Life cycle assessment of polypropylene meat tray

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Abstract:

Food packaging is a common, daily-use product but plays an important role in the food industry. A life cycle of a plastic meat packaging product could emit a high number of toxic substances to the environment. A life cycle assessment study was conducted in order to evaluate the environmental performance of polypropylene meat tray. The study first set up a benchmark scenario and assessed its environmental impacts. Based on its results, different scenarios were modelled and compared with the benchmark setting to optimize the product's environmental performance. For the main method, a life cycle assessment was applied following the ISO 14040 series standards. The scope of the study included production of raw material to waste treatment processes. The study concluded that a life cycle of polypropylene meat trays greatly affects global warming potential and abiotic depletion fossil potential. Other processes such as transportation or manufacturing processes only contribute mild impact to the overall environmental performance. The outcome also shows that the end-of-life stage has an important influence on the environmental performance of polypropylene meat trays, especially on the global warming potential. However, the production of raw material dominates the overall results. Based on the scenario modeling, improving product might involve different measures. Transportation distance could be optimized to mainly reduce global warming potential and acidification potential. Alternative measures like substituting with a more effective product and increasing recycled waste appear to be more competent as they demand less raw materials, leading to significant reduction in many environmental categories.

Keywords:	Life cycle assessment, sustainability, environment, meat tray, polypropylene
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1 INTRODUCTION

Food packaging has integrated into our lives as something rather essential, but we often treat it as trivial. It does not only help to keep food safe, fresh and clean but it also is very convenient to manufacture and to use. Modern solutions for food packaging have been improving for the past decades. Food packets, which used to be often contained in unappealing carton boxes, have become more well-designed and more attractive to costumers. The containers not only are more engaging from their appearance, but they also provide end users with convenience and ease in both consuming and preserving food. In addition, nutritional labels are compulsorily added onto the packaging to help consumers with their diet decisions. (Sumner, 2017) This results in the variety of packaging materials, as well as its form and shape. Almost all food come with some forms of packaging. Food packagings are usually made from many types of synthetic materials such as metal, cardboard, paper, and plastics. Other than the main compositions, food packaging often comes together with different kinds of coatings and labels and ink texts.

However, most types of food packaging are not meant to be reused or recycled. Therefore, the packaging, as a part of municipal solid waste, will go to landfills, oceans or will be incinerated. While some materials degrade rather quickly, many materials, especially plastics, may take from a few dozens to hundreds of years degrade completely. Incineration of plastics could also produce toxic substances to the environment if they are not treated properly. For instance, combusting plastics produces some combinations of the following air emissions: hydrogen chloride, sulfur dioxides, nitrous oxides and particulars (Air Emissions from MSW Combustion Facilities, 2016); landfill gas emitted contains greenhouse gases such as carbon dioxide or hydrogen sulfide (Center for Environmental Health, 2019). This has caused some severe impacts on the environment that we live in, affecting not only human life but other ecosystems such as marine life. Fish, sea turtles and seabirds ingest thousands of tons of plastic every year, causing them injuries and fatalities, yet plastics are still continuously released into the ocean (Biologicaldiversity, 2020). There have been increasing measurements in order to reduce the influence of plastic waste on the environment, such as limit the use of plastic, try to recycle plastic waste as much as possible. According to Eurostat, in 2017, about 28% of plastic packaging was recycled in Finland, which is relatively less than the average amount of the EU, 41.9% (Figure 1) (Eurostat, 2019)

Although there are more and more new degradable, environment friendly materials introduced to the market, it will still be a long way for them to replace all the existing common ones.

Unfortunately, apart from the disposal phase of food packaging, material processing and product manufacturing also generate harmful emissions to the environment. Depending on what type of packaging, it will require a lot of metals, wood, or petroleum as well as energy, water and chemicals. Throughout manufacturing processes, many different pollutants are generated such as greenhouse gases, heavy metals, particulates, wastewater, and toxic sludge (Food Print, 2017)

Figure 1: Plastic packaging waste recycling in EU (Eurostat, 2019)

It is encouraging to calculate or at least estimate how impactful food packaging, or a product in general, is to the environment. Nowadays, life cycle assessment (LCA) is a well-known tool or method to evaluate impacts a product or a service has on the environment for its entire life cycle. LCA analyses any stage in a product’s life, starting from raw material extraction, and continues all the way to its end of life. LCA helps users to decide whether a product is environmentally friendly or not, and to find a way to develop a more sustainable product.

This thesis attempts to do a life cycle assessment study for meat tray that is made from polypropylene (PP). The primary intended use is to study some environmental impacts from this type of food packaging. The setting will be PP base tray produced in Finland with imported materials. The methodology starts with analyzing impacts of the benchmark product, which is based on a specific type of plastic tray produced by PACCOR Finland Oy. The LCA study strictly follows the ISO series 14040 standards, which include four distinct phases: goal, scope and definition; inventory analysis; impact assessment; and interpretation. The inventory analysis and impact assessment phases will also be constructed and calculated in GaBi Education Software. Then we will build different scenario modellings using the same software in order to study further about how significant of the impact each process or phase during a life cycle of the product accounts for. The scenarios are also expected to provide further data on how to make the product more sustainable and more environment friendly. Finally, the results and their validity will be analyzed.

The first part of the thesis will be some background literature and then proceeds to the methods to execute the LCA study. After getting results, they will be reviewed, and some important impact categories will be discussed.

2 LITERATURE

2.1 Propylene as a material for food packaging

Packaging plays an important role in the food industry. A packaging protects the food from fungi and organisms, therefore delivers food fresh to end consumers. Compared to canned food and frozen food, raw meats and vegetables are more susceptible to being spoiled when directly in contact with the environment. That is the reason why we need food packaging to keep goods clean and fresh and preserve their nutritional values. Especially for raw meat, preserving in a suitable temperature alone is not always sufficient due to transportation, handling and storing purposes. There are various types of food packaging: they can be as simple as the paper wraps from local meat counters to carton boxes, plastic bags, or plastic trays in the supermarket. Similarly, the packaging can be made from different types of materials such as aluminium, paper and plastic.

Recently, plastics have become a popular choice for food packaging because they are superior to other material types in many aspects. Plastics provide more safety. Polymers generally are more durable and do not chemically interact with food, thus they prevent food from contamination and offer better shelf life. Another advantage of using plastics is they are cost effective. The cost of transportation and storage can be significantly lower than other materials since plastics are light weight. They also offer more aesthetic designs while still convenient to manufacture and to use. (Allahvaisi, 2012)

Among all polymers, polypropylene (PP) is stiff but not as brittle as some other, classified as a semi-rigid polymer. PP has a wide range of applications: rope, film packaging, food containers, etc. Due to having a high melting point, PP is also commonly applied for food packaging products that can be used in microwaves (Types of Plastic Food Packaging and Safety, 2021). In the Finnish market, a large amount of meat trays are often made from PP or PP mixed with one or two other types of polymer such as polyethylene or polyamide. The industrial processes to manufacture a final tray include film extrusion from granulates or pellets. The film sheets are then thermoformed into solid trays.

The waste generated from food packaging is generally disposed or treated by incineration, landfill or recycling. Although in the past most of this waste went to landfill, several countries have employed different policies to recycle higher amount of plastic waste. Especially for polypropylene waste because it decomposes slowly over 30 years in landfills and combusting PP may release dioxins and vinyl chloride. This affects severely to the living environment as well as other ecosystems. However, it is not economical to recycle PP when compared to other plastics like polyethylene or polyethylene terephthalate. Sometimes, incineration or chemically recycling PP into synthetic fuels are better choices and by doing so we are still able to reduce waste in landfill. (Thomas, 2012)

2.2 Life cycle assessment

Life cycle assessment is a method to evaluate environmental impacts in all stages of the life cycle of a product or a service. The stages of, for instance, a product may include raw material processing, manufacture of the actual product, distribution, use and disposal or recycling. The method is conducted by analysing an inventory of inputs and outputs of materials and energy. The environmental impacts, that normally consist of emission to water, air and soil, will be quantified and calculated. LCA identifies environmental hotspots or potential impacts and we can use the information to improve then environmental performance at any stage of the product's life cycle.

LCA is a reliable tool in sustainable engineering and designing, used by manufacturers or third-party services. It is often utilized for developing environmental strategies, reducing environmental waste, reducing cost, marketing or comparing of alternative products. In addition, the LCA process could be used to do comparisons between different products or alternatives, that is, to check which product or process contributes more or less potential impacts on the environment.

The LCA tool is also needed to create an Environmental Product Declaration (EPD). An EPD is a type of document that specifies environmental attributes of the life cycle of a product and provides comparable information to compare between different products of the same function. EPDS follow Life Cycle Assessment ISO series 14040. The development of the ISO series 14040 throughout the years is shown in Table 1 (Curran, 2012).

Number	Type	Title	Year
14040	International standard	Principles and framework	1996, 2006
14041	International standard	Goal and scope definition and inventory analysis	
14042	International standard	Life cycle impact assessment	2000[1]
14043	International standard	Life cycle interpretations	2000[1]
14044	International standard	Requirements and guidelines	2006[2]
14047	Technical report	Examples of application of ISO 14042	2003
14048	Technical report	Data documentation format	2001
14049	Technical report	Examples of application of ISO 14041	2000

[1] Updated in 2006 and merged into 14044.

[2] Replaces 14041, 14042, and 14043.

Table 1: ISO documents on life cycle assessment (Curran, 2012)

A widely accepted procedure for conducting LCAs is in accordance with the ISO 14000 series standard, ISO 14040, and ISO 14044 (ISO 14040:2006, 2006-2007). It consists of four interdependent phases: goal and scope, inventory analysis, impact assessment, and interpretation (see Figure 2 below).

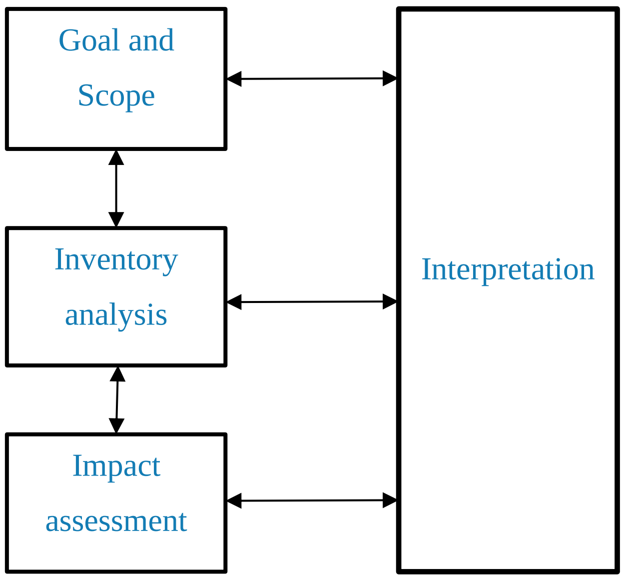


Figure 2: Framework of LCA according to ISO 14000 standards

The first phase defines the overall goal, target group, product description, functional unit, assumption, system boundary, and impact categories. It is important to clearly define a specific plan to follow in the first place. However, this is not always the case "The goal, as well as the scope, can be modified during the course of the work as data are collected and new information is revealed… Such modifications should be (and in some cases, have to be) described transparently in the data spreadsheets and final report" (M.A, 2017). In this step, the purpose of LCA study is established, a precise definition of the product, assumptions, and choice of impacts should be described. System boundary defines which processes and materials of the system are included and excluded or cut off in the LCA study, e.g., contribution of mass, energy, market value, processing steps, estimated impact, common processes. In comparative LCA, mutual processes can be omitted because it would make no difference in comparing and, therefore, does not affect the final results. A system boundary can be chosen subjectively based on the original purposes and needs of the LCA study. A life cycle included inside the boundary can generally start from extraction of raw materials and end where the product becomes waste, and the waste is treated or recycled. There are four common types of system boundaries, cradle to grave (production - use phase - end of life), cradle to gate (production – use phase), gate to gate (product use phase) and gate to grave (use phase – end of life). While setting system boundary, there can be processes where more than one product is produced, which are called allocation, and the input data as well as output data will be partitioned according to their relative contribution to one product or one other. The ISO 14000s standard advices to avoid partition and such partition should be made based on physical properties such as mass, energy values, etc. Figure 3 below shows a simple example of a cradle to grave boundary. It includes all the processes, energy input and emissions.

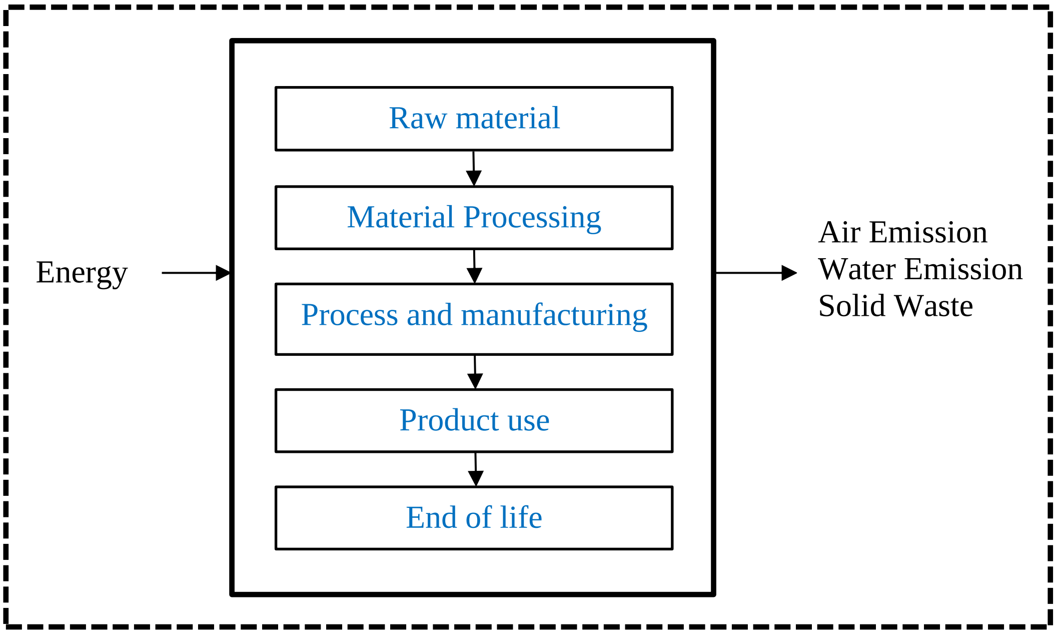


Figure 3: Model of cradle to grave boundary

Another crucial parameter is the functional unit. It is the quantified measurement of the function of a product. This functional unit should be as precise as possible. When doing comparisons in a study, the functional units of all product systems have to be identical. For example, when comparing incandescent light bulbs and LED light bulbs, we should not compare one unit of incandescent bulb with one unit of LED bulb because they have different life spans and performances. Instead, the functional unit could be set based on the amount of light needed to illuminate an area, such as, 'lighting a standard room of 15 square meters with 1000 lumen for 1 hour' (Curran, 2015). Here the functional unit is not based on the production amounts but based on the performance of both products. It is also expressed with as many details as required, area of illumination ($15m^2$) and the amount of light (1000 lumen) during a period of time (1 hour). After scoping the functional unit, reference flow will be defined. The reference flow interprets the functional unit as a specific, measurable number of products. In other words, the reference flow will measure how much material and how many product units that is required to fulfill the functional unit. For comparative LCA study, the reference flows set an equivalent basis to compare products alternatives and there are three aspects that need addressing: difference in performance of systems, differences in price and time consumption, effects on productivity (Consequential-lca, 2020)

This phase describes the impact categories as well. These categories include different types of emissions to the environment (air emissions, water emissions, and solid wastes) and are classified into global warming, eutrophication, acidification potential, …Air emissions include regulatory agencies like pollutants, together with non-regulated emissions like carbon dioxide. Some of the common air emissions are carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrogen oxides (NO_x), and sulfur dioxide (SO_2). Water emissions include all substances classified as pollutants. Some of the most common water emissions are acid, ammonia, biochemical oxygen demand (BOD), chemical oxygen demand (COD), chromium, dissolved solids, iron, and suspended solids. Solid wastes are wastes that are landfilled or incinerated with or without energy recovery (M.A, 2017). Each impact category relates to one or more areas of protection: Natural Resources, Natural Environment, Human Health (see figure 4 (JRC, 2010)).

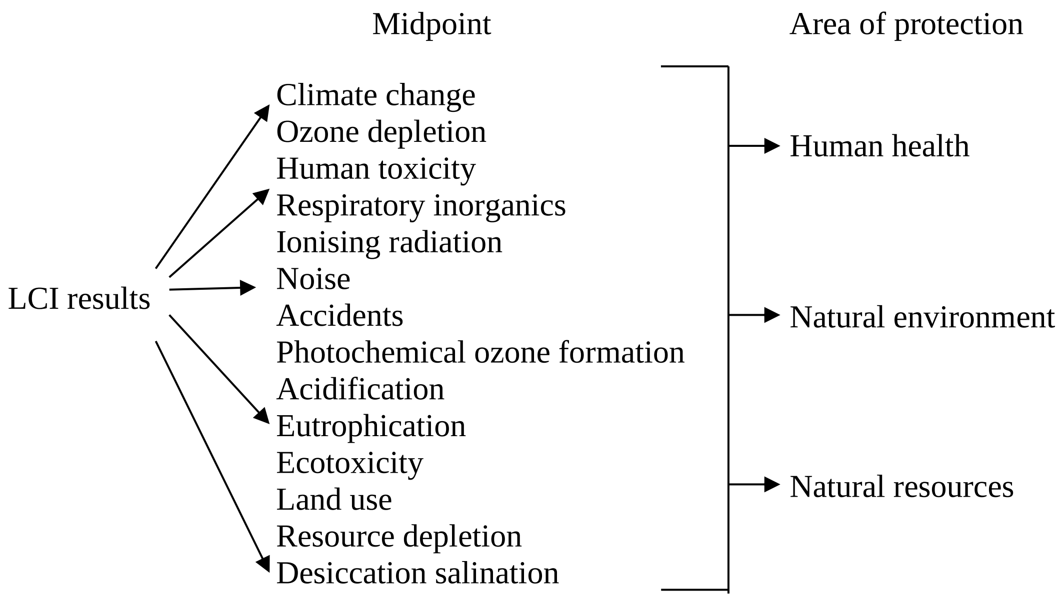


Figure 4: Relationship between impact categories and areas of protection (JRC, 2010)

The second phase in a life cycle assessment study consists of data collection and inventory compilation. After the goal and scope are defined, the next step is to collect the data which is everything that goes in and out of the system. The inventory consisting of those inputs and outputs of the system is call life cycle inventory (LCI) The data, as well as all the processes and flows are then modelled to calculate the life cycle inventory. This is one of the most important phases in a LCA study and the process of gathering data also takes the most time of a study. The inventory or the information must be complete and accurate in order to achieve the best overall results.

To construct a life cycle inventory, detailed information about both inputs and outputs is required. Inputs include natural resources, various forms of energy, raw materials, products such as parts or services or waste for treatment, waste for recovery. Outputs include products, emissions and pollutants to the environment (emissions to air, water and land) and waste for treatment. All of this data is needed for modeling of all the processes and flows within the system boundary and for further calculation of the life cycle inventory. Basically, we need to gather and document the following types of data for the life cycle inventory. According to Curran, the following information is needed to construct a life cycle inventory (Curran, 2015):

- Basis, time period, location of the process and facility
- Types, origins, and quantities of material inputs
- Mode and distance of incoming transportation of material inputs
- Types and quantities of useful outputs (final products, co-products, scrap)
- Types and quantities of freshwater inputs
- Types and quantities of emissions to air
- Types and quantities of emissions to water
- Types and quantities of emissions to land

The data gathering process requires collecting quantitative and qualitative data for every type of inputs and outputs in the system. Quantitative data is data that can be measured and quantified, and qualitative data cannot be measured but shows other characteristics. Data comes from different sources that are classified into two big groups, primary data and secondary data. Collection of primary data comes from on-site measurements or existing commercially databases. Secondary data comes from statistics and literature. Data that has been gathered will be then validated because the accuracy and the quality of data directly affect the final results in a study. Depending on how the system boundary is defined, the number of inputs and outputs can vary from a few to hundreds, however, all collected data must be related to the functional unit and the description of stated goals and scopes. Figure 5 (S. M. Shafie, et al, 2012) shows an example containing a table of inputs and outputs for an inventory from a LCA study of electricity generation from rice husk in Malaysia.

Flow	Unit	Input	Output
1. Paddy Field			
Fertilizers	kg/ha		
Nitrogen as N		55	
Phosphorous as P_2O_5		22	
Potassium as K_2O		15	
Herbicides		44	
Diesel used for farm	MJ/ha	2717.82	
Transportation	kg*km	33600	
Seed	kg/ha	140	
Water	m^3	144000	
Rice grain	kg		45600
Rice straw	kg/ha		3800
2. Rice Mill	kg		
Rice grain		45600	
Electricity	kWh	139.98	
Transport	kg*km	2188800	
3. Electricity generation			
Rice husk		10032	
Electricity produce	MWh		1.5

Figure 5: An example of LCI material inputs and outputs (S. M. Shafie, et al, 2012)

Another characteristic can be encountered when building inventory is co-product allocation. Allocation happens if a process generates more than one useful output. Besides the main product as an output of a process, there can be other co-products. The flows of these products and co-products need to be partitioned properly according to their relative contributions. However, the ISO series 14000 advises to avoid such allocation and partitioning. This can be done by expanding the system boundary or dividing the target process into smaller processes which would not result in co-product allocation. In case allocation is compulsory, partitioning should be done based on physical relationships and properties of the products. Two of the basic properties used for allocation are mass and energy. For instance, allocation by mass is to partition all inputs and outputs according to the mass ratio and it is important to partition all upstream unit processes. (Klöpffer, 2014)

ISO 14040 series (2006) defines a unit process as "Smallest element considered in the life cycle inventory analysis for which input and output data are quantified." (Life Cycle Initiative) Building a life cycle inventory is to quantify all the inflows and outflows for each and every unit process. Usually, all unit processes are connected by flows and there are two types of flows, elementary flows and intermediate flows. Elementary flows include energy and raw materials that enter and leave the system boundary to the environment without human transformation. Elementary flows need at least three elements to be identified. The first element is name of the material or energy (such as electricity, freshwater or aluminium). The second one is the flow context which is the origin and destination of the flow (for example, emission to water). The last one is flow unit such as mass (kg), volume (m^3) or energy unit (kWh). Elementary flows are important input used in LCIA method. These flows are classified and characterized with a respective factor, or unit of impact per unit of flow. These elementary flows in LCI have to match with those in LCIA sources to do assessment. (A, 2017) The impact assessment computation which uses results from LCI and LCIA method will be discussed in the next phase.

It is also important to note that even the system boundary was defined in the first phase, it, however, may be redefined here in order to avoid conflicts such as the co-product allocation mentioned above and new cut-off rules could be introduced to the system. For example, to manufacture a phone, every part and detail requires different materials, machines, and processes, moreover, producing these materials and machines also needs other materials and other machines, and so on. Therefore, there could be a lot of upstream processes that are not necessarily included within the study's concerns. Additionally, inputs and outputs that are negligibly contribute to the whole process could be cut off as well. Sometimes, data for some processes could not be collected or gathered in time for the study. However, we still need to consider carefully before applying any cut-off rule and estimate if the errors are tolerable. Omitting some materials could be harmful to the study and affects the accuracy of the overall results. Usually, criteria used to decide cut-off rules involve mass contribution, transportation of products or some types of tools and equipment.

Life cycle impact assessment is the third phase of a life cycle assessment study. During this phase, the results from the previous phase, life cycle inventory, are calculated and converted into relevant units corresponding to each concerned environmental impact category. The environmental impact categories should have been chosen beforehand in the goal and scope section and this phase will help to quantify as well as evaluate the significance of the potential environmental impact. First, LCI results will be classified and assigned to one or more environmental impact categories. Some commonly analyzed impact categories and emissions that contribute to each category include:

- Global warming potential: CO, CO_2, CH_4, N_2O
- Acidification potential: SO_2, NO_x, HCl
- Eutrophication: PO_4, NH_3, NO_x

in which substances such as CO, CO_2, CH_4, SO_2, NO_x, HCl are all emissions to air and PO_4, NH_3 are emissions to water. Other impact categories can include ozone depletion, abiotic depletion fossil, freshwater aquatic ecotoxicity potential.

The last phase in a life cycle assessment is the life cycle interpretation. After the inventory is calculated and all impact categories are computed, the findings will be reviewed and evaluated. The results of the study that already fulfil the goal and scope described in the first phase would be summarized in this phase. Life cycle interpretation also explains limitations and contribute recommendations relevant to the initial purpose of the study.

In general, interpretation mostly evaluates the completeness, sensitivity, and consistency of the study. Based on those results, interpretation should also identify the important issue, draw the conclusions of the whole study as well as discuss limitations of the study, and recommendations (Mohan, 2018).

The three main factors of an evaluation are completeness check, sensitivity check and consistency check (see Figure 6) (Nogueda, 2013). Completeness check confirms that all data in the study is complete and transparent. Sensitivity check evaluates the accuracy and credibility of the conclusions. Consistency check examines whether the methodologies and data used in the study are consistent. In addition, the evaluation should be presented in a way that offers with a straightforward and understandable conclusion for other interested parties (Umberto Desideri, 2018). Based on the choices of inputs, outputs and assumptions determined in the study, the life cycle interpretation could make recommendations about other possible approaches or further improvement for the study.

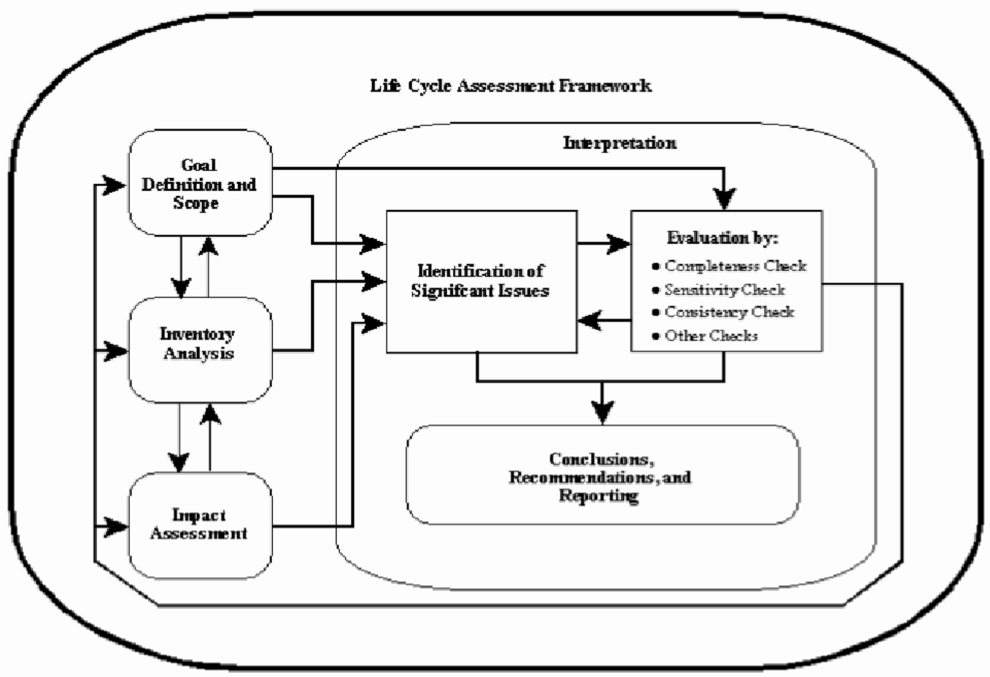


Figure 6: Interpretation in relation with other phases (Nogueda, 2013)

The final step of the LCA study is to prepare a final report where all data and methodologies are presented in an organized manner. The report should include the following information (Curran, 2015):

- Administrative information:
  - Name and address of conductor of the study,
  - Date of report,
  - Contact information
- Definition of goal and scope
- Life Cycle Inventory: data collection and calculation
- Life Cycle Impact Assessment: methodology and results
- Life Cycle Interpretation:
  - Results,

  - Assumptions and limitations,
  - Data quality assessment
- Critical review
  - Name and affiliation of reviewers
  - Reports
  - Responses to recommendations

3 BENCHMARK

The LCA study was conducted in accordance with the ISO 14040 series standards. This study also utilized GaBi software Education version for the inventory assessment phase. Therefore, a life cycle plan of a benchmark would initially be set up with GaBi software. The datasets built in GaBi mainly provided the flows' inputs. Based on those data, the software computed the environmental impacts of the benchmark and then the environmental hotspots would be identified and interpreted.

3.1 Goal, Scope and Definition

The goal of this LCA study was to evaluate the environmental impacts of food trays that are used to contain meat. The study targeted a type of polypropylene tray widely consumed in Finland and can be found at almost any market, a single tray can generally deliver from 400 to 500 g of meat. This type of trays is made from 100% of polypropylene. Meat trays are produced and consumed inside Finland. The results of this sample was then appointed to be the benchmark. From there, new sceneario models would be constructed in order to improve the product.

The data of inputs and outputs and processes in the system were partly based on the on-site measurements, or came from industrial insights, software database and other assumptions.

Functional unit analyzed was 100000 units of meat tray where each tray is able to contain from 400 to 500 g of meat. A single tray whose size was approximately 17.5 x 16 x 5.2 cm^3 weighted 20 g (Figure 7). The reference flow was 100000 trays or 2000 kg of polypropylene required to manufacture such number of trays.

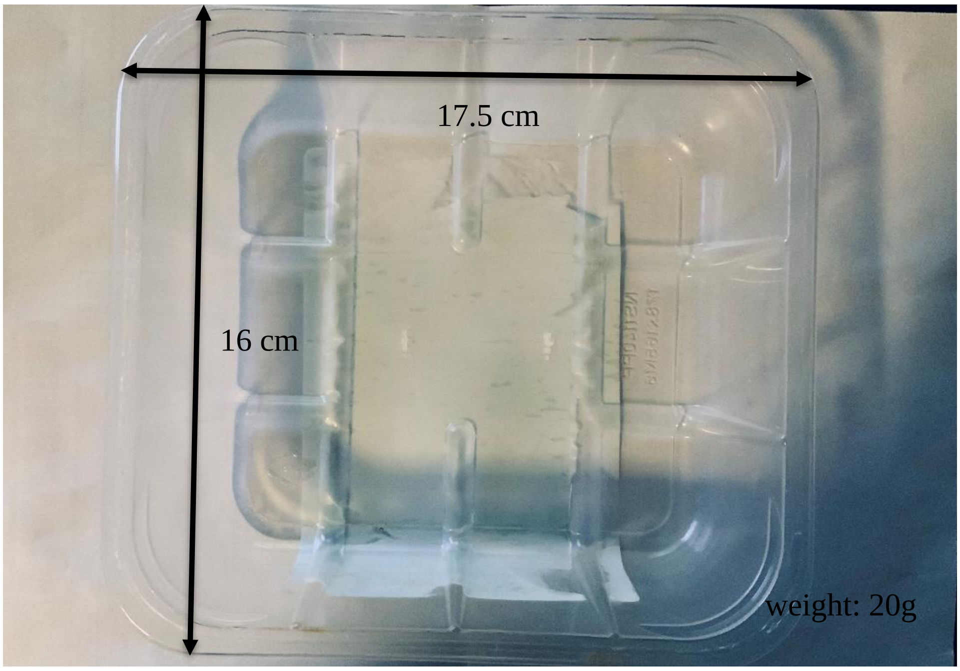


Figure 7: A representative product for the benchmark (100% PP meat tray, consumed in Finland)

For the material needed to produce the meat trays, we used polypropylene. According to some statistics, Germany has been Finland plastic import largest partner (WITS, 2021), therefore this study assumed that raw material was in granulate form, exported from Germany, transported to Finland by cargo and then delivered to the factory by truck for manufacturing. The weight of each tray was 20 g, therefore, the reference flow would be 2000 kg PP to produce 100000 units of meat trays.

The study analyzed a system boundary from cradle to grave. Figure 8 below shows the system boundary and unit processes in the system.

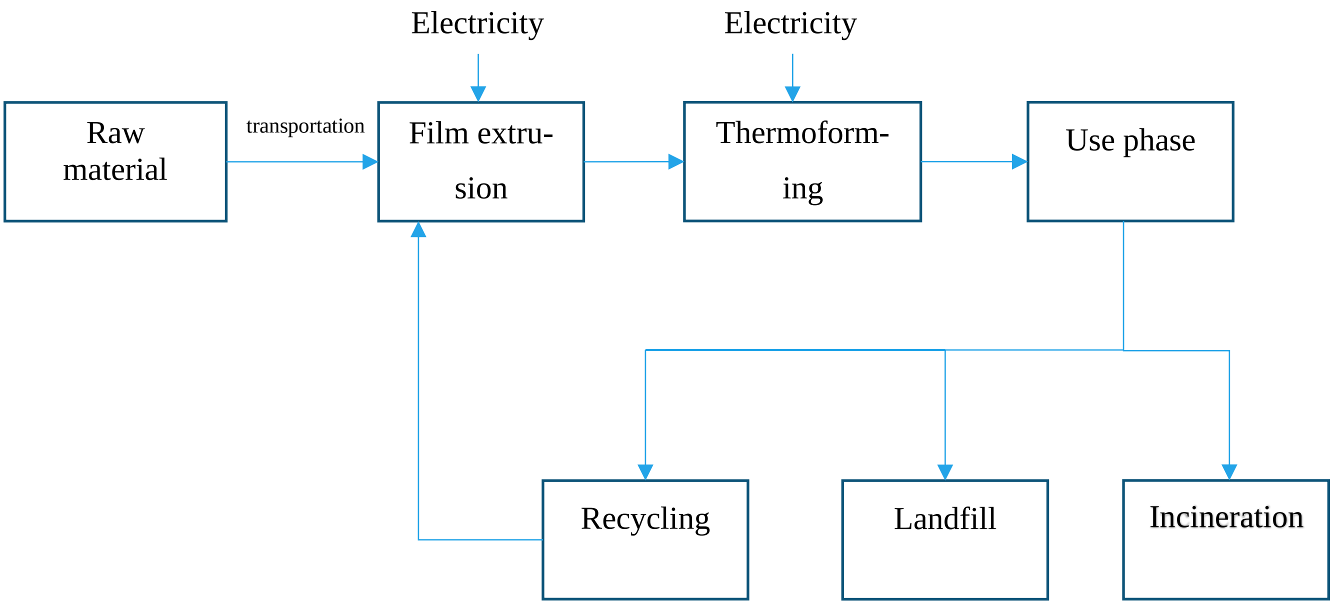


Figure 8: Defined system boundary of this study

The production system starts from raw material that originates from Germany. The material will then be transported to the manufacturer via cargo on sea and truck on land. Based on the conventional knowledge and some industrial insights, once the raw material reaches the destination, it undergoes two plastic processing phases in order to produce meat trays. The first process is film extrusion: PP granulates are melt and extruded into rolls of film. This phase mostly uses electricity as energy to operate and water or air for the cooling stage. Next, PP film will be thermoformed into final products. Thermoforming also consumes electricity. After the trays are being used, they will become household waste and from here there are several ways to handle the waste. One of these options is combustion; a portion goes to land fill and the rest will be recycled. The recycled fraction could be considered to be reused in the first manufacturing process. For the purpose of this study, the portions of household waste that go to incineration, recycling and landfill were 70%, 20% and 10%, respectively. This allocation was an assumption and worked as a benchmark for additional improvements.

Two processes of the system that resulted in allocation were film extrusion, thermoforming and solid waste treatment. The first two processes, besides main products PP film and meat tray, also produced a small amount of PP scrap. The scrap accounted for 2-4% of the total initial material and most of it was reused for film extrusion. Therefore, this insignificant amount of PP scrap can be negligible.

There were a few cut-off rules applied to simplify the study: water use neglected, PP scrap during extrusion and thermoforming was ruled out from the system and transportation for after-use phase did not involve.

Data sources employed in the study mainly came from public sources, GaBi database (GaBi LCA Databases), industrial insights and assumptions.

Due to the use of plastic and production of PP, we want to assess global warming potential, acidification potential and abiotic depletion potential. Some additional categories were recommended for an overall and well-rounded approach. Environmental impact categories introduced in this study include global warming potential, acidification potential, ozone depletion, eutrophication, abiotic depletion fossil, and freshwater aquatic ecotoxicity potential. These categories modelling was guided by CML 2001 Methods (Guinée, J.B., et al., 2002)

3.2 Inventory analysis

The main processes and flows in the system are explained in this section. To prepare for the next step, which involves calculating and convert the collected data into equivalent environmental impact factors, a systematic plan with all the processes and inputs is required.

Note that most energy, fuel and material input data would be taken from the available GaBi database. As calculated in 3.1 Goal, Scope and Definition, the number of products studied are 100000 units. However, we would input the data for one unit first and then set the scale factor to 100000 in the software to achieve results for the intended amount.

Raw material imported is polypropylene granulate from Germany. The amount of propylene needed to product one unit of meat tray is 20 g or 0.02 kg. To transfer the raw material to destination or a manufacture, the following types of transportation were operated. Cargo is a common and cost-effective way to import goods from abroad to Finland.

A reasonable choice from GaBi includes container ship 5000 to 200000 deadweight tonnage fuelled by heavy fuel oil. Then next means of transportation are run by truck whose gross weight is up to 7.5 tons. Fuels to operate ship and truck are heavy fuel oil (1.0 wt.%) and diesel mix at refinery, all of which are available from GaBi database. The distances by sea and by land were approximated to 1000 km and 300 km, respectively.

The main processes in the system involved plastic processing methods. Granulate PP was first extruded into sheets of PP. These sheets would then be thermoformed to obtain PP meat trays. Both processes made use of electricity to operate and the input electricity needs calculating. Each process consumed a different amount of energy and it depended on the specific energy consumption. It is generally not straightforward to decide the specific energy consumption for any type of plastic processing, for there are many factors directly influence the results and they vary with different materials and condition. The European Commission's Reduced Energy Consumption in Plastics Engineering (RECIPE) program surveyed various facilities and summarized the average specific energy consumption in Table 2 (Focus_on_energy, 2006)

Type of plastics processing	Specific energy consumption (kWh/lb of polymer)
Thermoforming	2.803
Rotational Molding	2.644
Compression Molding	1.437
Injection Molding	1.414
Profile Extrusion	0.683
Film Extrusion	0.611
Fiber Extrusion	0.386
Compounding	0.286

Table 2: Average Specific Energy Consumption by Plastic Process (Focus_on_energy, 2006)

The processes in this study comprised of film extrusion and thermoforming. The specific energy consumption and total energy consumption were calculated as the following:

- Specific energy consumption for thermoforming: 2.803 kWh/lb = 6.179 kWh/kg
- Specific energy consumption for film extrusion: 0.611 kWh/lb = 1.347 kWh/kg
- Energy needed to produce a single tray in two processes:
  - Film extrusion: 1.347 kWh/kg x 0.02 kg = 0.027 kWh
  - Thermoforming: 6.179 kWh/kg x 0.02 kg = 0.124 kWh
- Total energy to process 2000 kg of material in each process:
  - Film extrusion: 1.347 kWh/kg x 2000 kg = 2694 kWh
  - Thermoforming: 6.179 kWh/kg x 2000 kg = 1240 kWh

The two processes also generated, besides main products, PP scrap. However, as mentioned, the portion of scrap makes up only about 2% of the total weight and will be neglected in the system. After all these steps, a facility has produced 100000 PP meat trays. Up to this stage, the total amount of inputs and outputs are compiled and shown in Table 3.

Inputs/Outputs	Total	Unit
PP	2000	kg
Heavy fuel oil	4.61	kg
Diesel	47.5	kg
Electricity	3934	kWh
Meat trays	100000	unit

Table 3: Inputs and ouputs of transportation and production phases

In end-of-life phase, used plastic trays become municipal solid waste and will be collected, sorted and treated in different ways. A portion goes to incineration plant. The plant combusts the waste and recovers some energy from that. A portion is recycled and reused, in this case, recycled plastic contributes back to produce more plastic trays. Waste that cannot be recovered or recycled goes to landfill to decompose over time.

According to some sources, most polypropylene products are recycled and combusted (Thomas, 2012). It is safely to assume, for the purpose of this study, the waste allocation to incineration, recycling and landfill in percentage is 70%, 20% and 10%. In GaBi software, we built a precise plan (Figure 9) whose layout was in accordance with the system boundary mentioned above and the flows were chosen from the database as discussed so that they represented the industry as close as possible.

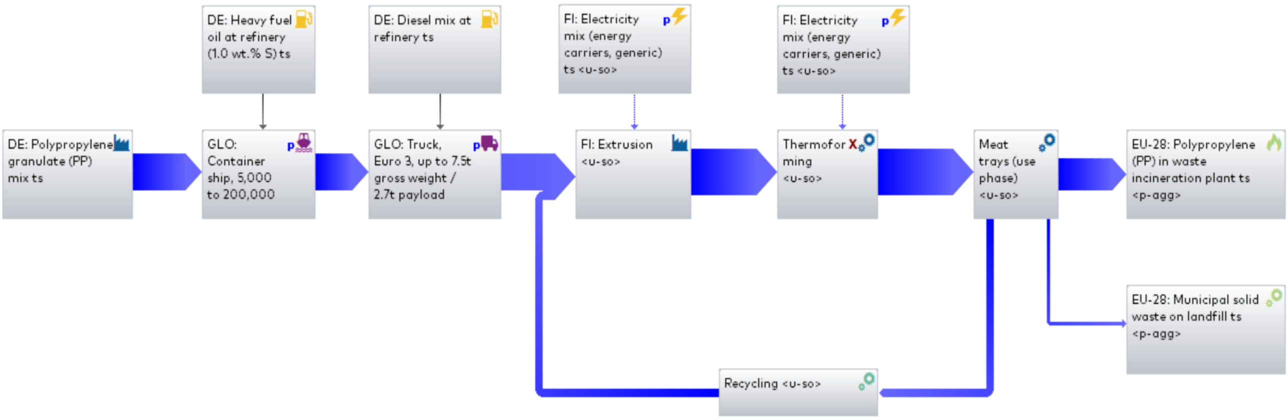


Figure 9: Life cycle of a polypropylene meat tray in GaBi plan

The following settings were established to construct a complete plan:

- Material (from database): DE: Polypropylene granulate (PP)
- Distance by container ship: 1000 km (Fuel: DE: Heavy fuel oil at finery 1.0 wt. %S)
- Distance by truck: 300 km (Fuel: DE: Diesel mix at refinery)
- Electricity: FI: Electricity mix
- Properties for 1 unit of tray:
    - PP mass: 0.02 kg
    - Electricity (film extrusion): 0.027 kWh
    - Electricity (thermoforming): 0.123 kWh
    - Waste to landfill 10%: 0.002 kg
    - Waste to incineration 70%: 0.014 kg
    - Recycled 20%: 0.004 kg
- Fixed process: Thermoforming
- Scale factor: 100000

In GaBi, incineration and landfill processes are guided by EU standard and they generate a total of 9403.3 MJ of electricity and 16600 MJ of steam.

3.3 Impact assessment and interpretation

LCIA results were computed and reported in different environmental impact categories. The results will be analyzed and compared between all flows or processes under the same category.

Global Warming Potential (GWP)

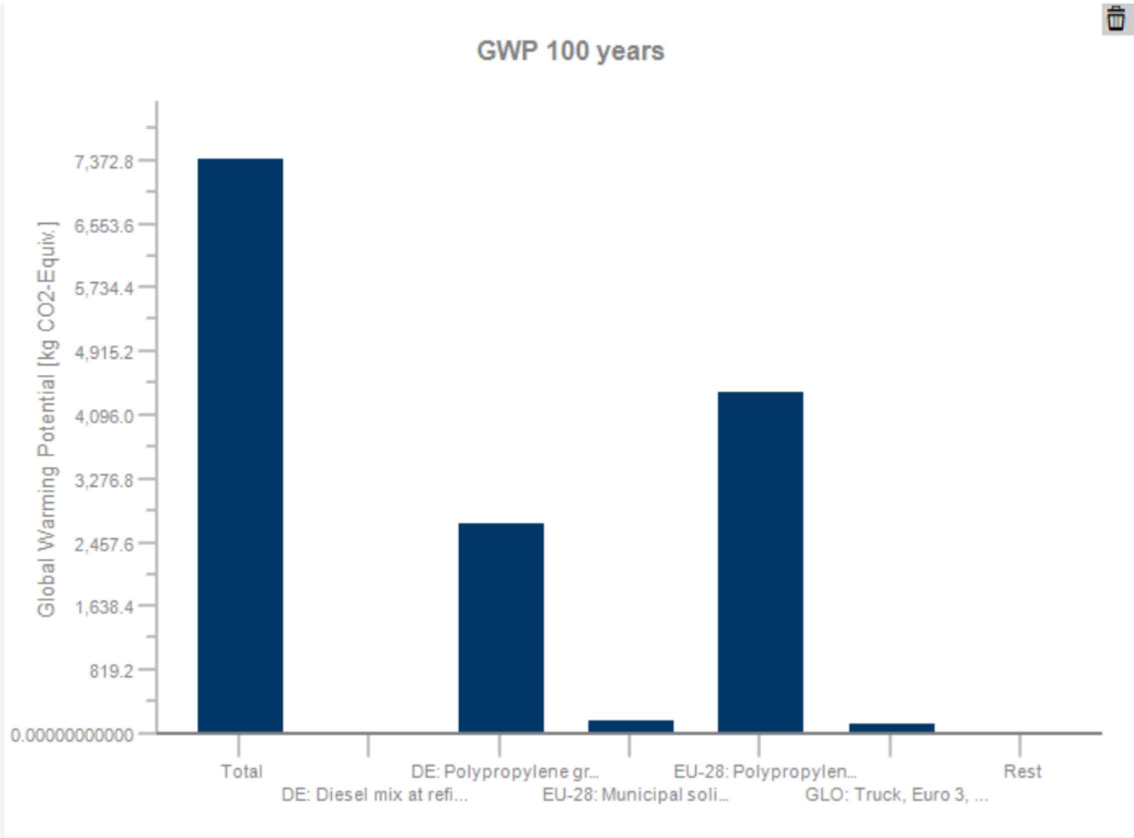


Figure 10: Global warming potential result for the benchmark parameters

Figure 10 shows the impacts to global warming contributed by all flows in a life cycle of the studied product. Every emission to air that contributes to global warming is converted to CO_2-eqv (kg). The total CO_2-eqv emitted is 7391 kg. Incineration of PP solid waste contributes the most to global warming impact, 4380 kg CO_2-eq (59.27% of total impact). This is followed by the contribution of raw material, PP granulate, which contributes about 2700 kg CO_2-eqv (36.54% of total impact). The production of PP or plastics in general significantly causes environmental issues. The whole procedure, starting from extraction of fossil fuel to cracking and synthesizing plastics, emits tons of carbon dioxide per year (Bauman, 2019). Waste incineration also releases various greenhouse gases which greatly raises the global warming potential.

Acidification Potential (AP)

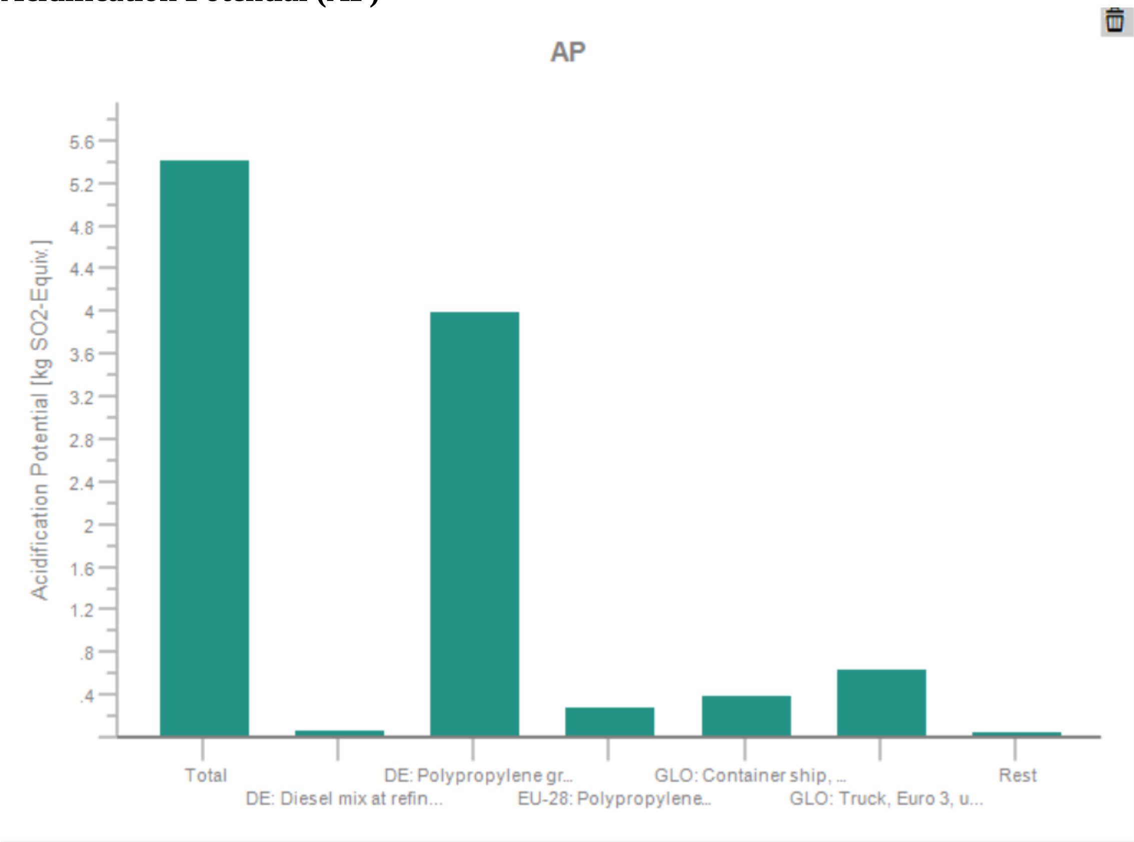


Figure 11: Acidification potential result for the benchmark parameters

Acidification potential has SO_2-eqv for the equivalent unit. The total amount of this impact category is 5.41 kg SO_2-eqv. The production of raw PP mainly contributes to acidification potential (3.99 kg SO_2-eqv, 73.75%). The rest splits between other processes, with a greater quantity to transportation due to burnt fuel and sulfur dioxide emitted by ships. For example, 0.635 kg SO_2-eqv (11.74%) from trucks and 0.388 kg SO_2-eqv (7.17%) from ships.

Ozone Layer Depletion Potential (ODP)

According to the Figure 12, meat trays' life cycle have no consequential effect on this category as the total ozone layer depletion potential is $1.89 \cdot 10^{-11}$ kg R11-eqv which is close to zero. The production of raw material significantly impacts the ozone layer depletion potential, up to 97.88% ($1.85 \cdot 10^{-11}$ kg R11-eqv) .The rest assigns to incineration process, which is negligible.

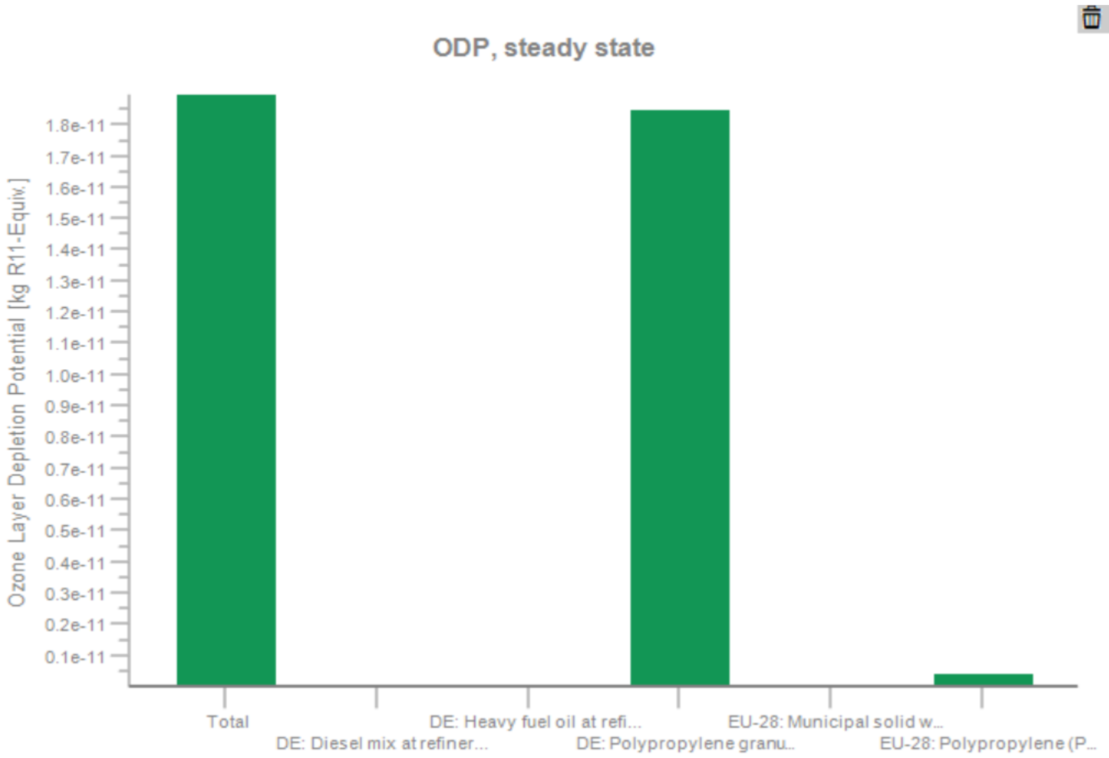


Figure 12: ODP result for the benchmark parameters

Eutrophication Potential (EP)

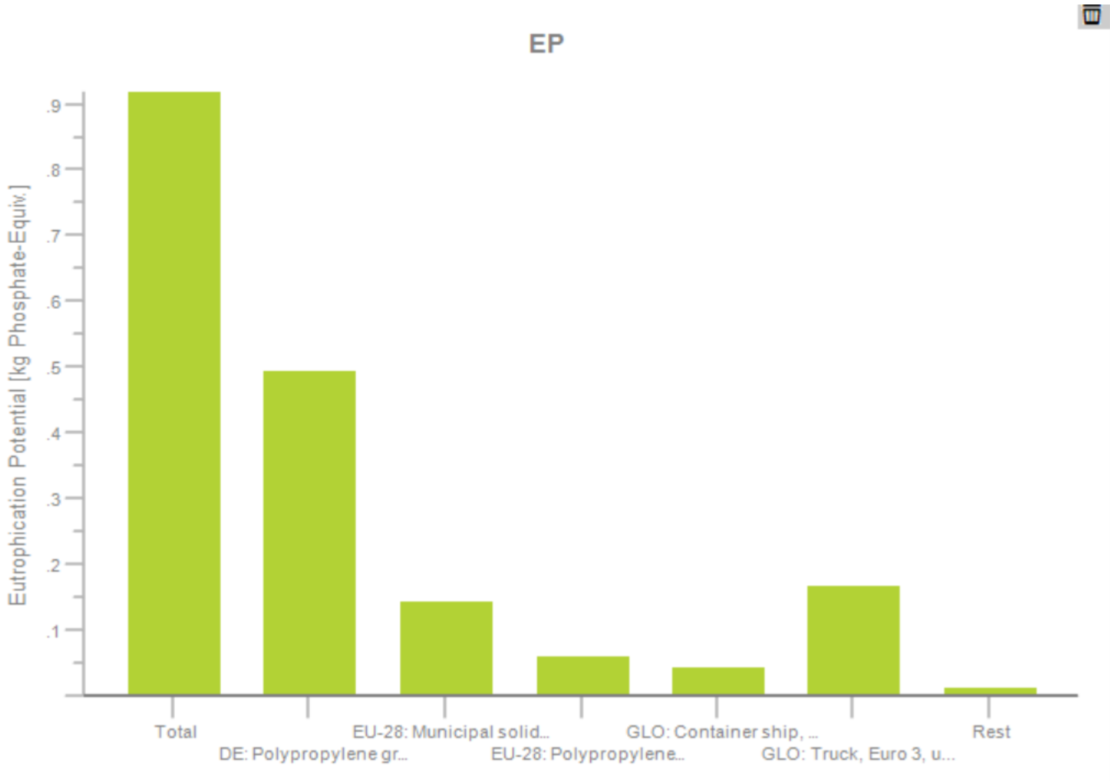


Figure 13: Eutorphication potential result for the benchmark parameters

Eutrophication is measured in PO_4-eqv. The whole system produces a total of 0.918 kg PO_4-eqv, in which production process of raw material make up 53.7% at 0.493 kg PO_4-eqv. Other portions are distributed unequally among all other processes. Landfill process emits 0.143 kg PO_4-eqv (15.58%), transportation by trucks and ships contribute 0.167 kg PO_4-eqv (18.19%) and 0.0434 kg PO_4-eqv (4.73%) respectively. Waste incineration process contribute 0.0598 kg PO_4-eqv or approximately 6.51%.

Abiotic Depletion fossil (ADP fossil) and Freshwater Aquatic Ecotoxicity Potential (FAETP)

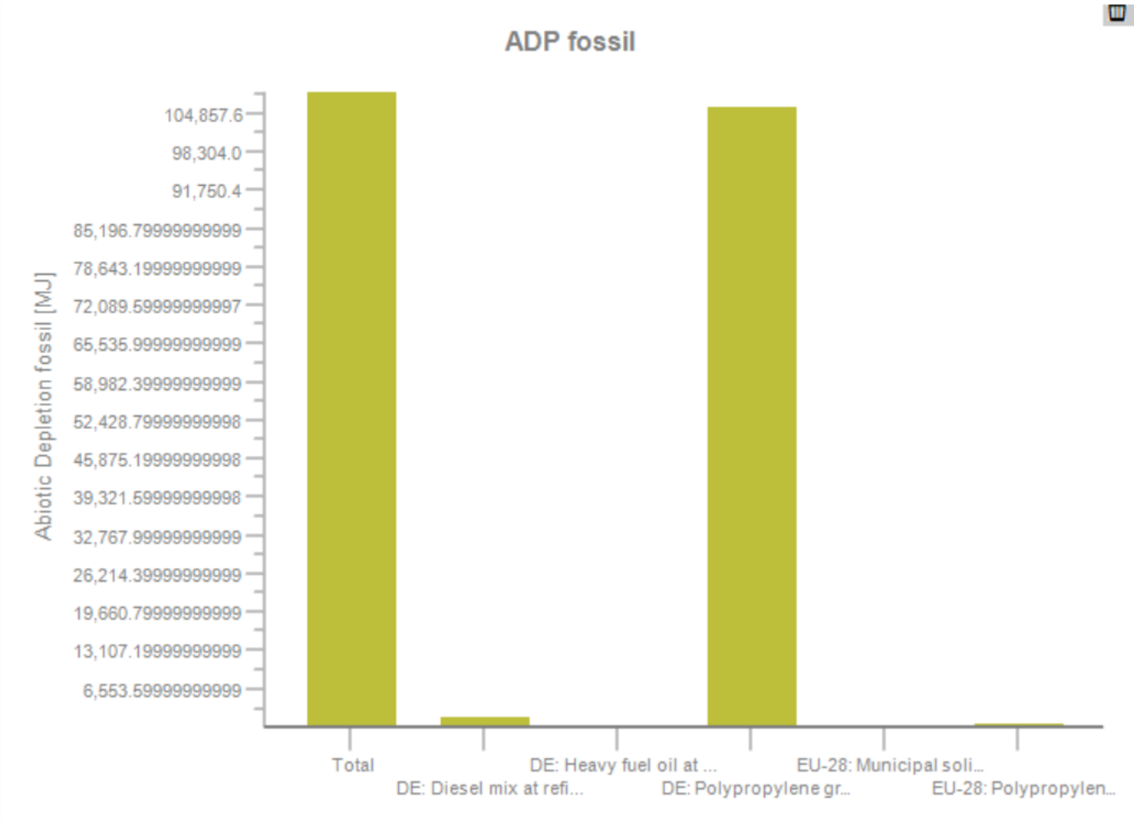


Figure 14: ADP fossil result for the benchmark parameters

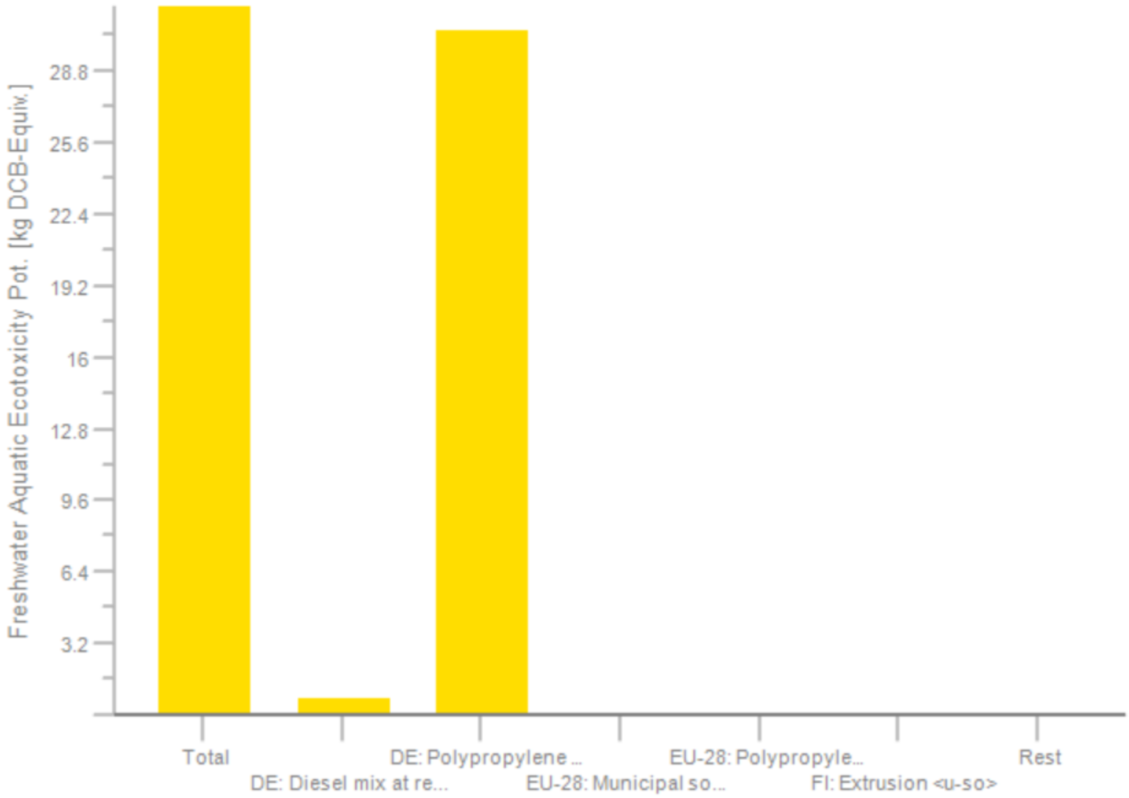


Figure 15: FAETP result for the benchmark parameters

The impacts in abiotic depletion fossil and freshwater aquatic ecotoxicity potential categories are shown in Figure 14 and 15. The total amounts are $1.08 \cdot 10^5$ MJ and 31.7 kg DCB-eqv. The main contributor to both categories is the production of polypropylene (98% of total ADP fossil and 96% of total FAETP). This is also due to emissions from procedures of fossil fuel extraction and refinement. Other processes such as film extrusion or incineration or landfill discharge some emissions to fresh water namely aldehydes and organic acids, adding only 0.4kg DCB-eqv to the FAETP.

All results of every environmental impact category for the benchmark parameters have been presented and the benchmark model's assessment was completed. In the next chapter, these results will be analyzed and concluded. We will also attempt to improve the product by constructing different scenarios and settings based on some potentially influential variables.

4 SCENARIO MODELLING

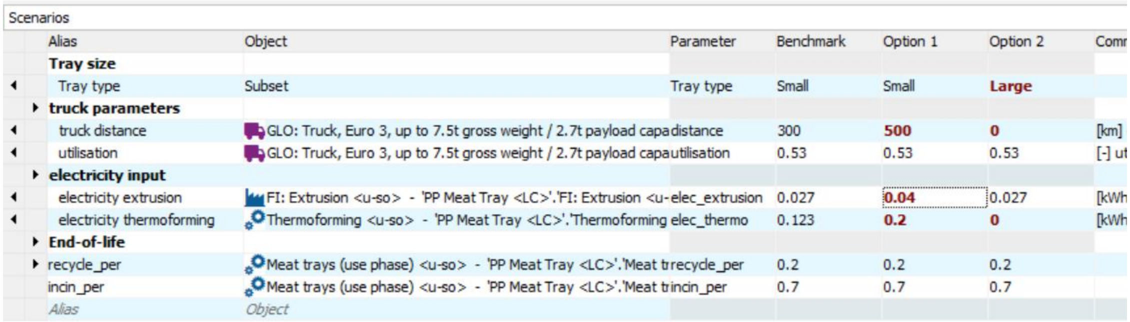
Based on the results from the preceding chapter, a life cycle of a PP meat tray mostly puts pressure on the global warming potential and abiotic depletion potential fossil. There are significant amounts of greenhouse gases (7390 kg CO_2-eqv) and natural fossil fuel resources depletion ($1.08 \cdot 10^5$ MJ) while some impacts have less than 1 unit of equivalent emission, such as ODP ($1.89 \cdot 10^{-11}$ kg R11-eqv) and EP (0.918 kg PO_4-eqv). The production of raw material has the major impact and makes up significant fractions on a lot of environmental impact categories. As discussed, fossil fuel processing generates various toxic emissions to air, water and land, which heavily increases the environmental potentials. Other considerable elements involve waste incineration and waste landfill. Incineration process emits mostly carbon oxides, nitrogen oxides, methane and numerous halogenated organic and inorganic substances, therefore, raises the global warming potential and acidification potential. Although the mainstream manufacturing processes, extrusion and thermoforming, release VOCs, particulate matters, aldehydes and organic acids but in very low amounts (2011), their impact fractions are negligible in most environmental impact categories. Finally, a slight contribution derives from transportation processes along with the usage of fuel.

In this benchmark study, there are a few variables that were approximated and assumed such as the energy input at two manufacturing phases or the end-of-life solid waste allocation. From the results above, we can certainly assume that the average values of specific energy consumption should work reasonably for this study since energy flows form negligible portions in any concerned environmental impact categories. On the other hand, waste allocation considerably affects the results, specifically in global warming potential and eutrophication potential. For instance, in the global warming potential category, waste incineration process contributes a large amount, up to 59%. The product can be improved by increasing the recycled waste volume, resulting in decreasing both the waste that goes to incineration plant and the initial plastic amount from production of material.

We ran different scenarios with different inputs using parameters feature built in GaBi. The results will be compared to the benchmark results in order to have a clearer view on how to optimize the PP meat tray life cycle.

The following scenarios were studied:

- Truck distance
- Subset for a larger tray with a weight of 30g
- Waste allocation



Scenarios

Alias	Object	Parameter	Benchmark	Option 1	Option 2	Comr
Tray size						
Tray type	Subset	Tray type	Small	Small	**Large**	
truck parameters						
truck distance	GLO: Truck, Euro 3, up to 7.5t gross weight / 2.7t payload capa	distance	300	**500**	**0**	[km]
utilisation	GLO: Truck, Euro 3, up to 7.5t gross weight / 2.7t payload capa	utilisation	0.53	0.53	0.53	[-] ut
electricity input						
electricity extrusion	FI: Extrusion <u-so> - 'PP Meat Tray <LC>'.'FI: Extrusion <u-	elec_extrusion	0.027	**0.04**	0.027	[kWh
electricity thermoforming	Thermoforming <u-so> - 'PP Meat Tray <LC>'.'Thermoforming	elec_thermo	0.123	**0.2**	**0**	[kWh
End-of-life						
recycle_per	Meat trays (use phase) <u-so> - 'PP Meat Tray <LC>'.'Meat tr	recycle_per	0.2	0.2	0.2	
incin_per	Meat trays (use phase) <u-so> - 'PP Meat Tray <LC>'.'Meat tr	incin_per	0.7	0.7	0.7	
Alias	*Object*					

Figure 16: Example of scenario modelling in GaBi used in this study

Truck distance

In the bechmark parameters, truck distanced was set to 300 km, which is an average distance of material transportation to a manufacturer. This variable would be modelled into a higher and a lower value to compare and evaluate the influence of truck transportation on studied categories. The distance was set to 150 km in option 1 and 500 km in option 2. Other parameters were kept the same as in the benchmark scenario. The results are summarized in Table 4.

Impact category	Benchmark	Option 1	Option 2
GWP (kg CO_2-eq)	7391.30	7324.83	7479.92
AP (kg SO_2-eq)	5.41	5.06	5.88
EP (kg PO_4-eq)	0.92	0.83	1.04
FAETP (kg DCB-eq)	31.70	30.26	36.11

Table 4: Environmental impact results for two truck distance settings

From Table 4, the results show that transportation distance does not immensely affect the overall environmental impacts because this unit process only makes up a small portion in each impact category as mentioned in chapter 3. In the first setting, global warming potential is cut by 66.47 kg CO2-eq, corresponding to 0.9% of the benchmark result. Even in eutrophication potential category where the transportation phase by truck takes about 18%, reducing the distance by a half results in 10% less in total quantity. However, if we examine only the affect from transportation process by truck and the diesel flow to global warming potential and acidification potential (Figure 17), we can observe that the emissions in CO_2-equivalent and SO_2-equivalent increase linearly with the distance. The distance of transportation depends on the location of manufacturing facilities and is difficult to adjust or to improve but it should still be considered, especially in the long run.

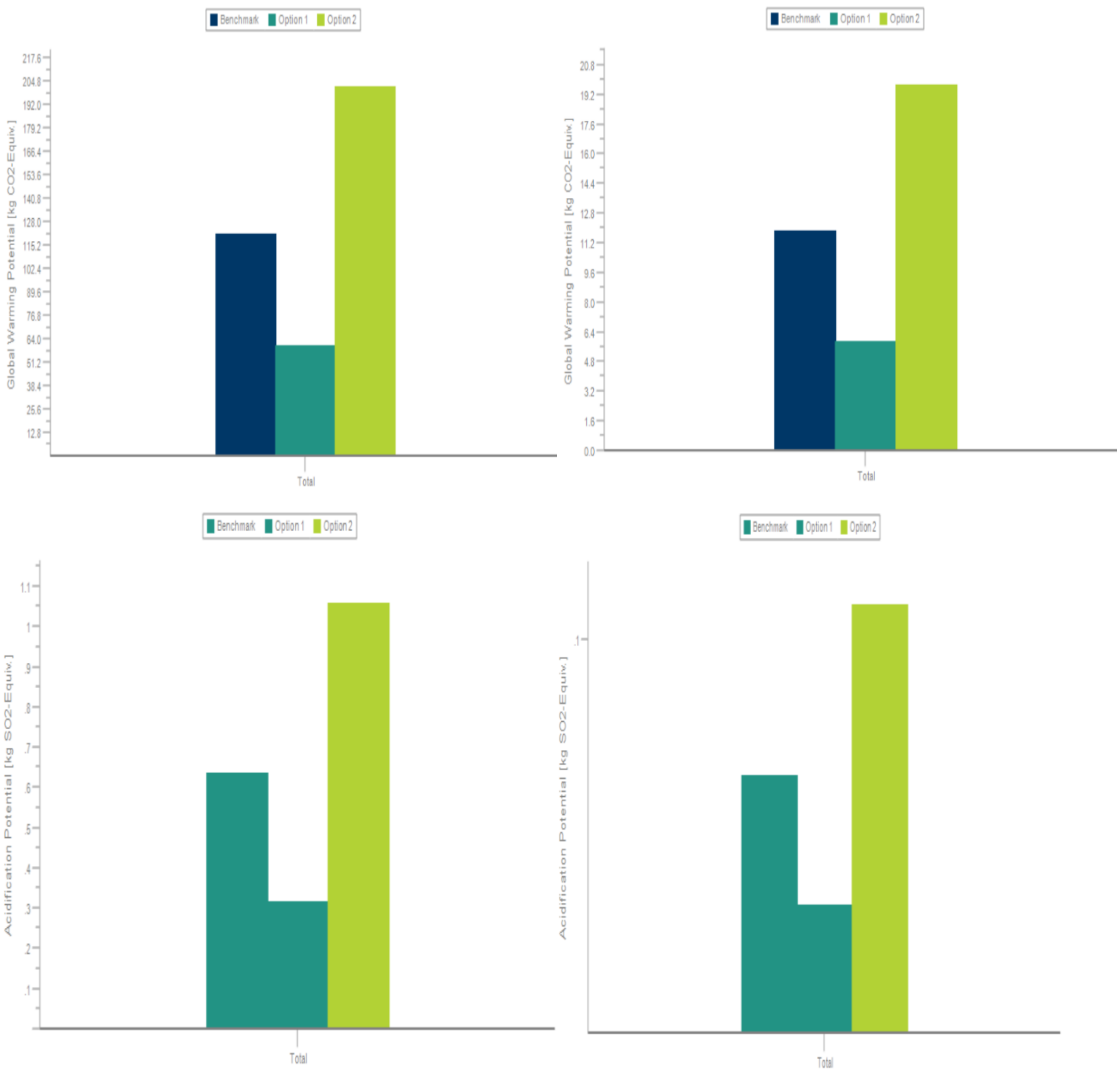


Figure 17: Contribution to GWP and AP of Truck (left) and Diesel (right)

Replace with a larger tray

One of the alternatives for the 20 g PP meat tray in the market is the larger meat tray that weighs 30 g. These trays are also made from 100% PP but can deliver about 800 to 1000 g of meat or poultry.

To properly conduct a comparison between two types of trays, we need to define a new functional unit more precisely for this case, that is, the number of 30 g trays that can contain a same amount of meat as 100000 of 20 g trays. Because a 30 g tray may contain double the amount of meat that a 20 g tray does, the total quantity of new 30 g tray would be 50000 units. Therefore, 1500kg of raw PP will be required, which is 25% less material than in the benchmark scenario. Other input parameters remained the same. Environmental impacts were recalculated and presented below. During benchmark study, the results show significant burdens on global warming potential category, abiotic depletion potential (fossil) category, and some influences in FAETP category, so this scenario focused on analyzing these environmental impact categories and comparing to those of the benchmark (Figure 18, 19, 20). For more references, other categories' results are summerized in Table 5.

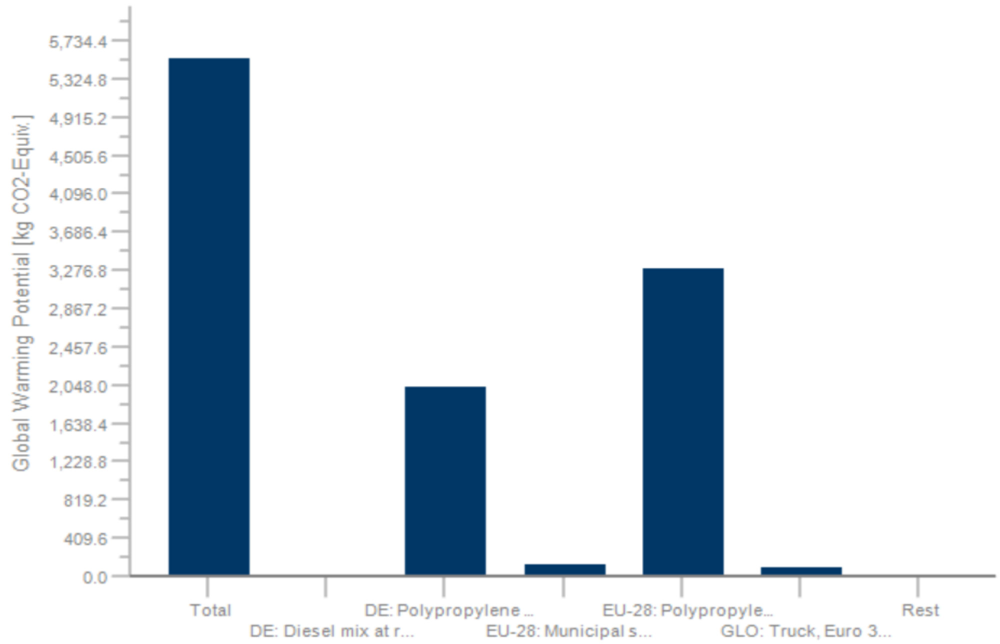


Figure 18: Large tray GWP result

Figure 18 represents the result of global warming category. The whole system produces 5540 kg CO_2-eqv, lower than the benchmark by 1850 kg, or is equivalent to 74,97% of the benchmark total. Incineration and raw material production are still the two processes that emits major air pollutants. Replacing 20 g trays with 30 g trays certainly lessens the impact to global warming by a large amount (25.03%) while fulfilling the original purpose of the final product.

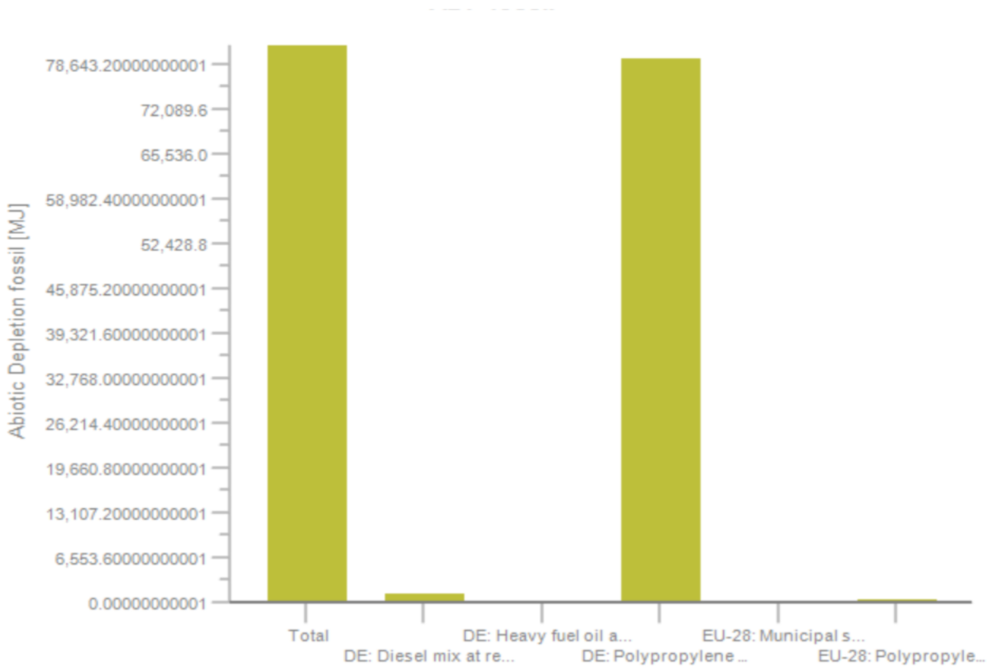


Figure 19: Large tray ADP fossil result

The total abiotic depletion value falls from $1.08{\cdot}10^5$ to $8.14{\cdot}10^4$ (Figure 19). This is converted to 24.35% in reduction. The production phase makes up 97.54% ($8.14{\cdot}10^4$ MJ). The shares between processes that directly contribute to this category are roughly the same as those in benchmark study. Similar to GWP and ADP fossil, emissions to freshwater also drops by 25% (Benchmark: 31.7 kg, Larger tray: 23.8%).

To sum up, each studied environmental impact decline proportionally with the input material mass in this scenario study. As the functional unit is defined, 50000 of 30 g trays can deliver the same amount of goods as 100000 units of 20g trays can do while a life cycle of the larger tray generates less emissions to the environment and easier to produce and consume.

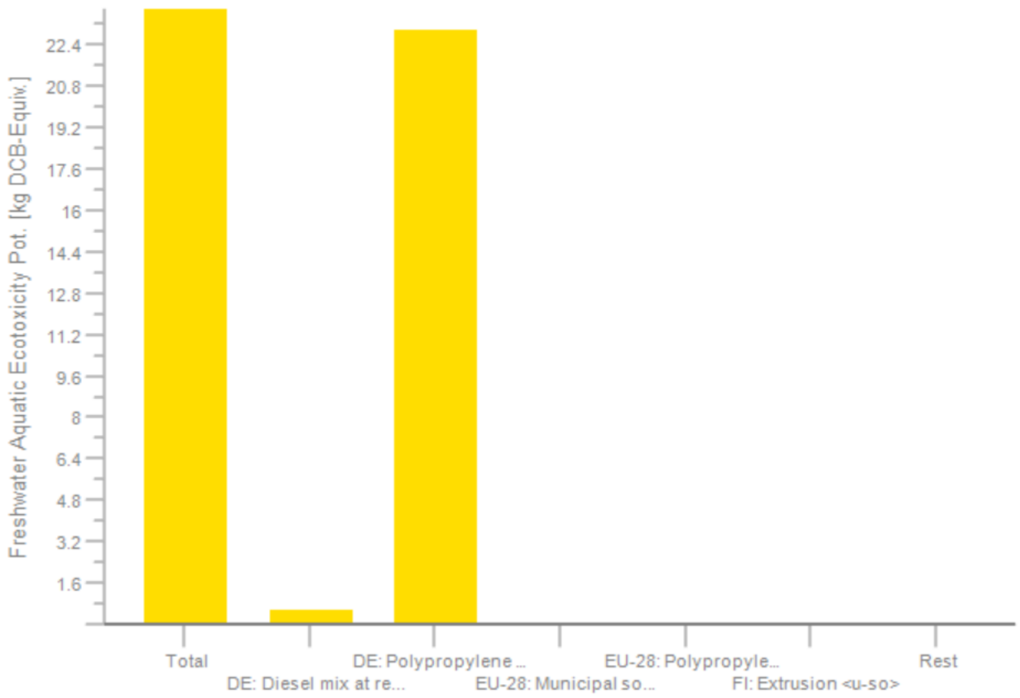


Figure 20: Large tray FAETP result

	Benchmark	Larger tray
GWP (kg CO_2-eq)	7391.3	5540
AP (kg SO_2-eq)	5.41	4.06
EP (kg PO_4-eq)	0.92	0.69
FAETP (kg DCB-eq)	31.7	23.8
ODP (kg R11-eqv)	1.89e-11	1.42e-11
ADP fossil (MJ)	1.08e05	8.14e04

Table 5: Large Tray results

Waste allocation

Initially, the percentage of recovered plastic, combusted waste and landfill was assumed to 20%, 70% and 10%, respectively in the benchmark. We increased it to 30% in both options, but for option 1 the combusted percentage covered 60% of total waste and for option 2, 65% was combusted and 5% went to landfill. The results are shown in Table 6 below.

It emerges that when we convert a portion of incinerated waste into recycled plastic (option 1), the environmental impacts will all lessen to different extents (13.3% for GWP, 12.4% for AP and FAETP, and 10.9% for EP). These fractions would drastically raise if the recycled and incinerated amounts were modified to 40% and 50% respectively. Although option 2 also manages to lower environmental impacts, the percentages of reduction are not consistent when compared to option 1. Option 2 reduces less emissions to GWP but more emissions to EP. For instance, in GWP category, option 1 reduces 13.3% of emission and option 2 reduces 10.1% while in EP category, option 1 reduces 10.9% and option 2 reduces 18.4%. However, both options lower the emissions to AP and FAETP by the same amount.

From these results, we can see that if we only focus on cutting incinerated waste total, more environmental impact in GWP can be deducted. However, if the cut off amounts from the incineration process and landfill process are distributed equally, we will benefit with less emissions to EP category. Since earlier in this study, it was analyzed that the environmental hotspot mainly lies in GWP category, option 1 has more advantages compared to option 2 as it reduces more global warming emissions.

	Benchmark	Option 1	Option 2
Incineration (%)	70	60	65
Recycling (%)	20	30	30
Landfill (%)	10	10	5
GWP (kg CO_2-eq)	7391.30	6409.06	6642.36
AP (kg SO_2-eq)	5.41	4.74	4.73
EP (kg PO_4-eq)	0.92	0.82	0.75
FAETP (kg DCB-eq)	31.7	27.77	27.71

Table 6: Results for two waste allocation settings

Even though recycling more plastic waste clearly enhances the product’s environmental friendliness, it is still necessary to consider which environmental aspect needs optimizing, deciding to combust or dispose more solid plastic waste or find a balance between the two approaches. In general, based on what has been calculated in this study, a PP meat tray’s life cycle inserts higher pressure into global warming potential than most of other environmental categories. This implies that a good method to quickly lower the overall environmental impacts involves cutting a portion of waste put into incineration plant, besides promoting the number of recovered raw material.

5 CONCLUSION AND DISCUSSION

In this study, a representative PP meat tray was chosen to demonstrate a LCA study case to evaluate the environmental impacts during a life cycle and identify hotspots of the same product. The study also set up various scenarios and attempted to find possible approaches in order to improve such product sustainably or further reduce emissions exhausted into the environment. The LCA practice focused on the following impact categories: global warming potential, acidification potential, eutrophication potential, ozone layer depletion potential, fossil fuel depletion potential and freshwater aquatic ecotoxicity potential.

The results showed that a life cycle of a PP meat tray, from cradle to grave, has led to significant environmental burdens regarding global warming and fossil depletion issues. Polymers in general or polypropylene as in this study have used up a huge supply of fossil fuels. More important, the practice of extracting and transporting fossil fuels emit various pollutants, including greenhouse gases and toxic substances to aquatic environment. However, statistics estimate that there is only a mild contribution to eutrophication potential and nearly none in ozone layer depletion potential category.

After different scenarios were analyzed, it can be concluded that there are various ways to improve the target product so that the environmental impacts become minimal. One of which involves redesigning the final product, take the inspected case in this study for instance, by substituting 20 g trays with 30 g trays, goods capacity is doubled per every unit while the total emission quantities could reduce up to 25%. However, not only manufacturers should innovate their technologies and their products, but consumers also need to be aware of the importance and different approaches to protect the environment. Recently, there have been more and more kinds of materials that are environmentally friendly and decomposable while staying convenient to use. Another way includes different approaches to waste treatment. The three major waste treatment methods are recycling, landfill and incineration. The results of an analyzed scenario revealed that by increasing the recovered plastic and balancing between the fraction of waste to incineration plant and to landfill, we can achieve an optimal way to cut off concerned environmental impacts.

Environmental issues and sustainable engineering have been growing and receiving more awareness. Generally, LCA is possibly one of the greatest tools for sustainable development. This study has not explored all application of LCA and there are still rooms for development such as optimization for alternatives and waste allocation. Further investigation can be done to construct a comprehensive framework for the same type of product with more skillful approaches.

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