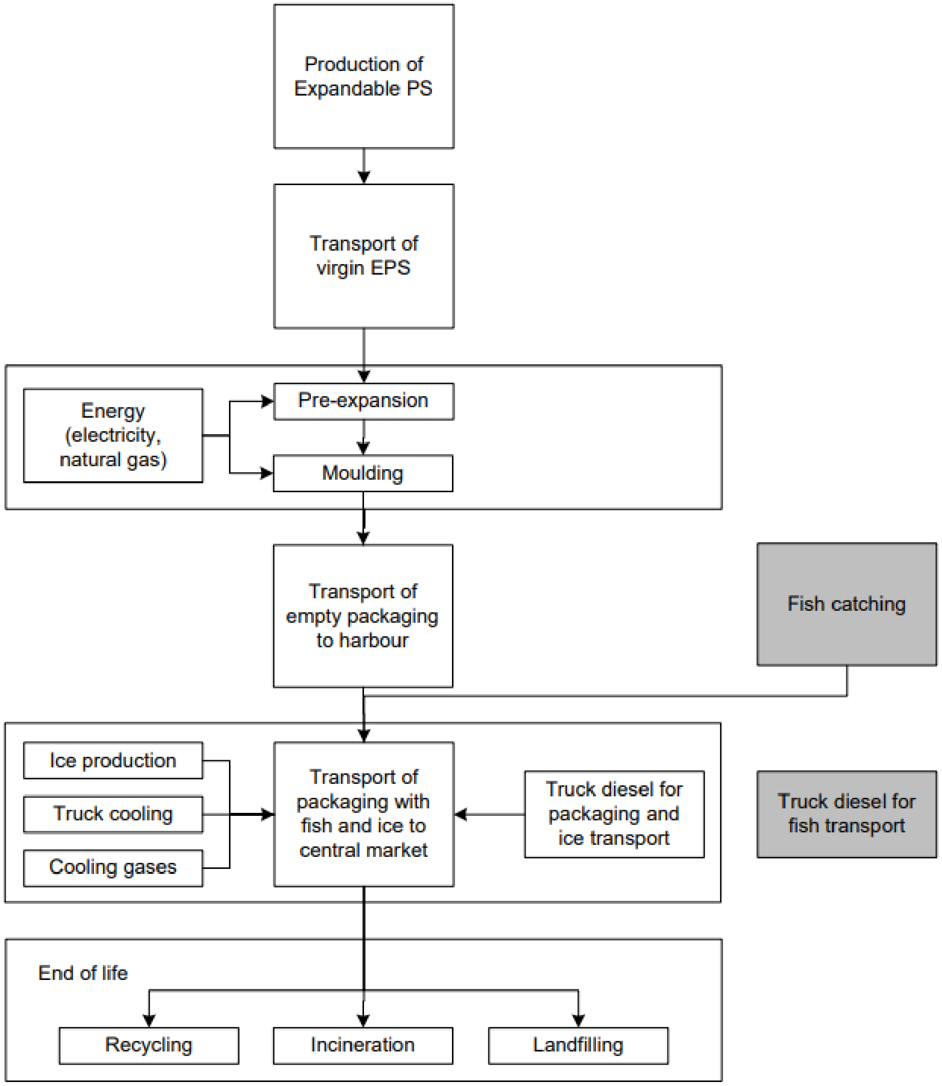


Figure A.4: Process flow diagram and system boundary (PwC Ecobilan, 2011).

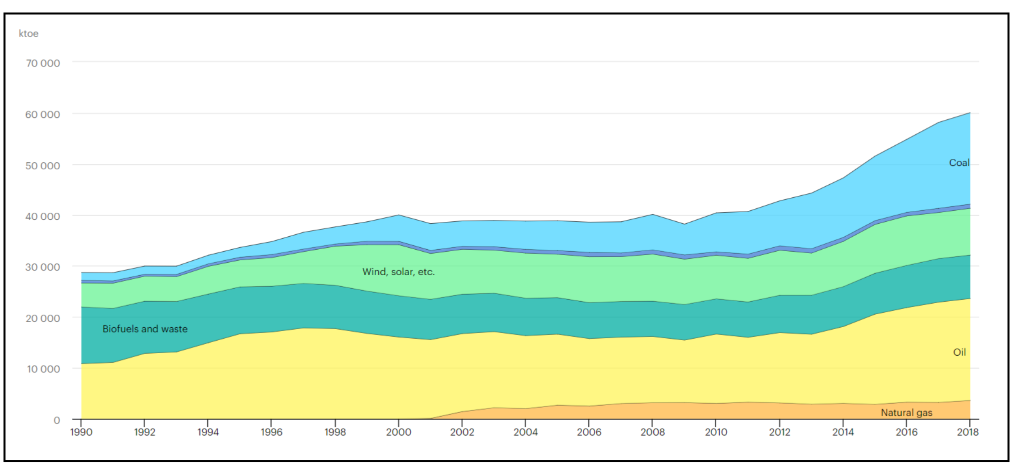


Figure A.5: Philippine electricity mix from 1990 to 2018 (IEA, 2020).

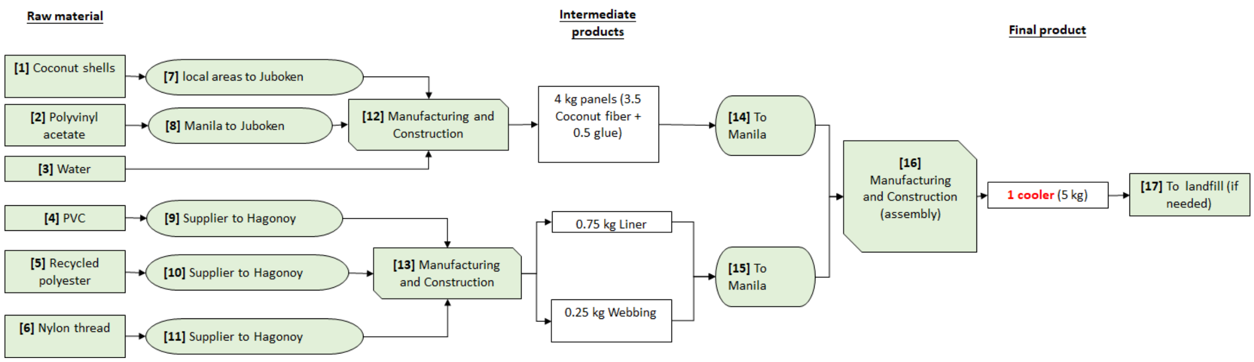


Figure A.6: Process Flow Diagram Used for LCC Analysis

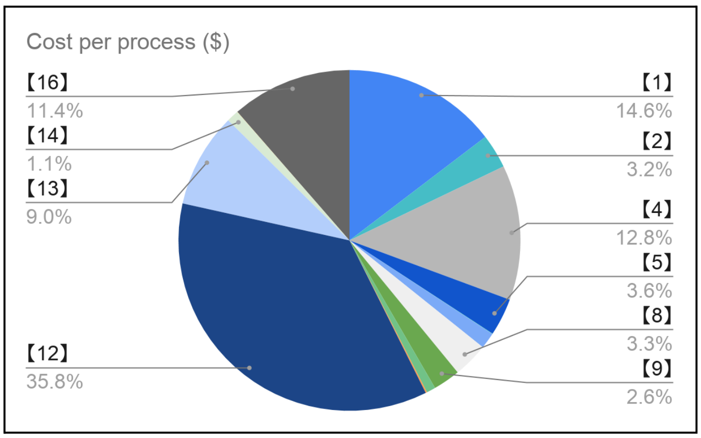


Figure A.7: The cost of each process

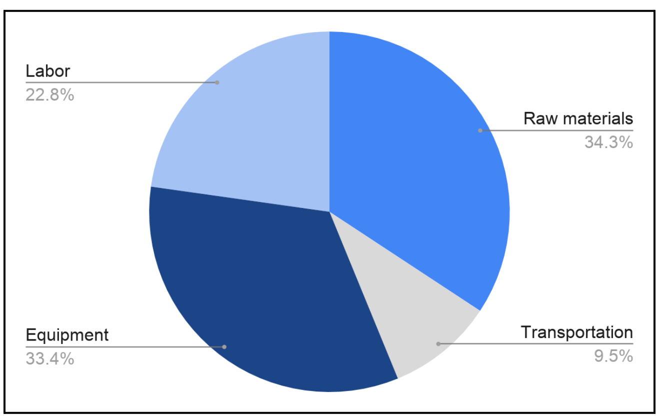
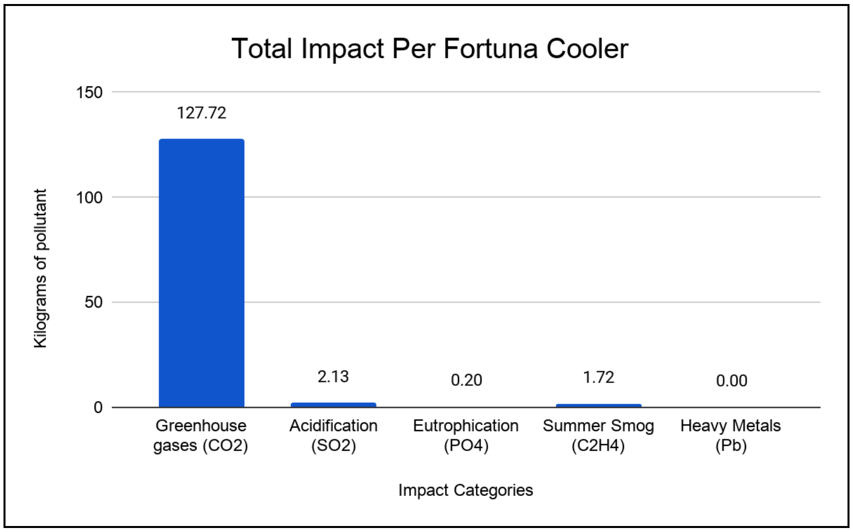


Figure A.8: The cost of each category



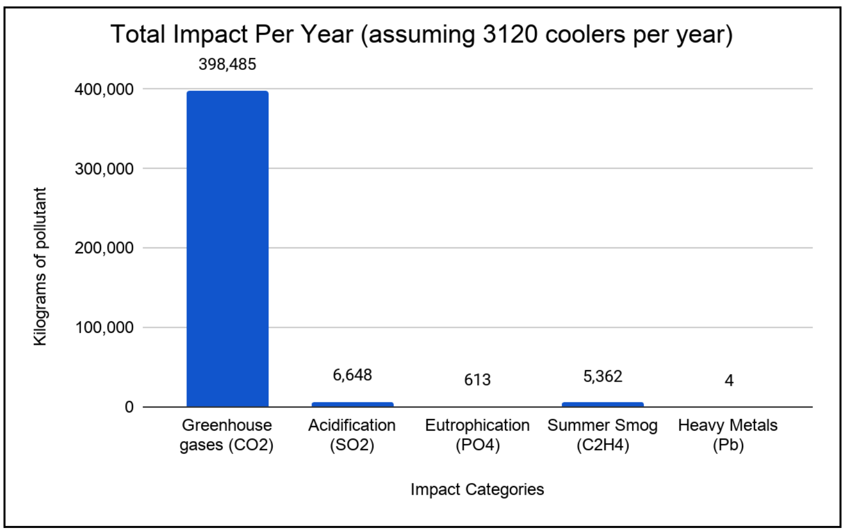


Figure A.9: Environmental impact by impact category

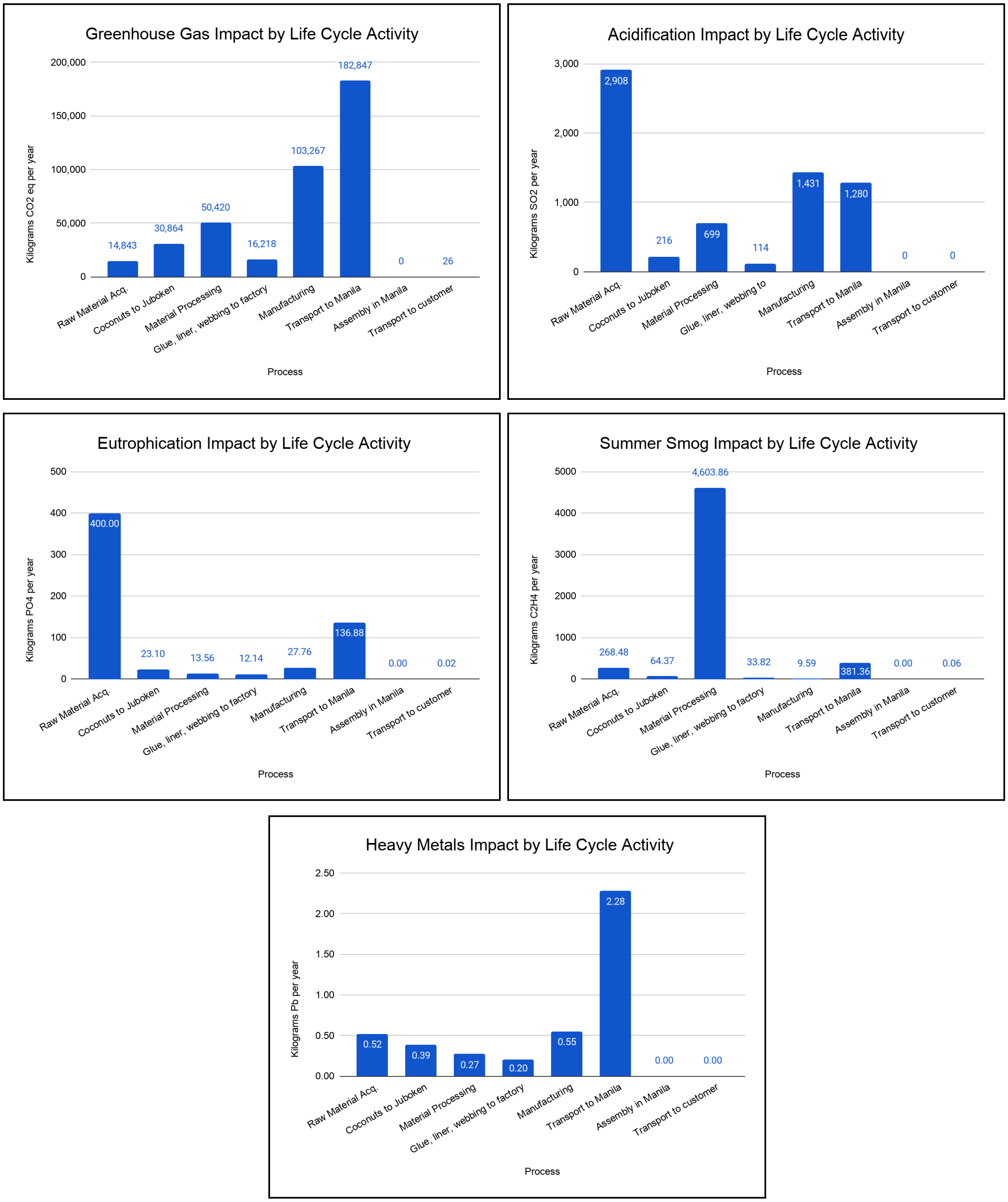


Figure A.10: Life Cycle Impact by Activity

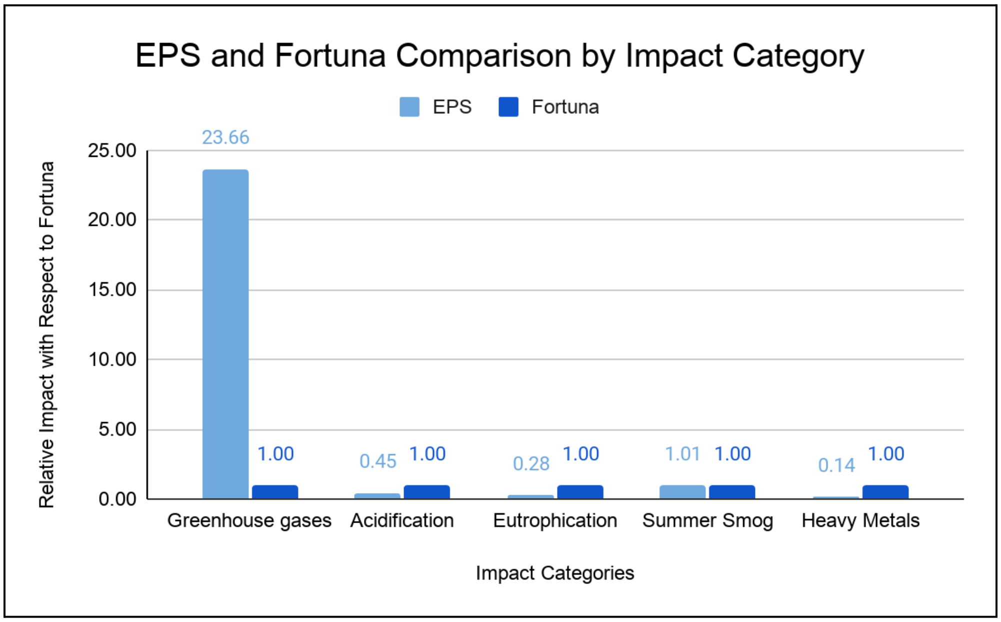


Figure A.11: Relative impact of EPS and Fortuna Cooler

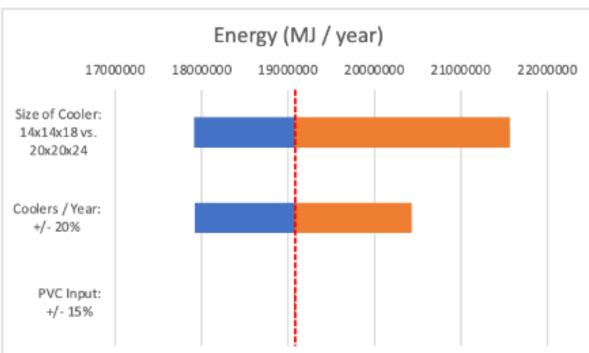


Figure A.12: Energy impact tornado diagram

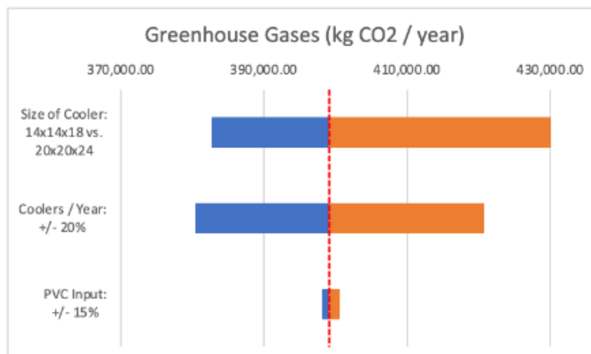


Figure A.13: Greenhouse gas tornado diagram

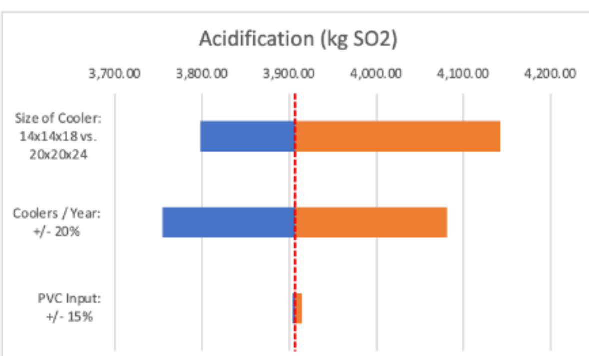


Figure A.14: Acidification tornado diagram

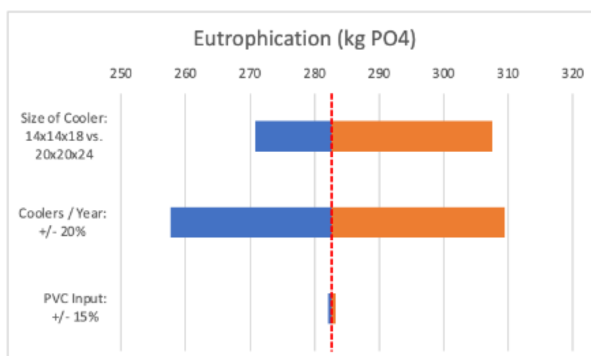


Figure A.15: Eutrophication tornado diagram

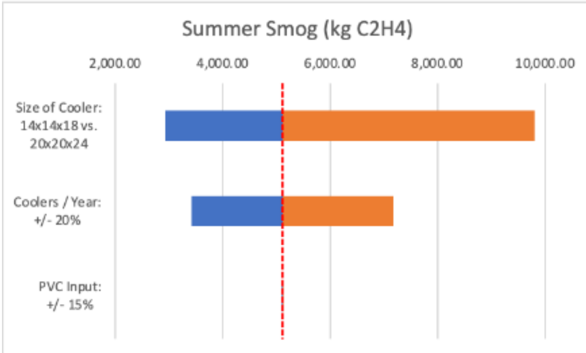


Figure A.16: Summer smog tornado diagram

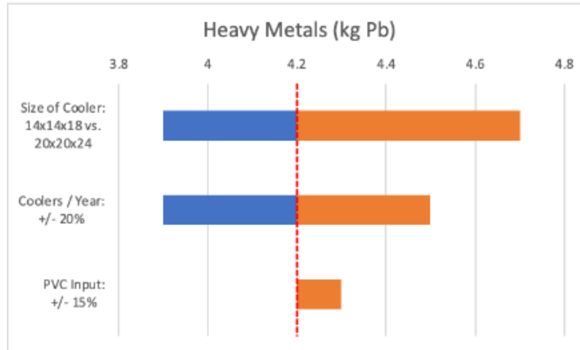


Figure A.17: Heavy metals tornado diagram

Tables

Table A.1: Impact categories

Impact Category	Unit
Greenhouse gases	kg CO2
Acidification	kg SO2
Eutrophication	kg PO4
Summer smog	kg C2H4
Heavy metals	kg Pb

Table A.2: Raw material costs

Item	Cost (USD)	Unit price (USD/kg)	Mass (kg)
Coconut shells	1.54	0.44	3.5
Polyvinyl acetate	0.34	1.28	0.26
Water	0.00	0.00	0.13
PVC	1.35	1.5	0.9
Recycled polyester	0.38	1.5	0.25
Polyester thread	0.005	8.25	0.0006042
Total	3.61		

Table A.3: Main assumptions for cost in use and service phase

Assumption	Value
Use frequency	2.5 trips/week
Transportation load	35 kg/cooler (full load)
Gasoline	~5L/trip (for EPS cooler)
Unit price of gasoline	1 USD/L

Table A.4: Cost comparison of Fortuna and EPS cooler

Parameter	Fortuna Cooler	EPS cooler
Unit price (USD)	33	4.2
Lifetime	1 yr	2 weeks
Cooler cost (USD)	33	109.2
Transportation cost (USD)	722.7	657
Total cost (USD/yr)	755.7	766.2

Table A.5: Sources of raw material data

Raw Materials	References
Polyvinyl Chloride	EcoInvent 3.01 - Eco-profiles of the European Plastic Industry
Vinyl Acetate	EcoInvent 3.01 - Process data based on stoichiometric calculations of few literature sources; Energy demand based on approximation from large chemical plant; Process emission based on estimations only
Nylon	EcoInvent 3.01 {RoW} | Production | Alloc Def, U
Coconut	Blonk Agri-footprint | Coconut husk, from dehusking at plant (PH) | Mass
Polyester	EcoInvent 3.01 | Polyester Resin | Unsaturated {GLO} | Alloc Def U

Table A.6: Estimated Raw Material Acquisition Per Year

Raw Material	Value	Units
Coconuts	109,200	coconuts per year
Glue	1,248	kg per year
PVC liner	2,808	kg per year
Polyester (webbing)	781.9	kg per year

Table A.7: Summary of Energy Impact for Fortuna Coolers

Description	Value	Units
Total Energy (MJ) Used Per Year	19077309	MJ per year
Estimated coolers produced per year	3120	Coolers per year
Energy (MJ) Used Per Cooler	6114.5	MJ per cooler

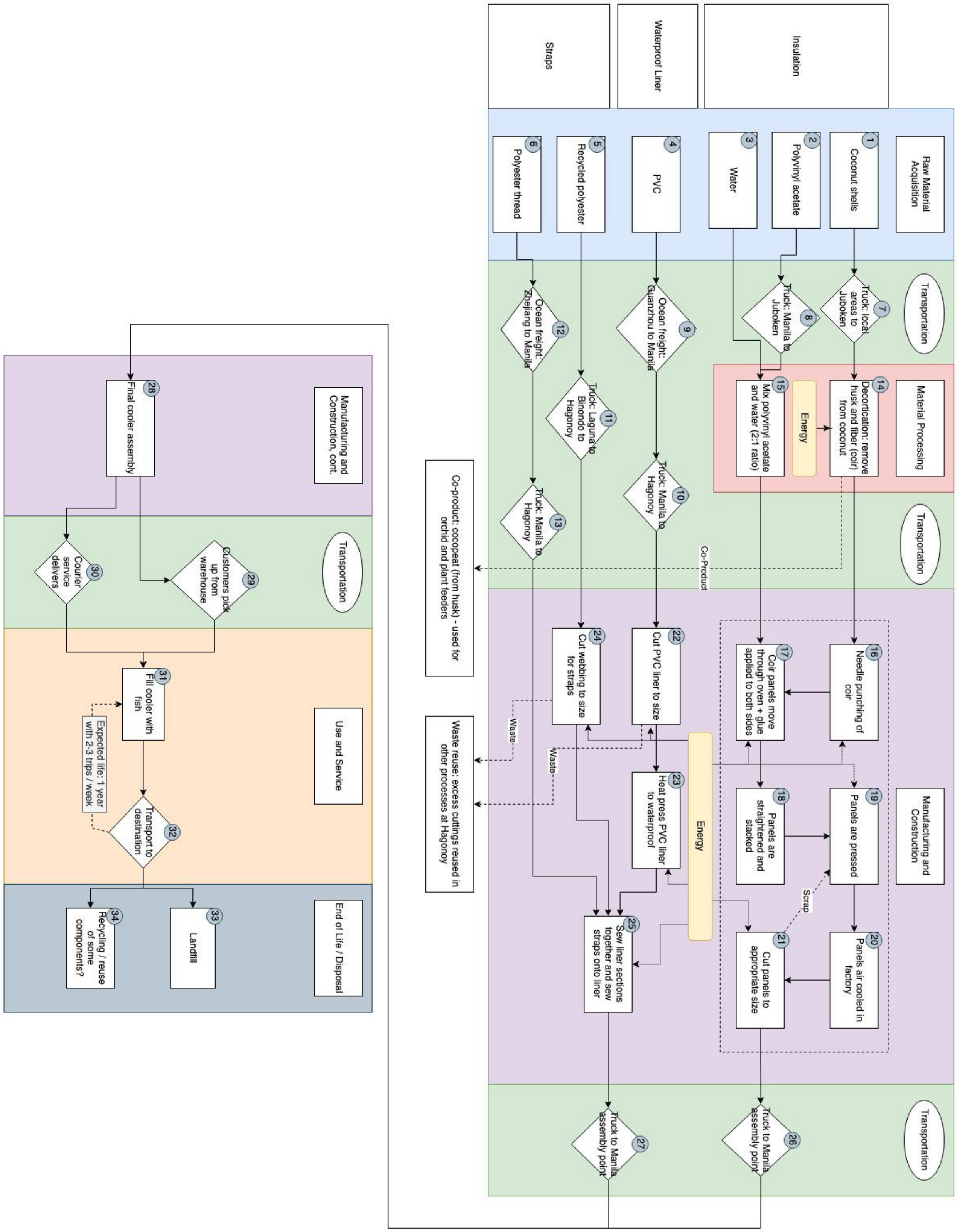
Table A.8: Difference of Estimated Annual Impact Measures

Categories	81,120 EPS Coolers	3, 120 Fortuna Cooler	Units
Greenhouse gases	351,154.77	14,842.72	kg of CO2
Acidification	1,294.36	2907.93	kg of SO2
Eutrophication	110.14	400	kg of PO4
Summer Smog	272.06	268.48	kg of C2H4
Heavy Metals	0.08	0.52	kg of Pb

Table A.9: Categories used in sensitivity analysis

Parameter	Min	Max
Cooler Production	-20% of baseline	+20% of baseline
Cooler Size	14" x 14" x 18"	20" x 20" x 24"
PVC used in Liner	-15% of baseline	+15% of baseline

Appendix B: Process Flow Diagram



Appendix C: LCI Distribution of Each Raw Material

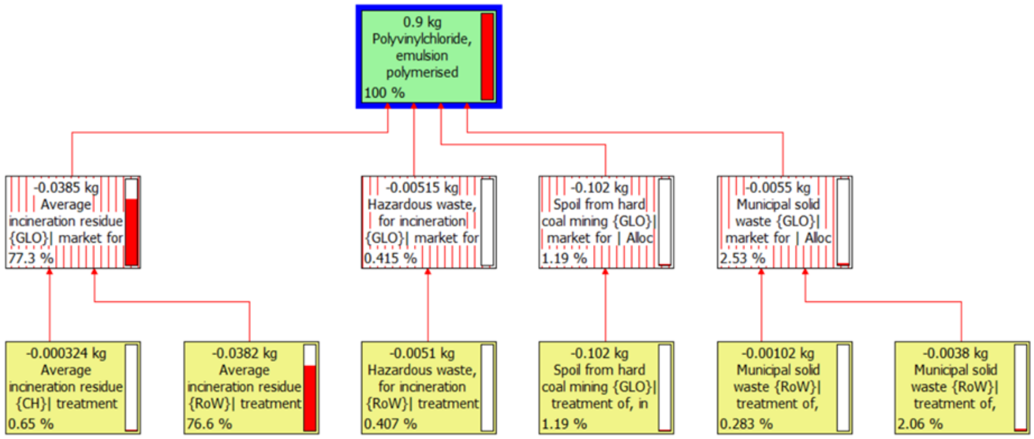


Figure C.1: Polyvinyl Chloride

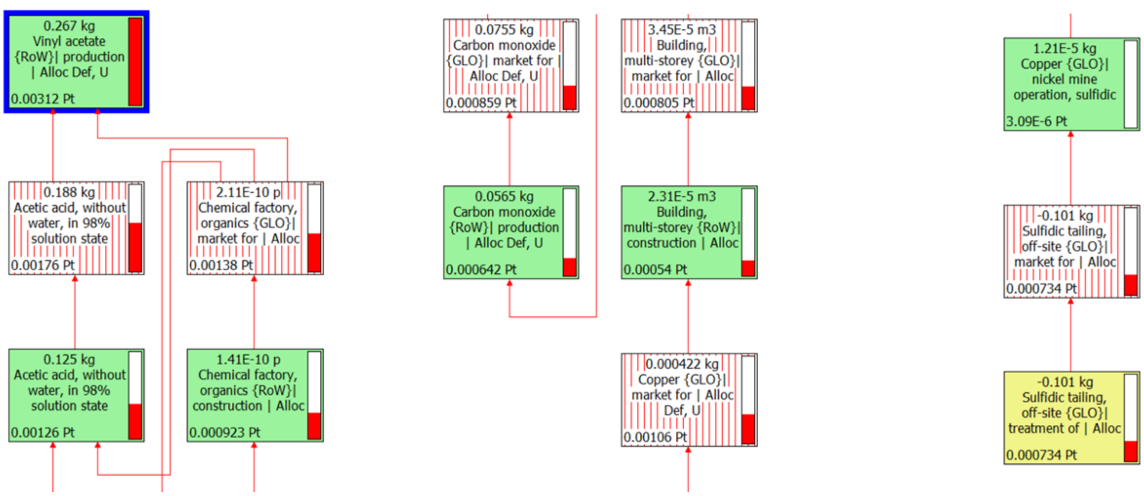


Figure C.2: Vinyl Acetate

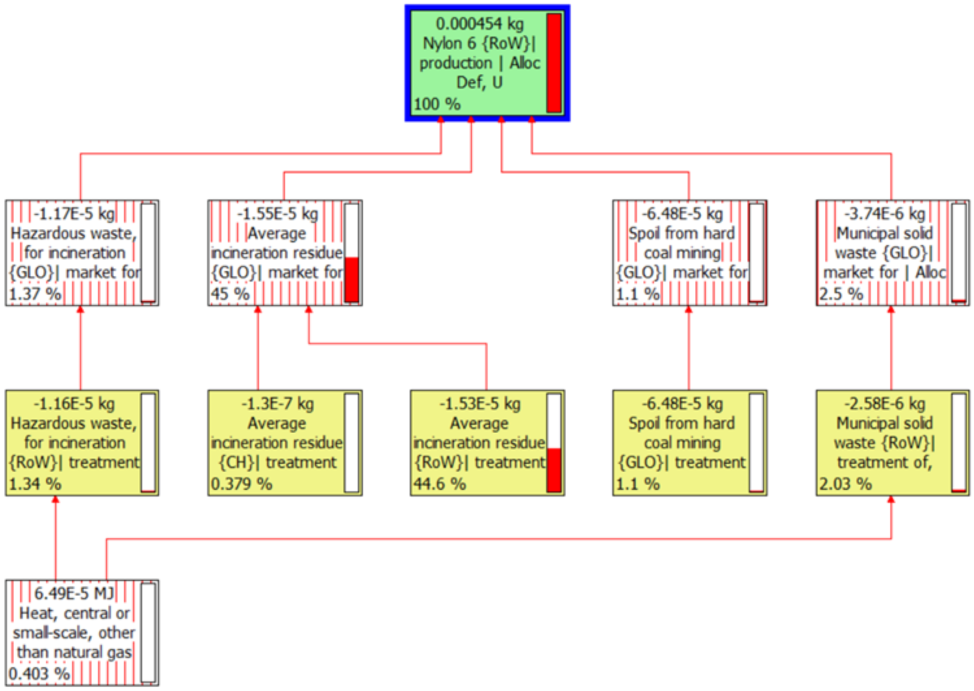


Figure C.3: Nylon

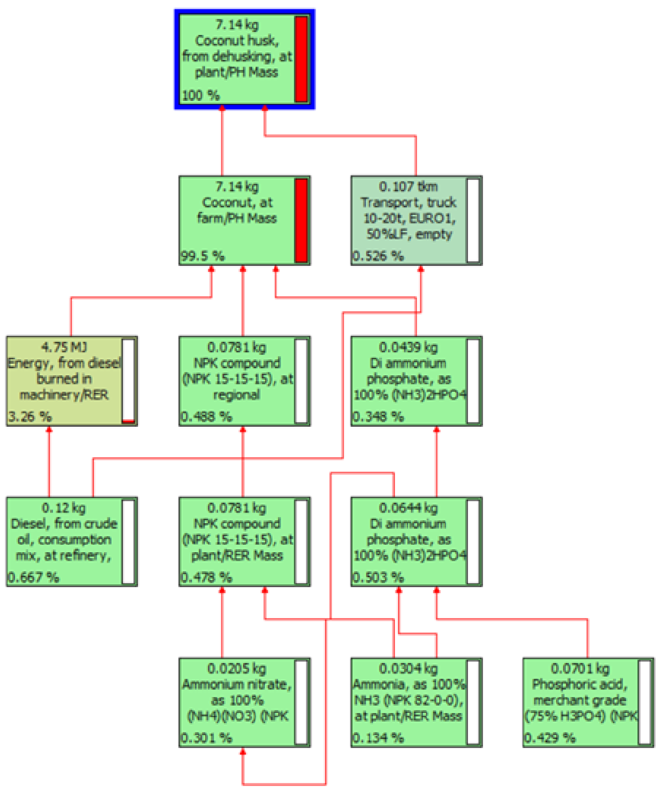


Figure C.4: Coconut

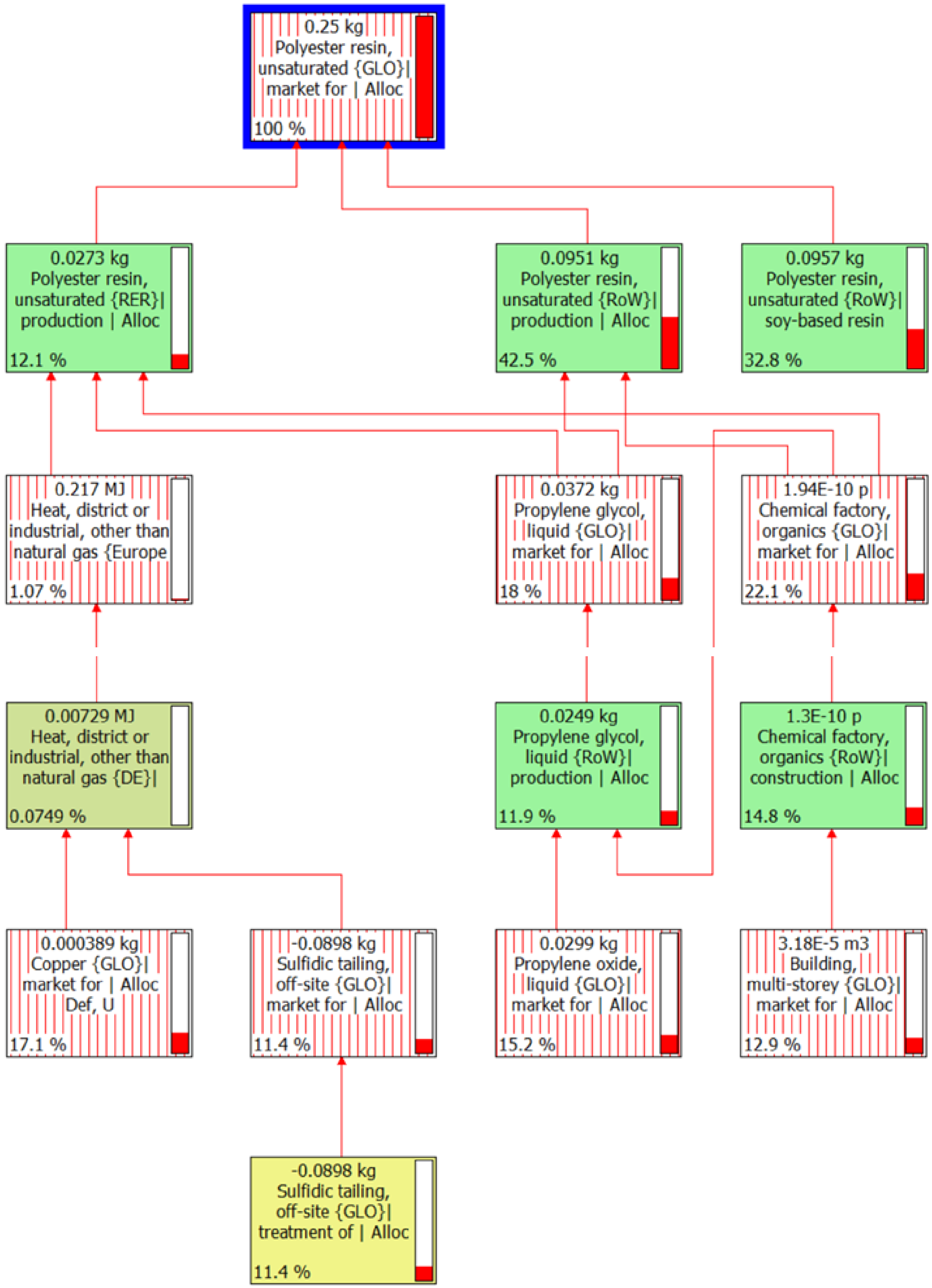
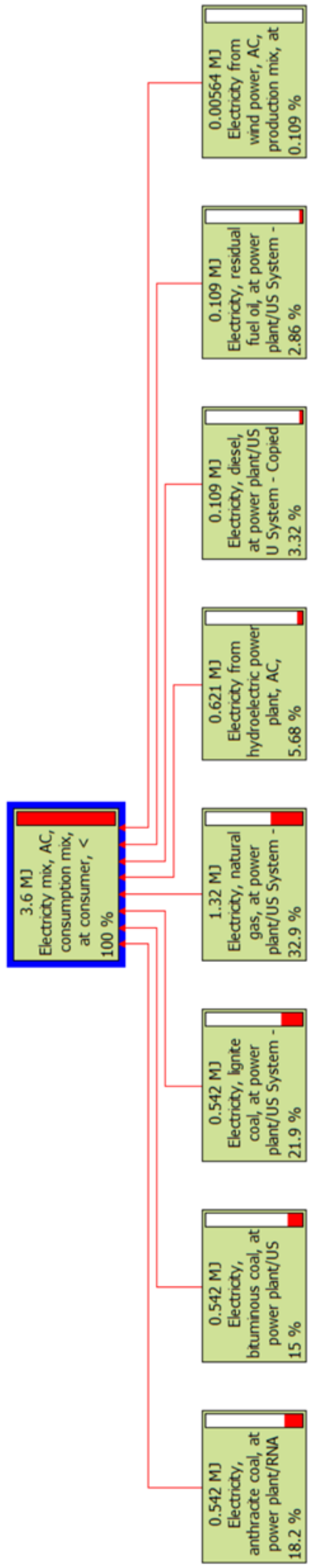


Figure C.5: Polyester

Appendix D: LCI of Philippine Electricity Grid



Appendix E: LCI of Various Sources of Energy

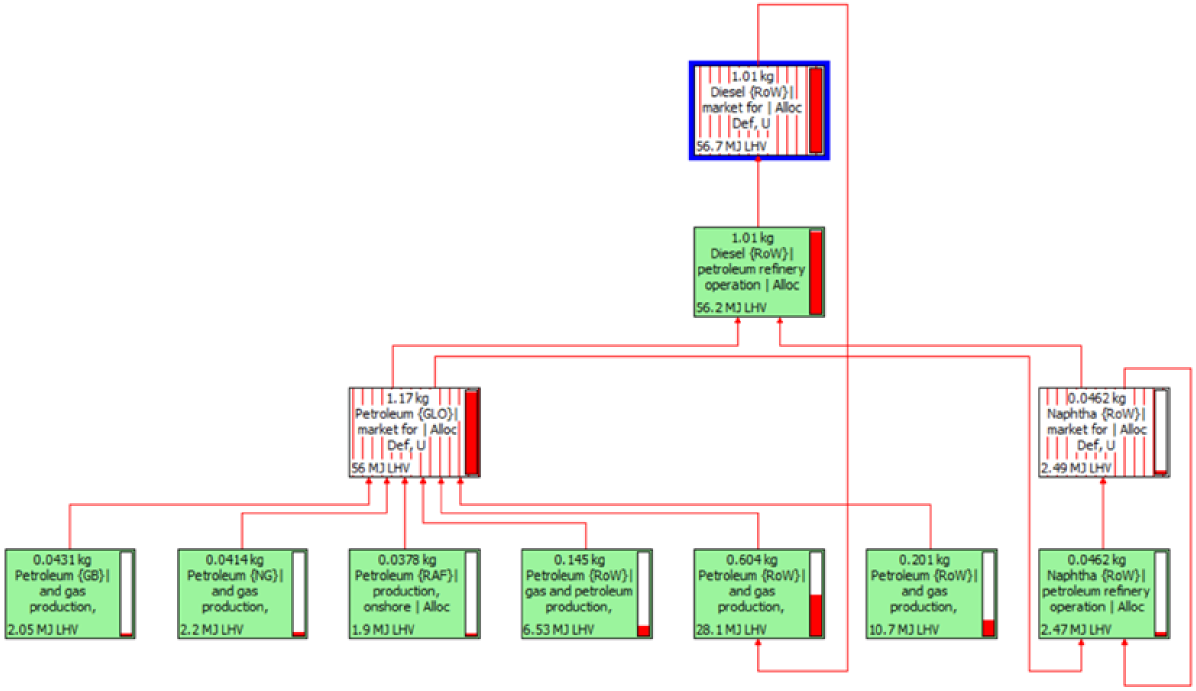


Figure E.1: Diesel

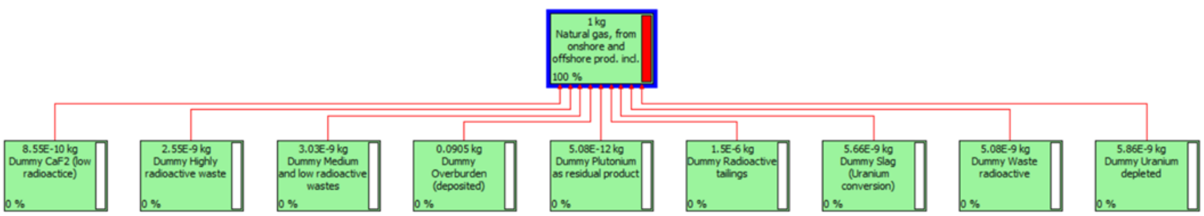


Figure E.2: Natural Gas

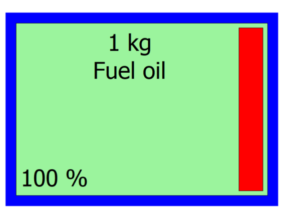


Figure E.3: Fuel Oil