Life Cycle Assessment of Stone Paper, Polypropylene Film, and Coated Paper for Use as Product Labels

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Abstract:

Environmental concerns are growing in today's societies, and governments, companies, and other organizations are looking to decrease the impacts on the environment from their products and the products they source. In order to do this, they need to know how a product is impacting the environment, and a life cycle assessment can help to understand the impacts of products and identify areas for potential environmental improvement.

This life cycle assessment analyzed the life cycle of three materials: coated paper, PP film, and Stone Paper, in the function of a product label. The aim was to perform comparative analysis of the materials by evaluating performance on multiple impact categories. From this analysis, information can be provided to decision makers and preliminary recommendations can be made to improve the life cycle of Stone Paper.

The results found that no material clearly dominated the other materials across all impact categories, but some general trends were identified. PP Film performed relatively poorly in fossil fuel related impact categories, whereas coated paper performed relatively poorly in land use and water depletion categories. Stone Paper fared relatively poorly in two human and environmental health impact categories. Strong general conclusions about the other impact categories cannot be made. Sensitivity analysis for transportation and end of life scenarios were carried out, and found a preference for short transportation distances for Stone Paper, landfilling for coated paper, and incineration for PP film were found.

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Table of Contents

Table of Figures

1 Executive Summary

1.1 Introduction

1.1.1 Project Background

Environmental concerns are growing in today's societies, and governments, companies, and other organizations are looking to decrease the impacts on the environment from their products and the products they source. In order to do this, they need to know how a product is impacting the environment, and a life cycle assessment can help to understand the impacts of products and identify areas for potential environmental improvement.

There are paper products on the market made from a variety of materials, and these paper products are used to make a multitude of finished products such as notebooks, posters, labels, and many others.

Taiwan Lung Meng Technology Co. Ltd. (TLM) is a company founded in Taiwan in 1998 to manufacture Stone Paper, a unique paper product also known as rich mineral paper and trademarked under various names around the world. This form of paper uses no wood pulp, and instead uses calcium carbonate as its main material, along with high-density polyethylene and additives.

This report contains a life cycle assessment (LCA) carried out to quantitatively evaluate the environmental impacts of Stone Paper compared to two competing products. The LCA takes into account raw materials extraction and processing, manufacturing processes, transportation, use, and end-of-life disposal stages that cover the entire life cycle of the product from cradle to grave. The report that follows is a comparative LCA of three options used for waterproof bottle labels, e.g. wine labels. The three types of label materials evaluated are:
1. Polypropylene film (PP film)
2. Coated paper
3. Stone Paper

The intent of this project is to provide an LCA for Stone Paper following the ISO 14040/14044 (2006) standards to assess cradle to grave environmental impacts and compare to coated wood pulp paper and oriented polypropylene film. This report is intended to communicate information on the environmental performance of each product. The LCA process results in a comparative analysis on the same measuring standard.

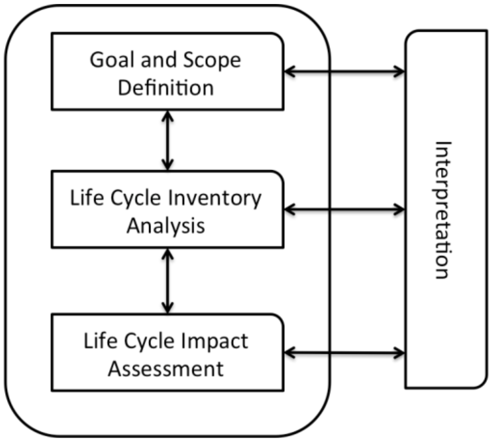
A team of three Masters students, Christopher Affeldt, Austin Leung, and Ke Yang, at the University of Michigan School of Natural Resources and Environment conducted this LCA study under advisement of Professor Ming Xu. This study was carried out according to the requirements of ISO 14040/14044 from February 2015 to April 2016. The report was requested by TLM, and the information will be shared with TLM and existing or potential distributors that have requested the information or may request it in the future. The intent is to provide a neutral analysis of the functional use of the materials selected.

1.1.2 LCA Overview

An LCA is a tool used to evaluate energy and raw material consumption, emissions, and other wastes related to a product or system's entire life cycle. It characterizes and quantifies the inputs, outputs, and environmental impacts of a specific product or system at each life-cycle stage[1]. Using this information, it is possible to identify which specific products or processes are major contributors to environmental harm, and improvements can be suggested to mitigate the effects of such areas.

As defined in the ISO standards, the LCA method has four phases, goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation, as shown in Figure 1. The stages of an LCA are summarized below.

Figure 1. LCA Framework Schematic Based on ISO Standards



Stages of an LCA:
1. Goal and scope definition: define the intended application and intended audience and define the boundaries of the product system studied.
2. Life Cycle Inventory (LCI): identify and quantify inputs and outputs of a product system throughout its life cycle rom raw material extraction through material production, manufacture and assembly, use, reuse or recycling where applicable, and end-of-life disposal.
3. Life Cycle Impact Assessment (LCIA): characterize and evaluate the magnitude of the potential environmental impacts of a product system using inventory analysis results.
4. Interpretation: draw conclusions and recommendations; identify major impacts from inventory analysis and/or impact assessment. The interpretation phase occurs throughout the entire process.

The product system is defined by the system boundaries set out in the goal and scope, and describes which unit processes analyzed in the model, along with any associated flows. A unit process is defined by ISO 14040 as the “smallest element considered in the life cycle inventory analysis for which input and output data are quantified”[2]. This amounts to a process in which all inputs and outputs which satisfy the cut-off criteria are described.

Inputs and outputs of unit processes are categorized as flows. Such products, materials, or energy will be defined as different types of flows depending on where they are traveling to and from. Products, materials, or energy traveling between unit processes are interpreted as intermediate flows, whereas inputs and outputs that move between the environment and the product system are elementary flows. While these definitions are used for clarity in an LCA, there are various more common monikers for flows. For example, gaseous elementary flows that move from the product system to the environment are commonly known as emissions.

The life cycle impact assessment uses the information from the inventory and calculates the effect of the product system on the environment based on selected impact categories, which are classifications of environmental issues of concern. Data can be presented in a number of ways including characterized models which compare the materials to each other or normalized models which compare the effects of the product system in the context of the impacts of a set unit over a period of time (such as the impact of an average person over a year).

1.1.3 Materials Studied

1.1.3.1 Paper

The paper industry is a very large manufacturing industry worldwide. In the U.S., the paper products industry gross output in 2014 totaled $193.9 billion[3], and it is also one of the largest in the U.S. The paper industry in the U.S. is the third largest industrial user of energy totaling 11% of total U.S. industrial primary energy use[4]. There are known environmental concerns of the paper manufacturing process, and there are several areas in which paper has impacts on the environment in its life cycle.

The first of these begins from sourcing, and the fact that it utilizes wood as a major resource. The paper industry is predicted to continue increasing its wood usage into the future, creating large pressure on wood stocks in the future. While agroforestry has been growing in popularity to help increase supply of wood, deforestation remains a large issue. Research shows that from 2000 to 2012, 2.3 million square kilometers of forests were deforested, as opposed to only 0.8 million square kilometers that were replanted[5]. In 2014 the European pulp and paper industry produced 13 million metric tons of pulp, while using 146 million m^3 of wood as raw materials[6]. Given an assumption that 11,000m^3 of wood can be obtained per square kilometer of forest[7], this would mean Europe consumed over 13,000 square kilometers of forest in 2014. This is equal to the area of a small country, such as Montenegro[8].

Another area in which paper has impacts is in its production phase. Besides the energy requirements to produce, the main environmental impacts from the production process come from water usage and the associated waste water. Production can use up to 60m^3 of water per ton of paper produced, depending on the type of paper[9]. There is typically some recycling of water in the process which helps to alleviate the burden to water resources.

However, any wastewater that is not treated has the potential to cause high levels pollution stemming from issues such as suspended solids, high chemical oxygen demand, and high biological oxygen demand. The effects of this pollution include severe impacts on fish. There is evidence of reduced liver function, and also decreased reproductive viability[10]. Given time, these effects could contribute to destabilizing ecosystems. A variety of other chemicals are used in the production process with varying effects on the environment. These substances include, but are not limited to: chlorine, ammonia, adsorbable organic halogens, and phosphorous[11]. Pulp and paper industries attempt to remedy these issues with treatment methods such as sedimentation and activated sludge treatment.

A final area in which paper has impacts is at the end of life. There are estimates that over 25% of all landfill waste comes from paper, and that methane produced by paper in landfills exceeds methane production by fossil fuel electricity generation by over 50 times[12]. These numbers exist largely due to the sheer volume of paper that is produced and disposed of on a regular basis. Coated paper has additional impacts during end of life, because the recycling process requires an extra step of removing the coating. If this is done, the coating itself is disposed of as solid waste[13]. It should be noted that many end of life effects can be mitigated through the recycling of paper, where the recycling rate of paper and paperboard reached 64.6% in the U.S. in 2012[14].

1.1.3.2 PP Film

The petrochemical industry is one of the largest in the world, and the global market is projected to reach $758.3 billion USD by 2022[15]. The industry produces a variety of products including ethylene, propylene, butadiene, and benzene, to name a few.

PP film is produced from the propylene subset of petrochemicals. Propylene accounted for over 15% of petrochemical production volume in 2014, making it the second largest subset in the petrochemical industry after ethylene. Polypropylene film is produced due to its properties of strength at low gauge, moisture barring, high printability, and light weight[16].

Despite its many benefits due to its properties, polypropylene film also has detriments. The first issue is that it made from a nonrenewable fossil fuel resource. As fossil fuel resources are depleted from the world, the supply for the raw materials to produce PP film become scarce, making it difficult to maintain high levels of production. Estimates for when prices will begin to increase due to limited supply vary, but increased scarcity will occur with continued use of the resource.

The largest environmental issues from polypropylene, and plastics in general, lies in their disposal. There are four basic options for disposal of plastics: landfilling, incineration, recycling, or biodegradation[17]. Landfills require very long term designation of land which may not be available in some cases. Most plastics are recyclable in theory, but difficulties in implementation due to problems such as sorting different types of plastics decrease its popularity. The recycling rate, as reported by EPA for plastics in 2012, equaled 8.8%[18]. Instead, they are often disposed of as MSW. Many plastics are not biodegradable, and even for plastics that are, they do not biodegrade quick enough to equal the input of other plastic waste, creating land use pressure from landfills. Incineration is also an option for plastics, although there are potential negative health effects from the substances emitted from the process, such as carcinogenic dioxins[19].

One of the main issues associated with plastics disposal is the persistence of the material. Plastics can accumulate in water bodies and break down into microplastics or form incredibly large masses and persist for thousands of years. One of the clearest examples is the “Great Pacific Garbage Patch”, which is estimated to be at least 700,000 square kilometers large (which is about the size of Texas). In an oceanic setting, plastics can also cause harm to marine life that ingests or is caught in the products[20].

Other environmental impacts exist earlier in the life cycle as well. In 2010, 2.7% of U.S. petroleum consumption was used for plastic production, as well is 1.7% of natural gas consumption. The energy requirements are significant, as the plastic manufacturing used 1.7% of U.S. total electricity consumption in 2010, which indicates that plastic production has global warming impacts, given the current fossil fuel dependent nature of the energy industry[21].

There are also environmental impacts from the refining process of oil or petroleum, both of which can produce the materials needed for plastic production. These facilities can release effluents that are known to pollute water with chemicals such as ammonia, sulfides, phenol, and hydrocarbons[22]. Each refinery is independent, so the exact effluents released is different for each.

A final issue stems from potential health effects from the overuse and overdependence of plastics in society. While plastic is not known to have high levels of bioaccumulation, the sheer volume of plastic products used has led to signs of the presence of a steady amount of plastic components evident in the human body. Signs of this have been found in the urine of 95% of males in the USA[23]. It is not yet known whether these compounds will have significant health impacts due to the novelty of the situation, but the presence raises questions for current societal resource use trends.

1.1.3.3 Stone Paper

Given the vast scale of the industry of paper and plastics, understanding their effect on the environment is important, along with finding environmentally sustainable alternatives. Stone paper is one potential alternative that could fulfill many of the same uses as paper and PP film. TLM makes a number of claims about Stone Paper and the process used to manufacture it. For example, TLM marketing materials emphasize the lack of forestry resources used in the material, a lack of major water pollution from the manufacturing process, and a lack of significant air emissions from the manufacturing process with the phrases “No Wood-Pulp”, “No Water Pollution”, and “No Air Pollution”[24]. The limited water used in manufacturing, wood free production process, and no emissions during production are all points that TLM have emphasized. This LCA investigates impact categories related to these claims along with other important impact categories.

Some of the claims that TLM have made are manufacturing process focused claims, but LCA is focused on the full life cycle cradle to grave impacts. Thus, not only are process focused impacts investigated, but effects from other stages of the life cycle are also be included. A discussion of the specific impact categories selected for the analysis occurs in the report below.

Stone Paper includes HDPE as a key component, and hence the environmental impacts of plastics are still relevant to the product, as described in section 1.1.3.2. Issues such as disposal and fossil fuel depletion apply, especially if Stone Paper is processed as normal solid waste.

TLM has stated that Stone Paper is both photodegradable and recyclable as an HDPE plastic, which has implications for the long term disposal of the product. It is not biodegradable as organisms will not consume the material. Although Stone Paper is recyclable as HDPE, there are currently no large scale recycling initiatives, due to the fact that the volume of Stone Paper in the market has not yet reached a threshold for which it would be practical to undertake such an action. The recycling capabilities of the material could have a more significant impact in the future.

The environmental impacts of the mining process may also be considered. A common way of mining in quarries, blasting, is shown to have impacts to structures and plants in surrounding areas[25]. Calcium carbonate production also has associated energy and carbon dioxide requirements[26], so the source of the energy used will also affect the global warming potential from calcium carbonate production.

1.2 Key Findings

- All product systems have room for improvement on key impact assessment categories. It cannot be stated that one product is better than another across the full range of life cycle impacts studied. The use of each product involves tradeoffs compared to the use of the other products. This LCA can help inform material selection and provide information about relative impacts. Each decision maker should decide what attributes matter, including life cycle impacts.
- The calcium carbonate material inputs to Stone Paper have relatively low life cycle impacts in the production phase compared to the use of more plastic resins.
- When comparing the same area and thickness product, the density of the product plays an important role in determining life cycle impacts. Denser products lead to higher life cycle transportation and end of life impacts, all else equal. This aspect helps the PP film life cycle and hurts the Stone Paper life cycle, relatively.
- The TRACI/USETox ecotoxicity characterization factors of heavy metals lead to an outsized impact from the long term emissions of solid waste treated in a sanitary landfill. This is a known area for continued research and methodology improvement in the LCA field. Alternate characterization method IMPACT 2002+ shows much lower normalized ecotoxicity impacts.
- Improvement analysis shows that the Stone Paper life cycle could be significantly improved by focusing on improving the profile of the electricity used in production through energy efficiency or the use of renewable energy. The electricity production process in Taiwan for the electricity used in the manufacturing of Stone Paper is a major contributor to a number life cycle impact categories, including global impacts, such as global warming, and local impacts, such as photochemical smog formation.
- Improvement analysis also shows that the Stone Paper life cycle could be improved by incorporating postconsumer recycled HDPE content.
- A lower transportation scenario benefits Stone Paper in the impact categories of ozone depletion, smog and acidification.

2 Goal and Scope Definition

2.1 Goal

The goal of this study is to report and interpret the life cycle impacts of three materials that can be used for waterproof bottle labels. The main focus of the study is to understand the potential environmental impacts and relevant tradeoffs of material selection. Additionally, this is the first LCA analyzing Stone Paper, so an additional goal is to report specific impacts and possible improvements to the life cycle of Stone Paper.

2.2 Scope Definition

2.2.1 Function

The function represented in this LCA is the display of product information on a glass bottle or other container via water resistant printed label. A wine bottle is the product used to model this system, but the labeled product could be another container serving a similar function without altering the LCA model.

2.2.2 Functional Unit

The functional unit for this LCA is the production, use, and disposal of one square meter of 100 micron thickness water resistant labels manufactured in Tainan, Taiwan, delivered to the U.S., and used and disposed in the U.S.

In order to understand the life cycle impacts of Stone Paper compared to similarly used materials, this LCA provides a comparative analysis between different products. To compare them, the products must be evaluated based on the same functional unit to ensure they have the same effective functional use. All analysis conducted will be based on the functional unit, so as to fairly compare the relative inputs and outputs of the life cycle of each product. As mentioned above, the study will compare between Stone Paper, coated paper, and PP film. The specific products modeled are discussed further below.

2.2.3 Product Systems

The product system chosen for this study is water resistant bottle labels that can be used similarly on a number of different products, for example as wine bottle labels. A label can be made with many different types of materials and perform essentially the same function. The materials in this LCA were chosen after conversations with TLM, a distributor of Stone Paper and other paper products, and a label making company in Taiwan[27,28,29]. To the best of the authors' knowledge, the materials chosen are commonly used and provide a useful comparison of product choice available in the marketplace to distributors and manufacturers. Additional materials may serve the same product function, but the scope was narrowed to keep the LCA legible and useful to the parties requesting the information.

2.2.3.1 Label Conversion

To create labels, label manufacturers receive the manufactured materials (known as facestock), before being fabricated into the desired final product. This is done through three main steps: application of adhesive, conversion, and printing[30].

The application of adhesives to the material requires several steps. The first of these is applying a silicone coating to a liner, which creates a surface that is suitable for the application of adhesives. After the adhesive is applied, the facestock (material) is applied, creating a large roll of the label.

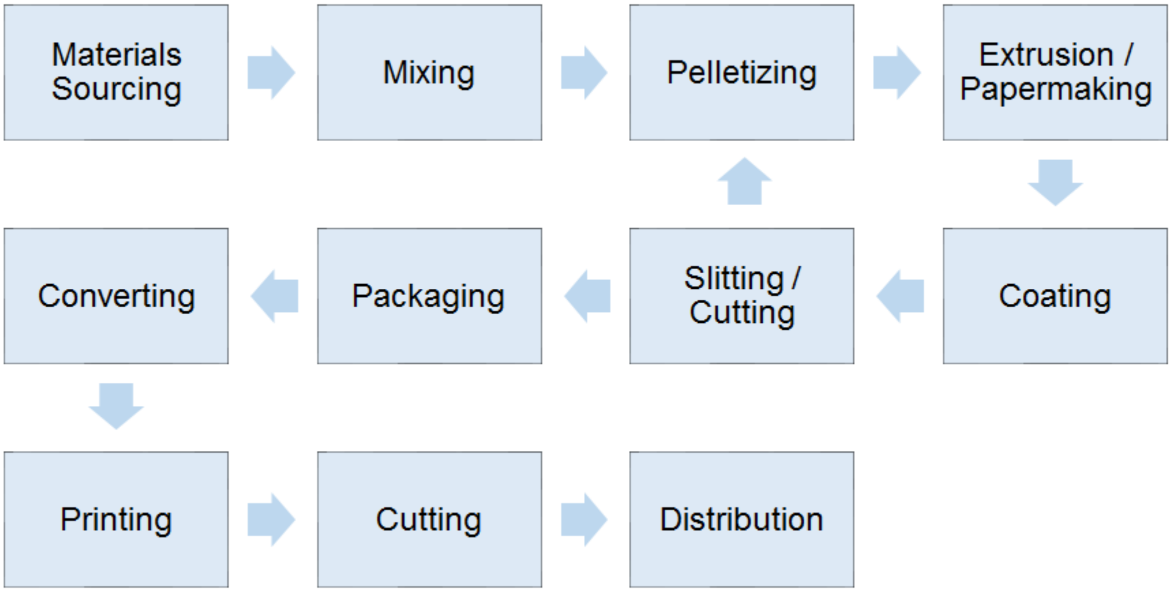
The label roll is then put through the conversion process, which includes slitting and die-cutting. Slitting cuts a large roll into multiple more narrow rolls, whereas die-cutting cuts the slit rolls into the desired final form or shape.

There are various methods for printing that are available for labels, including digital printing, flexographic printing, rotogravure printing, and offset printing, to name a few. For the purpose of this LCA, offset printing was chosen as the method that will be tested. Offset printing utilizes a printing plate which contains a copy of the desired image to be printed on the label. Ink is applied onto the plate, then transferred to a rubber blanket, before being applied to the printing surface[31] of paper, PP film, Stone Paper, or other printable materials.

2.2.3.2 Stone Paper

Stone paper is made from approximately 80% calcium carbonate and 20% HDPE, with several additives also added in small amounts. The first step to the process following obtaining the raw materials is to mix the crushed calcium carbonate with granulate HDPE and additives in a pelletizer to create new pellets. The pellets are then extruded into various thickness films. The film is then fed into the coating machines to finalize Stone Paper's version of a papermaking process. The resulting Stone Paper is then slit into rolls and shipped to label converters. The process produces a scrap rate of less than 5%, and most of the scrap from the slitting process is fed back into the pelletizing system. This creates a nearly closed internal loop and reduces the solid waste stream from the manufacturing process to about 1%. Figure 2 shows the general flow of the manufacturing process.

Figure 2. Generalized Stone Paper Manufacturing Process



2.2.3.3 Coated Paper

The first step to paper production is obtaining wood and putting it through debarking and chipping processes to make it suitable for the proceeding pulping. Wood chips or recycled paper must be dissolved into pulp to ensure fibers are separated. This process can be done either mechanically or chemically. Mechanical pulping achieves a higher yield, whereas chemical bleaching achieves higher quality[32].

The ensuing fibers are then cleaned, before entering the bleaching process. The bleaching process is done to increase strength of the paper, and to ensure it does not become discolored. Bleaching is commonly carried out using chlorine.

The pulp is then dried and fed into large rollers, which ensure they are flattened, and remove any last traces of moisture as well. The coating process is carried out after this. Coating applies a layer of various materials (including pigments, binders such as starch, and extenders such as clay) to the surface of the paper, which improves its aesthetic qualities and printing properties. From here, they are wound into large rolls of paper, before finally being cut into smaller, more manageable pieces[33].

2.2.3.4 Polypropylene Film

The first step to making polypropylene begins from raw material extraction and processing. Resources such as naphtha undergo a cracking process[34] in which they are broken down into monomers which have double bonds, such as ethylene or propylene. These materials are then put through the polymerization process, which binds the monomers together into long chains of hydrocarbons, which form the basis for plastics.

From that point, there are several ways in which polypropylene film can be made. One of the most common processes to do this currently is through cast film extrusion[35]. Cast film extrusion involves feeding plastic resins through gravimetric feeding systems to extruders. Within the extruders, the material is melted and mixed, before being filtered and fed into a flat die system, which molds it into its final shape. The plastic is then cooled, and put under the Corona treatment, which facilitates the adherence of ink to the material in the later printing process.

It should also be noted that there are two main types PP film that can be produced: cast polypropylene film (CPP), and biaxially oriented polypropylene film (BOPP). These different types of PP film have different properties. The cast film variation is softer due to a lower density, and is resistant to cross directional tears. On the other hand, BOPP is stiffer and has stronger barrier properties than CPP[36].

2.2.3.5 Products Modeled

The materials that were chosen to be compared to Stone Paper are coated paper and PP film, all of which are at 100-micron thickness. The information used for the calculation of weight assumptions were sourced from industry product examples. The aim was to choose a material for comparison that used coated paper or PP film as the predominant ingredient, and to show that the comparison of the three products is a realistic option based on the market. If a material could not be found at exactly 100-micron thickness, the values were scaled to match 100 microns, if it was shown that a 100 micron product was a reasonable assumption. Table 1 shows a description of modeled materials. These products are the basis for the reference product flows used in the LCA.

Table 1. Products Modeled

Material	**Thickness (microns)**	**Weight (g/m^2)**	**Weight at 100 microns (g/m^2)**
Stone Paper	100	120	120
Coated Paper[37]	100	90	90
PP (Yupo)[38]	95	73	77
PP (Yupo)	110	85	

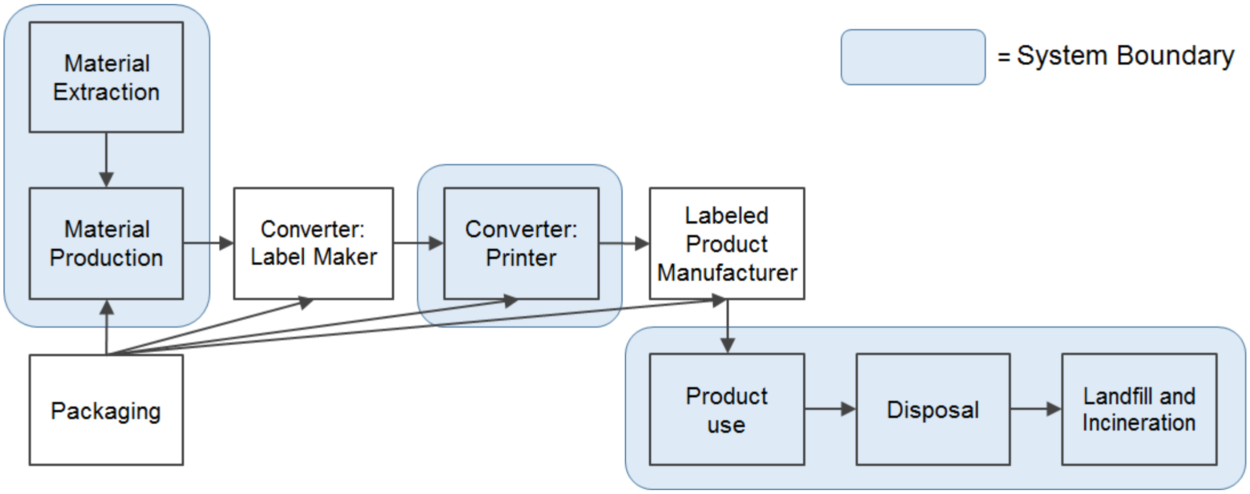
2.2.4 System Boundary

Figure 3 represents the general system boundary used for the life cycle of a product label in this LCA. The highlighted process stages are included in the analysis and the other processes are excluded. Life cycle material inputs, energy requirements, and emissions to the environment of all unit processes within the individual process stages are included for each product. The intent of the analysis is to study the processes of the system with potential for variation to provide meaningful results for the comparison.

According to research, discussion with manufacturers, and facility walkthroughs, it was determined that certain processes are the same for each product in the comparison, hence, they are not included in the system boundary of the LCA. The packaging, label making (adhesive and backing), and bottle making operations are assumed to be the same across the life cycle of each product. Excluded processes are further discussed later in the report.

The resource extraction and processing, material production, transportation, printing, and end-of-life processes were included to provide meaningful results for this analysis. Within the printing process, only the printing ink was modeled. The system boundaries and process flows for each of the products are described in the next sections. Additional scenarios are analyzed to provide sensitivity analysis for the life cycles of all three products. These scenarios are discussed below in the Modeling Approach and Sensitivity Analysis section.

Figure 3. System Boundary for Label Life Cycle



2.2.4.1 Stone Paper System

Figure 4 shows the process flow diagram for the life cycle of Stone Paper based labels. The raw material extraction stage includes the energy requirements and relevant emissions in the extraction of necessary raw materials calcium carbonate, high density polyethylene (HDPE), and other proprietary additives and coating materials for Stone Paper.

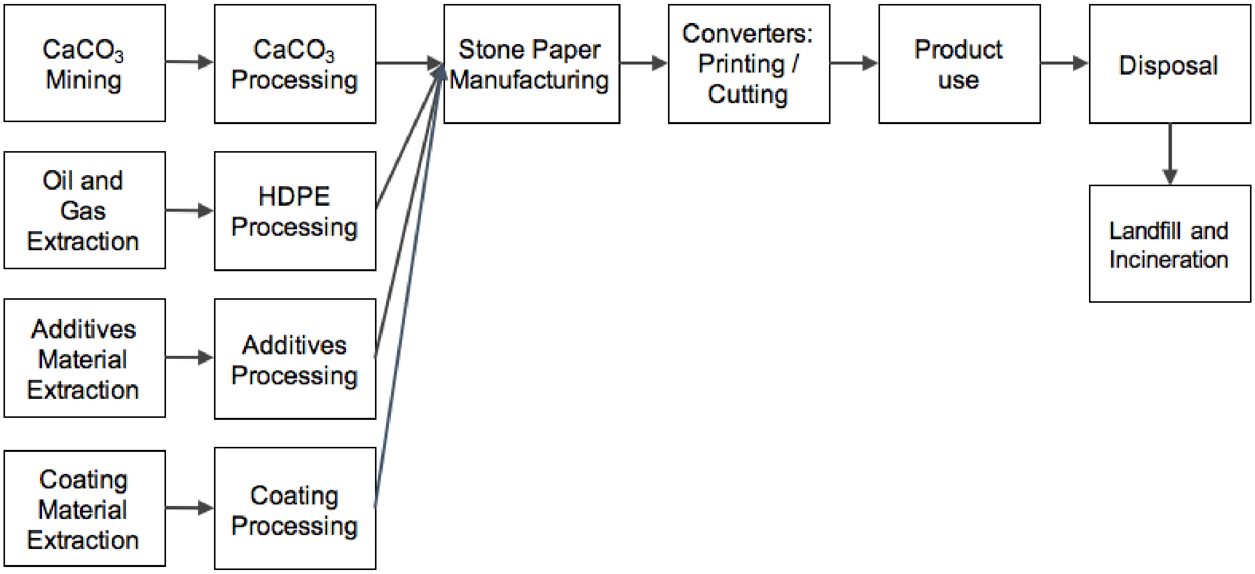
The materials extraction and processing phases refer to the transportation and processing of materials needed for manufacturing Stone Paper. The Stone Paper manufacturing phase refers to the manufacturing processes for the product. This includes the inputs and emissions associated with the transportation of raw materials to manufacturing facilities, as well as the material and energy inputs and emissions associated with the manufacturing. The label conversion and printing processes follow Stone Paper manufacturing, and only the printing ink within the printing process is modeled.

The life cycle stages after the Stone Paper manufacturing are modeled based on actual processes used by downstream manufacturers and users. Transportation and distribution processes are modeled for the material inputs to the manufacturing facility and the distribution, use, and disposal for the product.

The label printing process is included in the system boundary, because there are variations in the printing process for Stone Paper. Each material can be used in the same commercial offset printing process, but it was reported that Stone Paper uses approximately 20% more ink than the other materials. The printing ink process is incorporated into the life cycle model of each product, and the extra ink required by Stone Paper is factored into the model. For the printing process, three grams of color ink are used per square meter in offset printing[39], and Stone Paper uses 20 percent more ink than the other materials[40].

Following the manufacturing of the label, it is transported to a distributor, then distributed to a manufacturer to label a bottle, and then ultimately used and disposed along with the bottle it is attached to. Besides transportation, there are no inputs or emissions associated with the use phase.

Figure 4. Stone Paper Label System Boundary and Process Flow Diagram



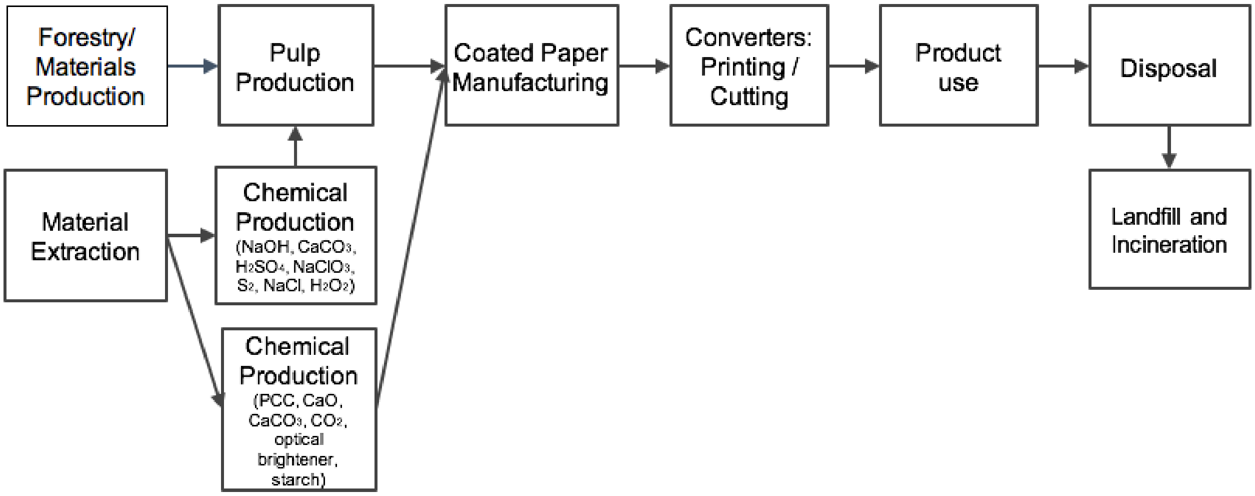
2.2.4.2 Coated Paper System

Figure 5 displays the process flow diagram for the life cycle of coated paper based labels. The raw material extraction stage includes the material inputs, energy requirements, and relevant emissions in the extraction of necessary raw materials in the form of forest products and other materials for the pulp production and chemical production necessary to manufacture coated paper.

The materials extraction and production phases include the transportation and processing of materials needed for manufacturing coated paper. The coated paper manufacturing phase refers to the manufacturing processes for the product. This includes the inputs and emissions associated with the transportation of raw materials to manufacturing facilities, as well as the material and energy inputs and emissions associated with the manufacturing. The label conversion and printing processes follow coated paper manufacturing, and only the printing ink within the printing process is modeled.

Following the manufacturing of the label, it is transported to a distributor, used to label a bottle, and then ultimately disposed along with the bottle it is attached to. Besides transportation, there are no inputs or emissions associated with the use phase.

Figure 5. Coated Paper Label System Boundary and Process Flow Diagram



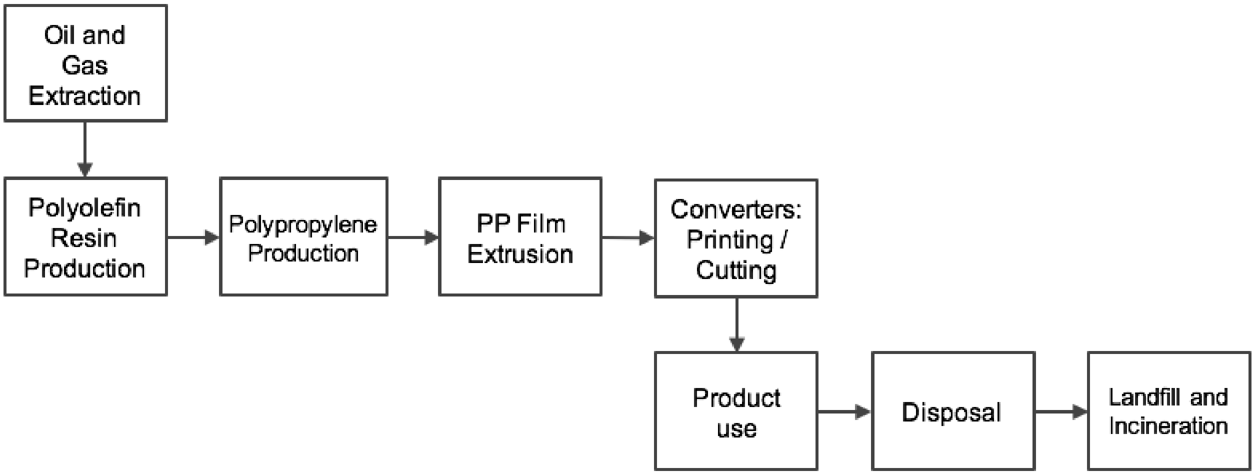
2.2.4.3 Polypropylene Film System

The process flow diagram for the life cycle of polypropylene film based labels is displayed in Figure 6. The raw material extraction stage includes the material inputs, energy requirements, and relevant emissions in the extraction of necessary raw materials in the form of oil and gas extraction, polyolefin resin production, and other materials necessary to manufacture polypropylene granulate then used in the film extrusion process.

The materials extraction and production phases include the transportation and processing of materials needed for manufacturing polypropylene film. The polypropylene manufacturing phase includes the manufacturing processes for the product. This includes the inputs and emissions associated with the transportation of raw materials to manufacturing facilities, as well as the material and energy inputs and emissions associated with the manufacturing. The label conversion and printing processes follow polypropylene film manufacturing, and only the printing ink within the printing process is modeled.

Following the manufacturing of the label, it is transported to a distributor, used to label a bottle, and then ultimately disposed along with the bottle it is attached to. Besides transportation, there are no inputs or emissions associated with the use phase.

Figure 6. Polypropylene Label System Boundary and Process Flow Diagram



2.2.5 Allocation Procedures

The Stone Paper production process was modeled as a single output process, so no allocation was necessary. The manufacturing process produces one type of Stone Paper at a time, and all data collected from the manufacturer were modeled according to the flow of the material selected for the functional unit of the LCA.

All other processes modeled in this LCA are from the Ecoinvent 3 database processes, and all processes use the default system allocation process with partitioning and allocation at the point of substitution.

2.2.6 End-of-Life Methodology

The end of life disposal and recycling was modeled for all products.

As indicated in several recycling guidelines, it was considered that all three scenarios of coated paper label, PP film label, and Stone Paper label, are treated as MSW and landfilled or incinerated at end of life. The reasons for making this assumption are as follows.

- In the recycling process, glass bottles are re-washed. After crushing, any non-glass objects are removed, during which labels are removed from the recycling process. Furthermore, the remaining adhesive after washing off makes it even harder to recycle. Also, labels are removed before tossing bottles in the recycling bin in Japan.[41][42]
- Paper loses its recycling value when shredded into small pieces. The length of the paper fiber is the source of value of the paper, and every time paper gets recycled, the fiber gets shorter. Labels made out of paper are cut into small pieces, which make them non-recyclable.[43]
- Current technology for paper recycling utilized paper fibers, which is not present in Stone Paper (calcium carbonate and HDPE), thus making Stone Paper incompatible with current paper recycling methods.
- Polyethylene coated paper is neither biodegradable nor recyclable. Thin polyethylene films are also low in their recycling value.

According to 2012 MSW data from the U.S. Environmental Protection Agency (EPA), 34.5% of total wastes are recovered, 11.7% are combusted for energy recovery (i.e. incineration) while 53.8% are discarded (landfilled). Given the assumption that no labels are recovered, only incineration and landfill are considered for this scenario. Thus, based on the ratio of incineration/landfill provided by EPA, a ratio of 82.1% landfill and 17.9% incineration was assumed for all three products in the baseline scenario.

2.2.7 Excluded Processes

The following processes were judged to be the same for all three products, so they have been excluded from the LCA:

- Manufacture, use, and disposal of label adhesive and backing.
- Manufacture, use, and disposal of labeled bottle and contents.
- Manufacture, use, and disposal of packaging.
- All slitting and cutting processes.

Additionally, the manufacture of machinery used in the manufacturing processes, research and development processes, and return trips and empty trucks on return are excluded from the model, because the potential impacts were deemed small or out of the scope of the purpose of the study.

2.2.8 Modeling Approach and Sensitivity Analysis

The modeling approach for this LCA consists of a comparative analysis of baseline systems and additional sensitivity analyses. The sensitivity analyses explore alternate transportation and end-of-life scenarios to test the sensitivity to change of the impact assessment results. See below for details of model and sensitivity analysis.

2.2.8.1 Transportation Scenarios

Transportation is an essential aspect of consideration in the life cycle process, given the global nature of supply chains. Two options were considered to test the effects of different distances traveled in realistic scenarios. Various LCAs were considered, and several scenarios were developed according to findings of transportation modeling from these examples. Values used in the scenarios can be found in the Life Cycle Inventory section.

Baseline Scenario:

The baseline scenario consists of distribution from TLM’s factory in Tainan, Taiwan to the port of Kaohsiung, shipping from Kaohsiung to the Long Beach port in California, distribution across the country to a manufacturer, then distribution to a user. This scenario was selected based on discussion with a distributor of Stone Paper and other products located in California. Discussion with the distributor found much of the distribution was centralized in the mid-U.S. region. This prompted calculation of an average distance of rail freight to other manufacturers or distributors in the mid-U.S. region, through finding the distance of rail from Los Angeles to New York, and then halving the distance traveled. Average distance of distribution per shipment of wine bottles in the U.S. was found from the 2012 Commodity Flow Survey under the section “Wine and other fermented beverages”.

Coated paper and PP film were assumed to have the same transportation route as Stone Paper. This assumption was made to compare production of alternative materials that could theoretically be made in the same geographical. Based on discussion with the Stone Paper distributor, it is realistic to source paper or polypropylene from Taiwan or China.

High and Low Transportation Scenarios:

Two alternative scenarios were also considered. Stone Paper distributors are also present in Spain and Japan, so new transportation scenarios were modeled to test the effect of varying shipping distances on the life cycle impacts of the three materials.

The distance of shipping to both countries was found from Kaohsiung to the ports of Barcelona and Shimuzu for Spain and Japan, respectively. For Spain, an assumption was made that the Stone Paper would be then transported by truck to throughout the European Union to manufacturers. Frankfurt was selected as a central European transport location. From there, data from the EU was found for average freight distance for a product to model for distance between manufacturer and user.

In the case of Japan, only the distance from Shimuzu to Tokyo was modeled. Shimuzu is a large port in Japan, but there are a vast number of ports in the country due to its island nature. For other areas of the country, shipping could be done to various ports, resulting in shorter inland transport distances.

2.2.8.2 End-of-life Scenarios

End of life treatment is an important part of LCA. Generally speaking, major end of life treatment for solid waste includes landfill, incineration, and recovery. In this LCA several scenarios have been considered to test the effects of different end of life treatment methods with realistic assumptions. The scenarios considered for all three materials are developed according to the assumptions generated in the end of life methodology section and factsheet on MSW treatment provided by EPA in 2012. As indicated, all labels, regardless of material, are mixed and treated together at end of life. Thus, the same treatment methods are considered for all three materials in both the baseline scenario and alternative scenarios. Values used in the scenarios can be found in the Life Cycle Inventory section.

Baseline Scenario:

The baseline scenario is based on the general MSW treatment method in U.S. and data were obtained from the EPA fact sheet on MSW. All label materials are landfill and incinerated with a proportion of 82.1% and 17.9%, respectively.

Alternative Scenarios:

Given the alternative scenario that the labels are distributed to Japan and Spain, two alternative scenarios, waste disposal in Japan (A) and Spain (B) were also considered. According to the guidelines in Japan waste collection, all paper scraps are collected as combustible garbage and are 100% incinerated at end of life[44]. Based on the country average provided in Eurostat, in 2012, the ratio between landfill and incineration of MSW in Spain was calculated as 2.38. Considering the assumption of no recycling, a scenario of 70.4% landfilled and 29.6% incineration is developed for labels disposal in Spain[45].

Note that the product selected for comparative analysis is a label, while there are other common uses of wood-pulp paper, Stone Paper, and polypropylene film. Thus, a general end of life treatment is considered to qualitatively demonstrate a more common disposal method for these materials.

According to the EPA factsheet, the recovery rate for nondurable paper and paperboard is 50.5%, and the rest goes into incineration (8.8%) and landfill (40.7%). Overall, U.S. post-consumer plastic waste for 2008 was estimated at 33.6 million tons; 2.2 million tons (6.5%) were recycled and 2.6 million tons (7.7%) were burned for energy, while 28.9 million tons, or 85.5%, were discarded in landfills[46].

Qualitatively speaking, the end of life impact would generally be lower for common paper products like notebooks than labels due to higher recycling rates. While in the case of plastic film, there is not much of a difference in the end of life impact of a label or other polypropylene products given that the recycling rate is already low.

2.2.9 Data Requirements

ISO standards 14040 and 14044 detail various aspects of data quality and data quality analysis. The critical data quality requirements are time-related coverage, geographical coverage, and technology coverage.

Geographic Coverage:

The geographic scope of this portion of the study is product distribution from Taiwan to the U.S. This scope also includes raw material sourced within the Taiwan region. The main sources of data and information for geography-dependent processes (e.g. energy production) are drawn from databases specific to Taiwan. Primary data specific to TLM operations are collected from TLM and their suppliers for facilities in Taiwan, which distributes the product to the U.S. Background processes for each product system are specific to processes in Taiwan where applicable. For most background processes for which Taiwan is not applicable, “rest of the world” data is used.

Secondary data were adapted from the Ecoinvent 3 LCI Database. The following material and background processes are specific to the “rest of the world” geographical region:

- Materials transport processes
- Fossil fuels extraction, processing, and combustion
- Process water treatment
- Printing ink
- Polypropylene production and film extrusion
- Paper production
- Chemicals production
- End-of-life incineration and landfill processes

Only wastewater treatment processes utilized the process specific to China, while electricity and process solid waste incineration processes are specific to the Taiwan region. Transportation during product distribution by truck is specific to rest of the world, and rail is specific to the U.S., while ocean freight utilizes global data. Detailed processes and materials used in this study, including geographical coverage and data sources, can be found in the life cycle inventory section.

Technology Coverage:

Primary data were collected for the specific technology currently used by TLM and TLM suppliers. For data from secondary sources, the most recent average technology information was utilized as appropriate for the associated geographic scope.

Temporal Coverage:

Annual production data was collected for primary data from TLM and suppliers. Data were collected for the most current full calendar year from 2014 to 2015. For data from secondary sources, the most current publically available data appropriate to the designated geographical scope were used where applicable.

Cut-Off Criteria:

A one percent by mass cut-off criterion was used in this study to model the Stone Paper manufacturing process. Any material flow comprising less than one percent by weight of the system was excluded. This cut-off assumption was based on past LCA studies that demonstrate that materials which comprise less than one percent of system weight have a negligible effect on total LCA results. Excluded materials and processes can be found in the excluded processes section.

2.2.10 Data Sources

Data used for the Stone Paper system are based on primary data from TLM, the TLM supply chain, and label converting and printing companies. Primary data collected for the Stone Paper dataset include the specifications of materials, energy, and water required for manufacturing; direct air, water, and waste emissions; as well as the transport distances and methods for the distribution of source materials, products, and solid waste in Taiwan. All data and information were provided by TLM, suppliers, and converters.

Data for raw materials used in Stone Paper manufacturing were compiled by facility representatives from company records and are representative of operations in Taiwan. These specifications included details on the quantity of raw material used, recycled content in material, as well as transportation method and distance travelled. Data for energy, fuel, and water used during the production of Stone Paper were also provided based on direct measurement and company purchasing and utility records for the same data year. Air emissions, wastewater, and solid waste disposal data from the manufacturing process were also collected. Data on transportation logistics, including transportation mode and distance, were also provided.

An attempt was made to collect primary data from the TLM supply chain in Taiwan all the way to resource extraction. Data collection was successful for the first tier of suppliers, but collection was unsuccessful in the second tier of suppliers. Thus, material inputs to the TLM process are modeled with the Ecoinvent 3 database to provide full life cycle data.

For data that was not collected directly for this project, data from credible published sources or licensable databases were used wherever possible in order to maximize transparency. Production of the polypropylene and coated paper labels was modeled using secondary data from Ecoinvent 3 database.

2.2.11 Life Cycle Impact Assessment Methodology

The life cycle impact assessment (LCIA) is the most critical step within an LCA. LCIA is used to transform results from the life cycle inventory analysis into impact categories through environmental modeling. Both natural science and social, political, and ethical issues are considered in LCIA models through characterization, normalization, and weighting. LCIA methodologies are developed to characterize life cycle inventory analysis to categorized environmental impacts. Two approaches, mid-point approach and end point approach are most commonly used in LCIA. In this study, the mid-point approach was used for impact assessment.

In the midpoint approach, the cause-effect chain starts with a specific process or an activity which leads to emissions, and, consequently, primary changes in the environment appear. These primary changes often occur early in the cause-effect chain, and are often chemical and physical changes. For example, in the case of studying the primary effects of climate change, changes in concentrations of gases in the atmosphere or changes in infrared radiation are observed. At this point, the LCIA results represent contributions to different environmental problems such as global warming or stratospheric ozone depletion. This is how the midpoint approach works. Thus, the midpoint approach is also known as the problem-oriented approach[47].

The following LCIA methods were chosen for this analysis:

TRACI 2.1 Version 1.03

The Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) is a midpoint oriented life cycle impact assessment methodology developed by the U.S. Environmental Protection Agency[48]. Part of the life cycles modeled, including transportation and disposal, take place in the U.S., and the TRACI method is commonly used for U.S analyses. All TRACI impact assessment categories will be characterized and compared across the products. See Table 2 for the impact categories characterized.

ReCiPe Midpoint (Hierarchist) Version 1.12

The ReCiPe method was created by RIVM, CML, PRé Consultants, Radboud Universiteit Nijmegen and CE Delft[49]. This method was chosen in addition to TRACI to provide additional impact categories focused on land use and water depletion. See Table 2 for the impact categories characterized.

Table 2. LCIA Impact Categories Modeled

Impact Category	**Method**	**Characterization Unit**
Ozone Depletion	TRACI 2.1	kg CFC-11 eq
Global Warming	TRACI 2.1	kg CO2 eq
Photochemical Smog Formation	TRACI 2.1	kg O3 eq
Acidification	TRACI 2.1	kg SO2 eq
Eutrophication	TRACI 2.1	kg N eq
Human Health Cancer (Carcinogenics)	TRACI 2.1	CTUh
Human Health Noncancer (Non Carcinogenics)	TRACI 2.1	CTUh
Human Health Particulate (Respiratory Effects)	TRACI 2.1	kg PM2.5 eq
Ecotoxicity	TRACI 2.1	CTUe
Fossil Fuel Depletion	TRACI 2.1	MJ surplus
Water Depletion	ReCiPe 1.12	m3
Agricultural Land Occupation	ReCiPe 1.12	m2a
Urban Land Occupation	ReCiPe 1.12	m2a

2.2.12 Assumptions and Limitations

Major assumptions made in this analysis:

- Production occurs in the exact same location.
- Transportation distances are equivalent for each finished product from factory gate until disposal.
- There are no use phase energy or material requirements for the product labels.
- A number of other assumptions are made in the model discussed elsewhere in the Goal and Scope section of the report.

Limitations:

- Geographic location of Ecoinvent processes and availability of local data.
- Data for production processes of coated paper and polypropylene film are modeled entirely with Ecoinvent data.
- Self-reported unit process data from TLM.

2.2.13 Critical Review

This report has not yet received a critical review.

3 Life Cycle Inventory

3.1 Introduction/Overview

3.1.1 Data Collection Procedure and Methodology

The dataset for Stone Paper was obtained through collection of primary data from the manufacturing company and its suppliers via company records, direct observation, and interviews. Interviews with TLM staff and tours to the manufacturing plant were carried out to identify materials and processes necessary to implement the Stone Paper system. Data collection sheets were sent to facilities, including the producer of stone paper, TLM, the suppliers of TLM and the printing facility. Data collection sheets in both Chinese and English were provided to ensure accurate understanding of the form. Guidelines for filling out the data collection form in both languages were also provided. Data collection sheets were collected electronically. Data collection was an iterative process, requiring at least one to two rounds of questions between the data suppliers and the practitioners to ensure all necessary life cycle information was being reported. The correspondence with TLM and participating data providers ensured that all aspects of the LCI data and assumptions used in the data collection process were clearly understood and consistent with the system boundaries of this study. For material or process data not collected for this project, data from credible published databases are used in order to maximize transparency and reproducibility. Ecoinvent 3 database was used for all data not primarily collected in this study.

3.2 Baseline Inventory

Table 3 displays the reference flows for each product in the LCA. The reference flow through the system defines the inputs required and emissions of each unit process. All inventory inputs and emissions and all impact assessment results are per one square meter of product label.

Table 3. Reference Product Flows

Stone paper (kg/sqm)	Coated paper (kg/sqm)	PP film (kg/sqm)
0.12	0.09	0.077

3.2.1 Baseline Scenario for Product Labels

The following sections describe the model used to build a baseline life cycle inventory for each product system in the analysis.

3.2.1.1 Baseline Production Life Cycle Inventory

Table 4 provides the material inputs and processes used for the baseline model of the Stone Paper life cycle.

Table 4. Stone Paper Production Life Cycle Processes

Materials					
	Value	**Unit**	**Source**	**Life Cycle Process Name**	**Life Cycle Data Source**
CaCO3	0.0904	kg	TLM	Limestone, crushed, washed {RoW}| production	Ecoinvent 3
HDPE	0.0255	kg	TLM	Polyethylene, high density, granulate {RoW}| production	Ecoinvent 3
Proprietary Additives	0.0050	kg	TLM	Proprietary	Ecoinvent 3
Printing Ink	0.0036	kg	TLM Printer	Printing ink, offset, without solvent, in 47.5% solution state {RoW}| printing ink production, offset, product in 47.5% solution state	Ecoinvent 3
Processes					
Electricity	0.0938	kWh	TLM	Electricity, medium voltage {TW}| electricity voltage transformation from high to medium voltage	Ecoinvent 3
Fuel Oil	0.1189	MJ	TLM	Heat, central or small-scale, other than natural gas {RoW}| heat production, light fuel oil, at boiler 10kW condensing, non-modulating	Ecoinvent 3
Process Water	0.0707	L	TLM	Tap water {RoW}| tap water production, conventional treatment	Ecoinvent 3
Wastewater	0.0012	kg	TLM	Wastewater, average {CH}| treatment of, capacity 4.7E10l/year	Ecoinvent 3
Solid Waste	0.0013	kg	TLM	Municipal solid waste {TW}| treatment of, incineration	Ecoinvent 3
Materials Transport	37.097	kg-km	TLM	Transport, freight, lorry 16-32 metric ton, EURO5 {RoW}| transport, freight, lorry 16-32 metric ton, EURO5	Ecoinvent 3

Table 5 shows the processes used for the baseline model of the coated paper life cycle.

Table 5. Coated Paper Production Life Cycle Processes

Process	**Value**	**Unit**	**Source**	**Life Cycle Process Name**	**Life Cycle Data Source**
Paper Production	0.090	kg	See 2.2.3.5	Paper, woodfree, coated {RoW}| paper production, woodfree, coated, at non-integrated mill	Ecoinvent 3
Printing Ink	0.0030	kg	TLM Printer	Printing ink, offset, without solvent, in 47.5% solution state {RoW}| printing ink production, offset, product in 47.5% solution state	Ecoinvent 3

Table 6 displays the materials and processes used for the baseline model of the PP film life cycle. Note that the value of polypropylene granulate material input and film extrusion process is higher than the mass of the reference product flow. This is because the Ecoinvent film extrusion process models at 0.976:1 film output to material input ratio, hence the higher mass of polypropylene granulate modeled.

Table 6. Polypropylene Film Production Life Cycle Processes

Materials					
	Value	**Unit**	**Source**	**Life Cycle Process Name**	**Life Cycle Data Source**
Polypropylene Granulate Production	0.0789	kg	See 2.2.3.5	Polypropylene, granulate {RoW}| production	Ecoinvent 3
Printing Ink	0.0030	kg	TLM Printer	Printing ink, offset, without solvent, in 47.5% solution state {RoW}| printing ink production, offset, product in 47.5% solution state	Ecoinvent 3
Processes					
Film Extrusion	0.0789	kg	See 2.2.3.5	Extrusion, plastic film {RoW}| production	Ecoinvent 3

3.2.1.2 Baseline Transportation

Tables 7 and 8 exhibit the baseline transportation scenario used for all three product systems included in the analysis. Transportation distances and the life cycle processes modeled are shown in the tables.

Table 7. Baseline Transportation Scenario

Mode	**From**	**To**	**Distance (km)**	**Source**
Truck	Tainan, Taiwan	Kaohsiung, Taiwan	86	TLM
Ocean Freight	Kaohsiung, Taiwan	Port of Los Angeles	11,336	SeaRates.com[50]
Rail	Port of Los Angeles	Manufacturer/Distributor	2,379	FRA[51]
Truck	Manufacturer/Distributor	User	331	US Census[52]

Table 8. Transportation Life Cycle Processes

Process	**Stone paper (kg-km)**	**Coated paper (kg-km)**	**PP film (kg-km)**	**Life Cycle Process Name**	**Life Cycle Data Source**
Truck	10.32	7.69	6.26	Transport, freight, lorry 16-32 metric ton, EURO5 {RoW}| transport, freight, lorry 16-32 metric ton, EURO5	Ecoinvent 3
Ocean Freight	1,360.32	1,013.44	825.26	Transport, freight, sea, transoceanic ship {GLO}| processing	Ecoinvent 3
Rail	285.48	212.68	173.19	Transport, freight train {US}| diesel	Ecoinvent 3
Truck	39.72	29.59	24.10	Transport, freight, lorry 16-32 metric ton, EURO5 {RoW}| transport, freight, lorry 16-32 metric ton, EURO5	Ecoinvent 3

3.2.1.3 Baseline End-of-Life

The baseline processes and assumptions for waste treatment at the end of the label product life are displayed in Table 9. All product systems use the same baseline treatment.

Table 9. Baseline End-of-Life Scenario and Life Cycle Process

Material	**Type**	**Percent**	**Source**	**Life Cycle Process Name**	**Life Cycle Data Source**
Stone Paper	Landfill	82.1	EPA MSW factsheet	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill	Ecoinvent 3
	Incineration	17.9	EPA MSW factsheet	Municipal solid waste (waste scenario) {RoW}| treatment of municipal solid waste, incineration	Ecoinvent 3
Coated Paper	Landfill	82.1	EPA MSW factsheet	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill	Ecoinvent 3
	Incineration	17.9	EPA MSW factsheet	Municipal solid waste (waste scenario) {RoW}| treatment of municipal solid waste, incineration	Ecoinvent 3
PP Film	Landfill	82.1	EPA MSW factsheet	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill	Ecoinvent 3
	Incineration	17.9	EPA MSW factsheet	Municipal solid waste (waste scenario) {RoW}| treatment of municipal solid waste, incineration	Ecoinvent 3

3.2.1.4 Life Cycle Inventory Output

The life cycle inventory emission results for the Stone Paper baseline life cycle can be found in Appendix A.

3.2.2 Transportation Scenario Modeling

3.2.2.1 High Transportation Scenario

Table 10 shows the processes used to model the high transportation scenario for distribution in Europe. It models for transport from Taiwan to Spain, then distribution throughout the European Union.

Table 10. High Transportation Scenario

Mode	**From**	**To**	**Distance (km)**	**Source**
Truck	Tainan, Taiwan	Kaohsiung, Taiwan	86	TLM
Ocean Freight	Kaohsiung, Taiwan	Barcelona, Spain	15,341	SeaRates.com[53]
Truck	Port of Barcelona	Manufacturer (Frankfurt)	1339	Maps.google.com[54]
Truck	Distributor	User	122	Eurostat[55]

3.2.2.2 Low Transportation Scenario

Table 11 exhibits the processes used to model the low transportation scenario for distribution in Japan. It models for transport to Shimizu, Japan, then distribution to Tokyo, Japan. Further areas are not considered because there are other ports that are in much closer proximity.

Table 11. Low Transportation Scenario

Mode	From	To	Distance (km)	Source
Truck	Tainan, Taiwan	Kaohsiung, Taiwan	86	TLM
Ocean Freight	Kaohsiung, Taiwan	Shimizu, Japan	2399	SeaRates.com[56]
Truck	Port of Shimizu	Tokyo, Japan	167	Maps.google.com[57]

3.2.3 End-of-Life Scenarios

3.2.3.1 Scenario A - Japan

Table 12 shows the processes used to model the end of life scenario in Japan.

Table 12. Japan End of Life Scenario

Material	Type	Percent	Source	Life Cycle Process Name	Life Cycle Data Source
Stone Paper	Incineration	100	See 2.2.8.2	Municipal solid waste (waste scenario) {JP}| treatment of municipal solid waste, incineration	Ecoinvent 3
Coated Paper	Incineration	100	See 2.2.8.2	Municipal solid waste (waste scenario) {JP}| treatment of municipal solid waste, incineration	Ecoinvent 3
PP Film	Incineration	100	See 2.2.8.2	Municipal solid waste (waste scenario) {JP}| treatment of municipal solid waste, incineration	Ecoinvent 3

3.2.3.2 Scenario B - Spain

Table 13 displays the processes used to model the end of lie scenario in Europe.

Table 13. Spain End of Life Scenario

Material	Type	Percent	Source	Life Cycle Process Name	Life Cycle Data Source
Stone Paper	Landfill	70	See 2.2.8.2	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill	Ecoinvent 3
	Incineration	30	See 2.2.8.2	Municipal solid waste (waste scenario) {ES}| treatment of municipal solid waste, incineration	Ecoinvent 3
Coated Paper	Landfill	70	See 2.2.8.2	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill	Ecoinvent 3
	Incineration	30	See 2.2.8.2	Municipal solid waste (waste scenario) {ES}| treatment of municipal solid waste, incineration	Ecoinvent 3
PP Film	Landfill	70	See 2.2.8.2	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill	Ecoinvent 3
	Incineration	30	See 2.2.8.2	Municipal solid waste (waste scenario) {ES}| treatment of municipal solid waste, incineration	Ecoinvent 3

4 Life Cycle Impact Assessment

4.1 LCIA Methodology

The software Simapro 8.1.0.60 created by Pre Consultants was used to model the LCA. Two life cycle impact assessment (LCIA) methods were used within Simapro to characterize the life cycle inventory data into midpoint impacts.

The following LCIA methods were chosen for this analysis:

TRACI 2.1 Version 1.03

The Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) is a midpoint oriented life cycle impact assessment methodology developed by the U.S. Environmental Protection Agency. Part of the life cycle modeled, including transportation and disposal, take place in the U.S., and the TRACI method is commonly used for U.S analyses. TRACI facilitates the characterization of environmental stressors that have potential effects, including ozone depletion, global warming, acidification, eutrophication, tropospheric ozone (smog) formation, ecotoxicity, human health criteria–related effects, human health cancer effects, human health noncancer effects, fossil fuel depletion, and land-use effects. All TRACI impact assessment categories will be characterized and compared across the products. See Figure X for the impact categories characterized.

ReCiPe Midpoint (Hierarchist) Version 1.12

The ReCiPe method was created by RIVM, CML, PRé Consultants, Radboud Universiteit Nijmegen and CE Delft. In ReCiPe 18 midpoint indicatiors and 3 endpoint indicators are determined. This method was chosen in addition to TRACI to provide additional impact categories focused on land use and water depletion. See Figure X for the impact categories characterized.

For the purpose of this LCA, characterization and normalization models were investigated. Valuation and weighting models were not used, as a single score comparison was not considered to be appropriate for the study.

4.2 LCIA Results

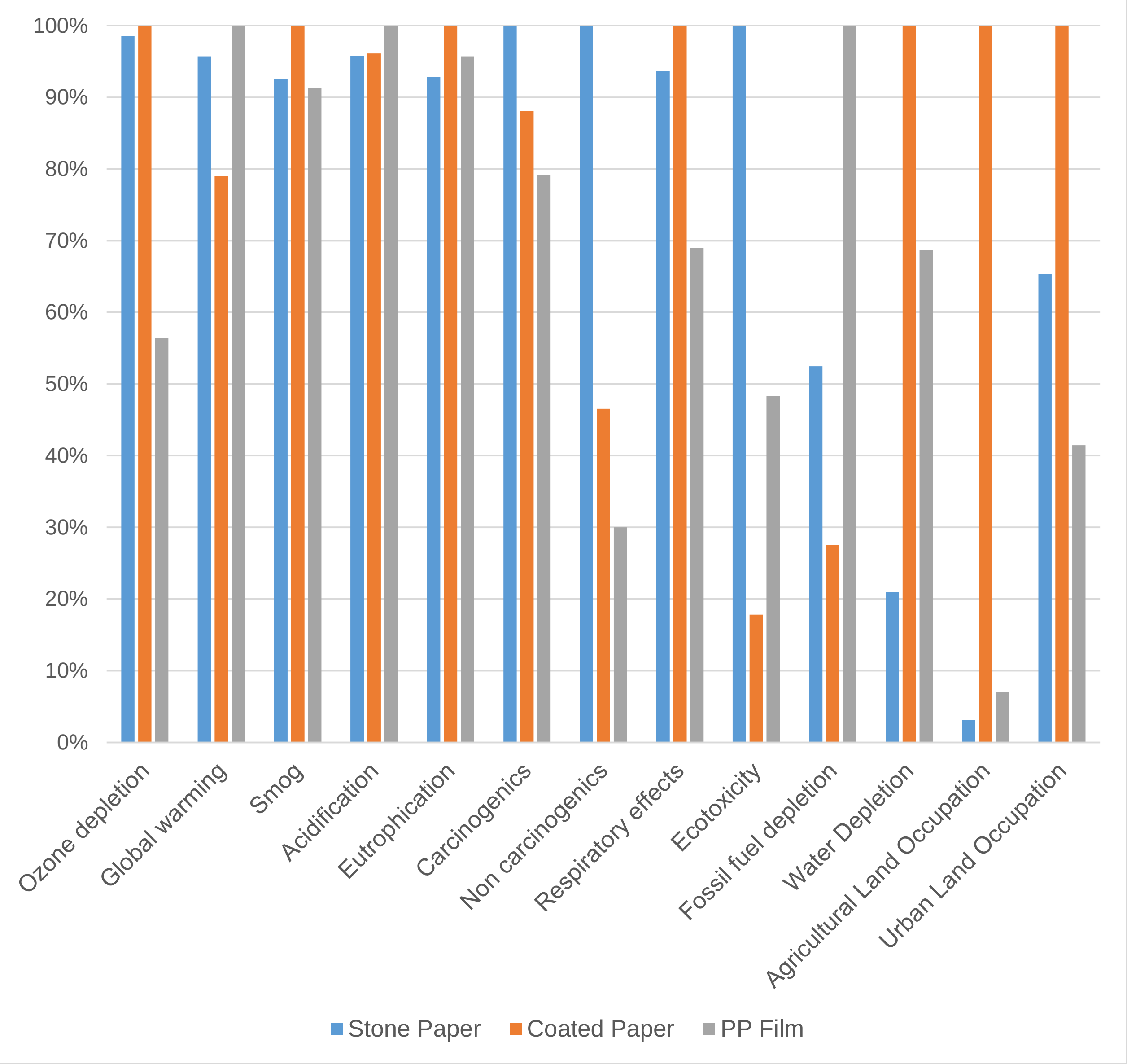
Table 14 below lists the TRACI and ReCiPe LCIA characterization results by impact category. The characterization and normalization results are also visualized below.

Table 14. LCIA Characterization Results

Impact Category	**Method**	**Characterization Unit**	**Stone Paper**	**Coated Paper**	**PP Film**
Ozone Depletion	TRACI 2.1	kg CFC-11 eq	2.03E-08	2.05E-08	1.16E-08
Global Warming	TRACI 2.1	kg CO2 eq	2.75E-01	2.27E-01	2.88E-01
Smog Formation	TRACI 2.1	kg O3 eq	1.71E-02	1.85E-02	1.69E-02
Acidification	TRACI 2.1	kg SO2 eq	1.17E-03	1.17E-03	1.22E-03
Eutrophication	TRACI 2.1	kg N eq	1.37E-03	1.47E-03	1.41E-03
Human Health Cancer (Carcinogenics)	TRACI 2.1	CTUh	1.04E-08	9.16E-09	8.23E-09
Human Health Noncancer (Non Carcinogenics)	TRACI 2.1	CTUh	1.73E-07	8.06E-08	5.20E-08
Human Health Particulate (Respiratory Effects)	TRACI 2.1	kg PM2.5 eq	1.70E-04	1.81E-04	1.25E-04
Ecotoxicity	TRACI 2.1	CTUe	1.34E+01	2.38E+00	6.45E+00
Fossil Fuel Depletion	TRACI 2.1	MJ surplus	4.81E-01	2.53E-01	9.17E-01
Water Depletion	ReCiPe 1.12	m3	9.56E-04	4.56E-03	3.14E-03
Agricultural Land Occupation	ReCiPe 1.12	m2a	1.15E-02	3.73E-01	2.64E-02
Urban Land Occupation	ReCiPe 1.12	m2a	2.64E-03	4.03E-03	1.67E-03

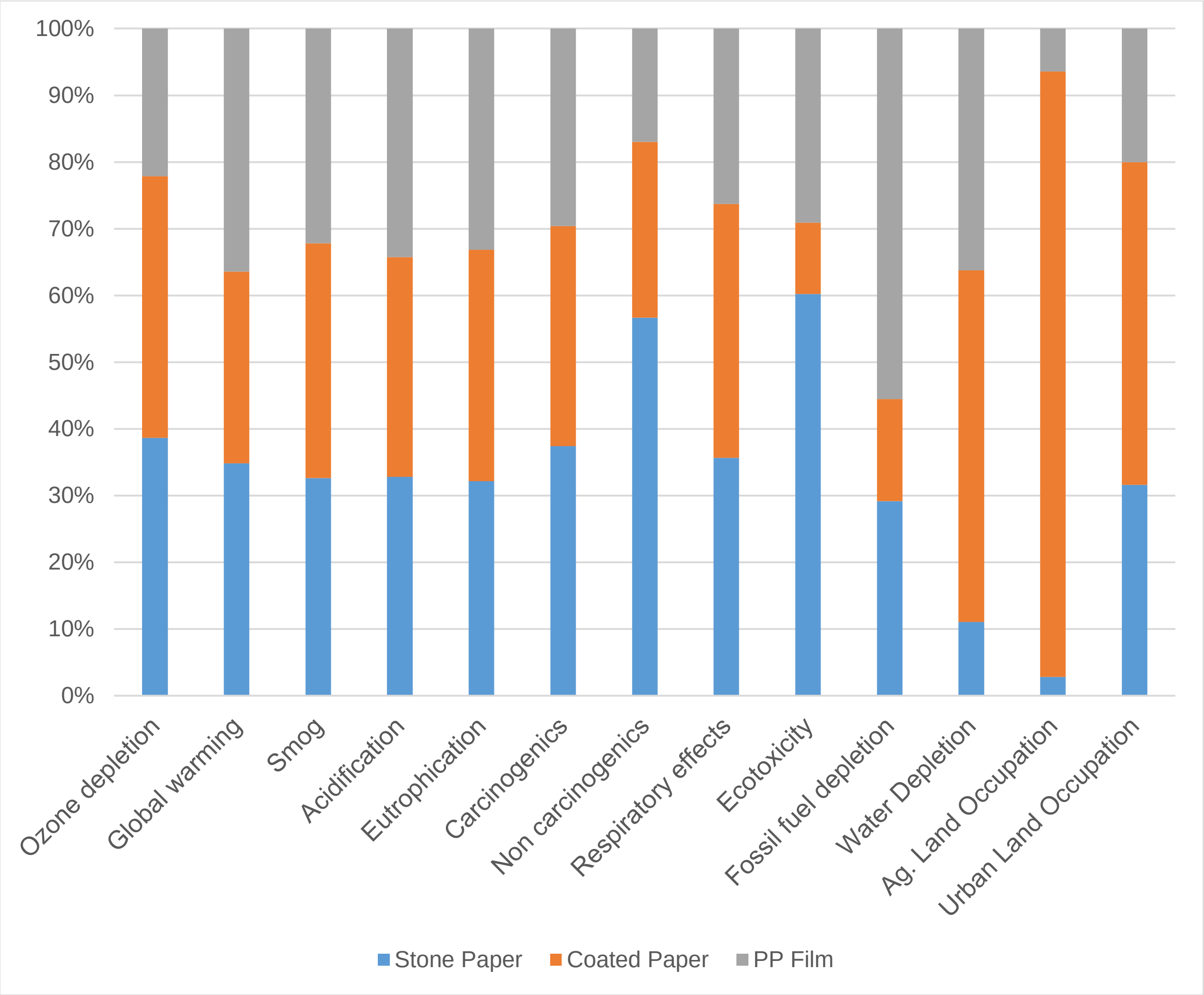
Figure 7 displays the impact assessment characterization results for each impact category and all three materials. The material with the largest impact factor result in each category is set at 100% and the other materials are scaled to it. The LCIA results are interpreted and discussed in this section of the report below.

Figure 7. LCIA Characterization Results



An alternate visualization of the baseline LCIA results is presented in Figure 8 presenting the relative share of all materials on one bar for each impact category.

Figure 8. LCIA Characterization Results Alternate Visualization



4.2.1 Product System LCIA Results by Life Cycle Stage

To understand the product life cycle impacts, Figures 9, 10, and 11 present the share of the impacts contributed to by each of the life cycle stages - production, transportation, and end of life – for each material and impact category separately.

Figure 9. Stone Paper LCIA Results by Life Cycle Stage

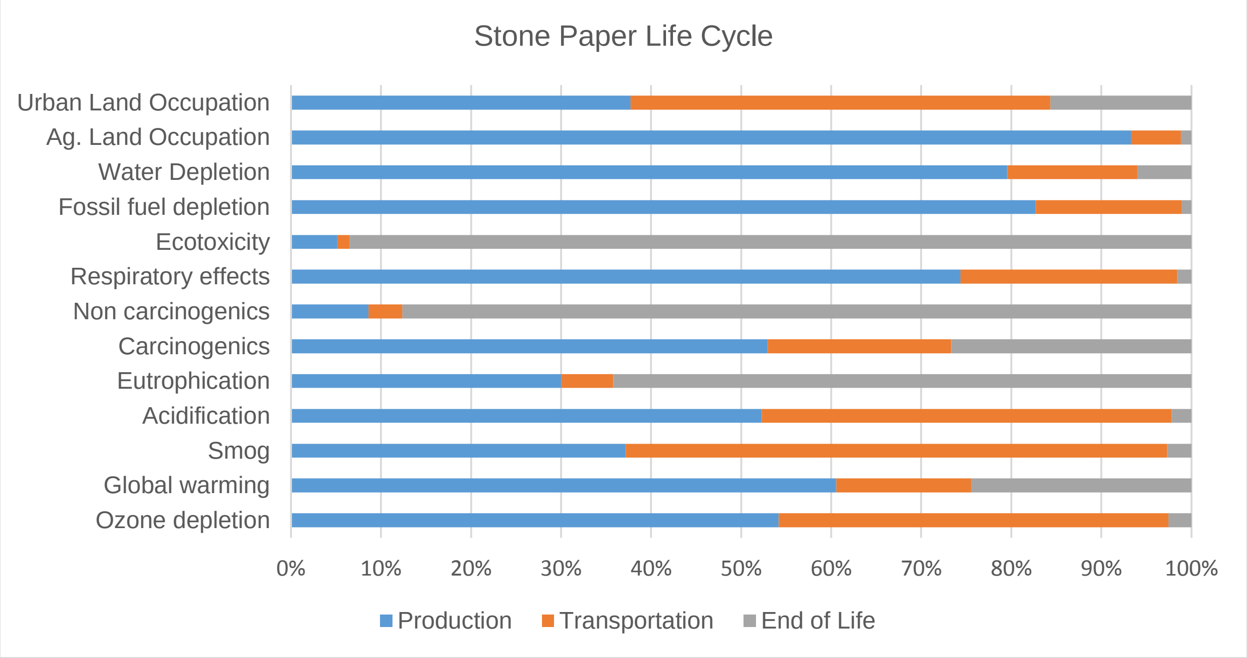


Figure 10. Coated Paper LCIA Results by Life Cycle Stage

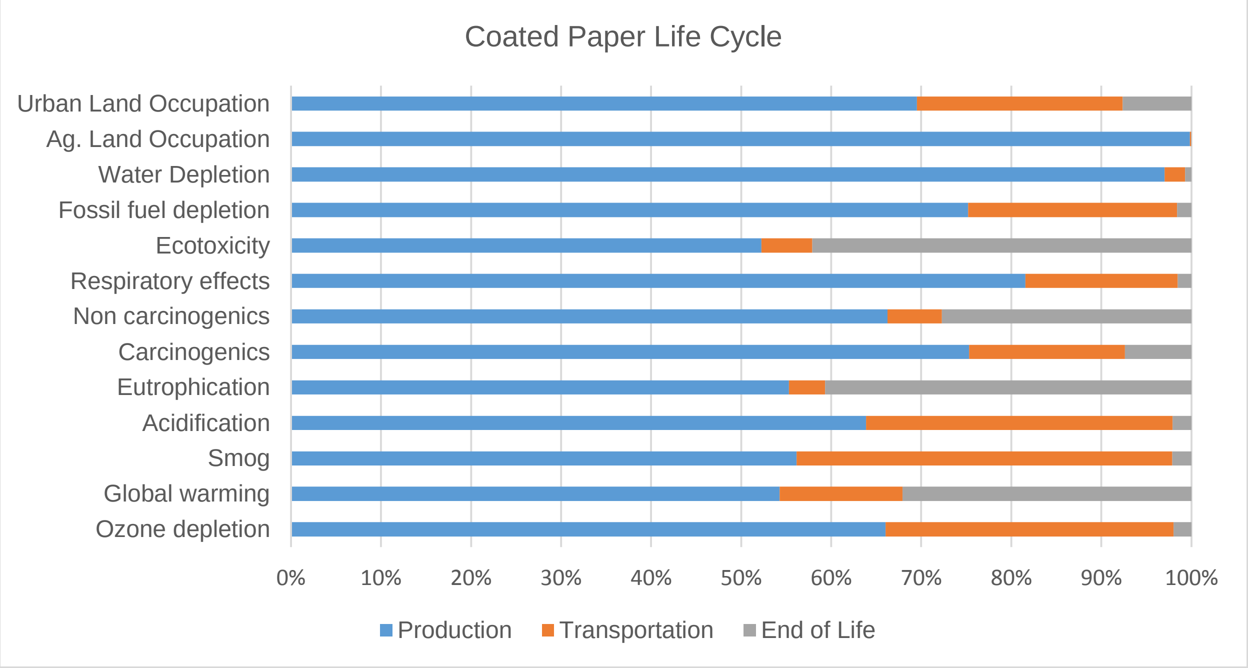
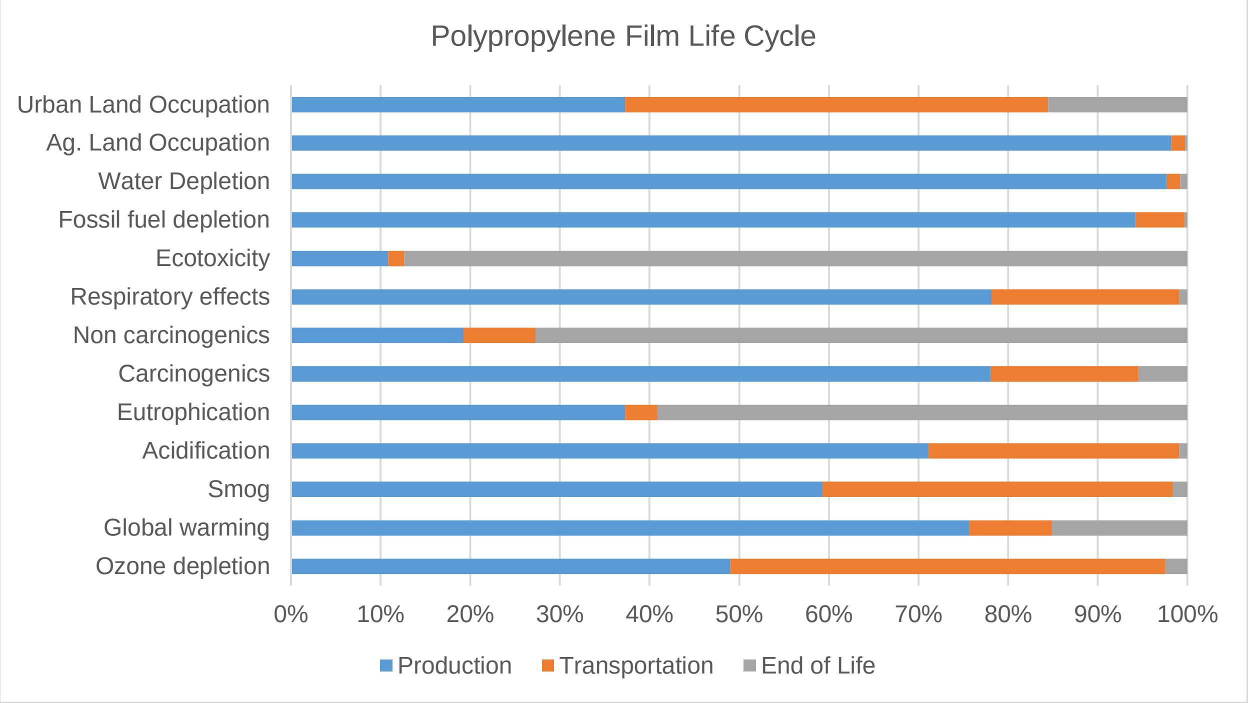


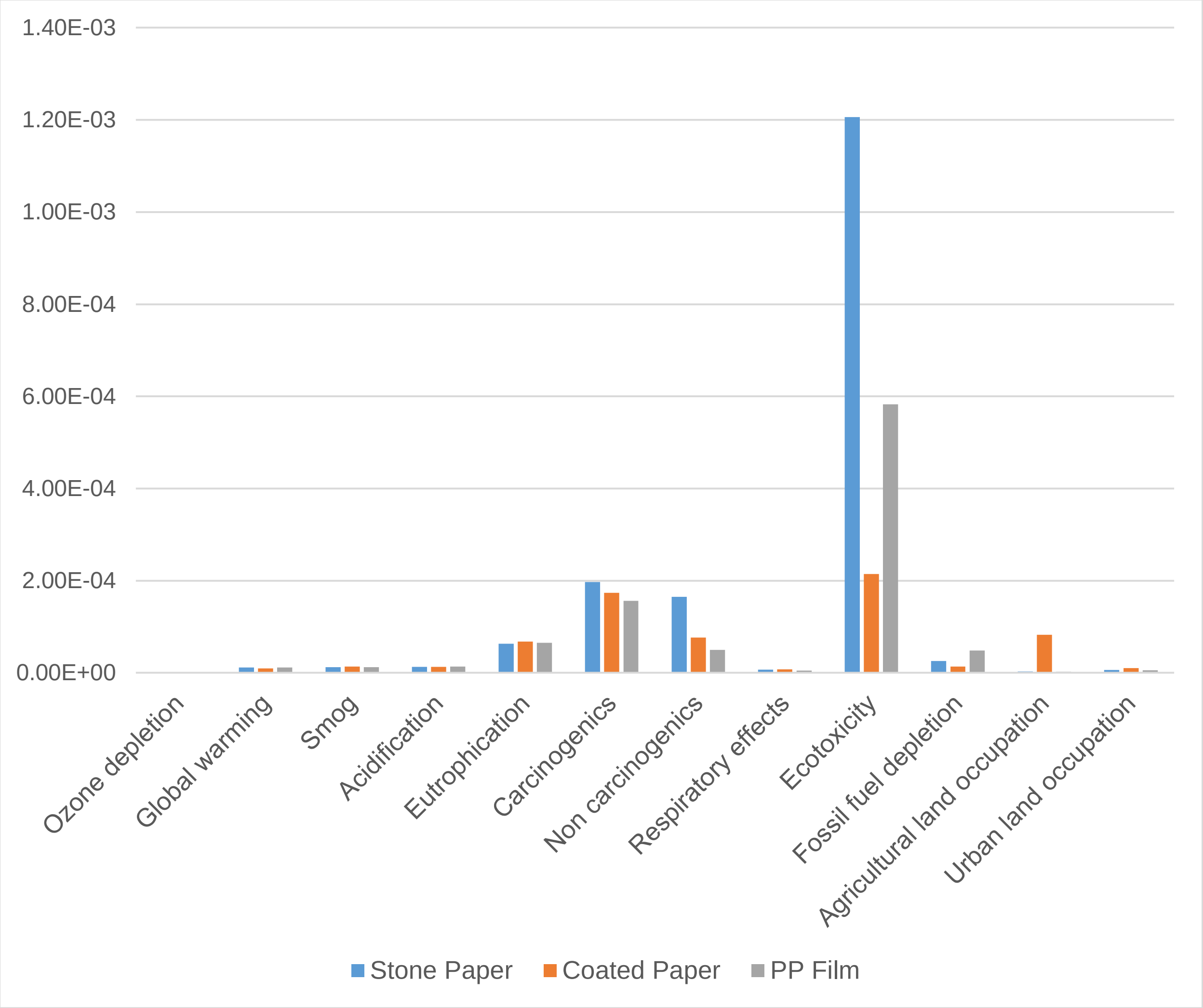
Figure 11. Polypropylene Film LCIA Results by Life Cycle Stage



4.2.2 Normalized LCIA Results

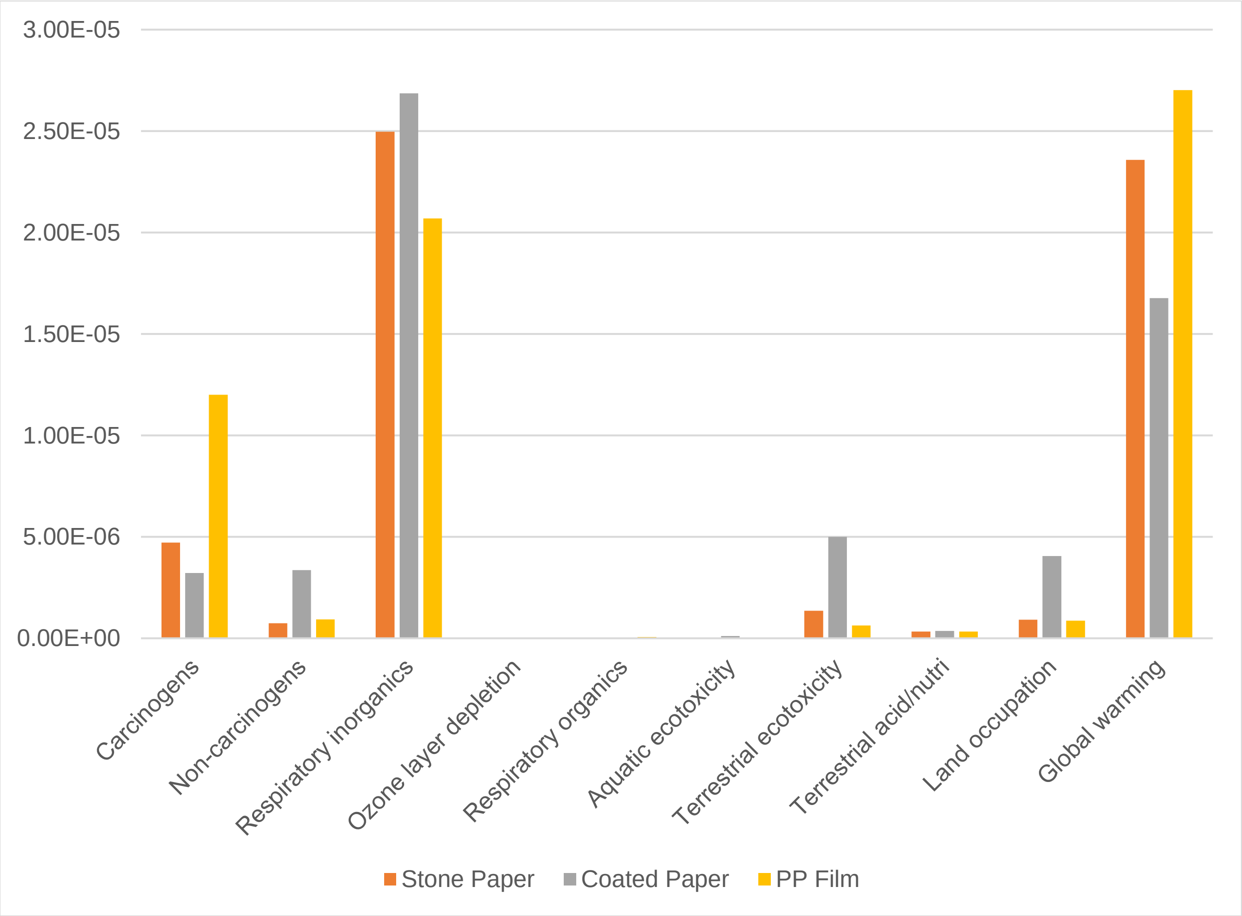
The SimaPro software was used to calculate the normalization of the LCIA characterization results. Normalization involves a calculation that translates the impact results to the proportion of average impacts caused by one person in one year. Normalization factors are important for relating LCIA results to a common reference. The TRACI impacts are normalized according to the impacts of the average person in the U.S. in the year 2008[58]. The ReCiPe impacts are normalized according to the impacts of the average person in Europe in the year 2000[59].

Figure 12. Normalized TRACI and ReCiPe LCIA Results



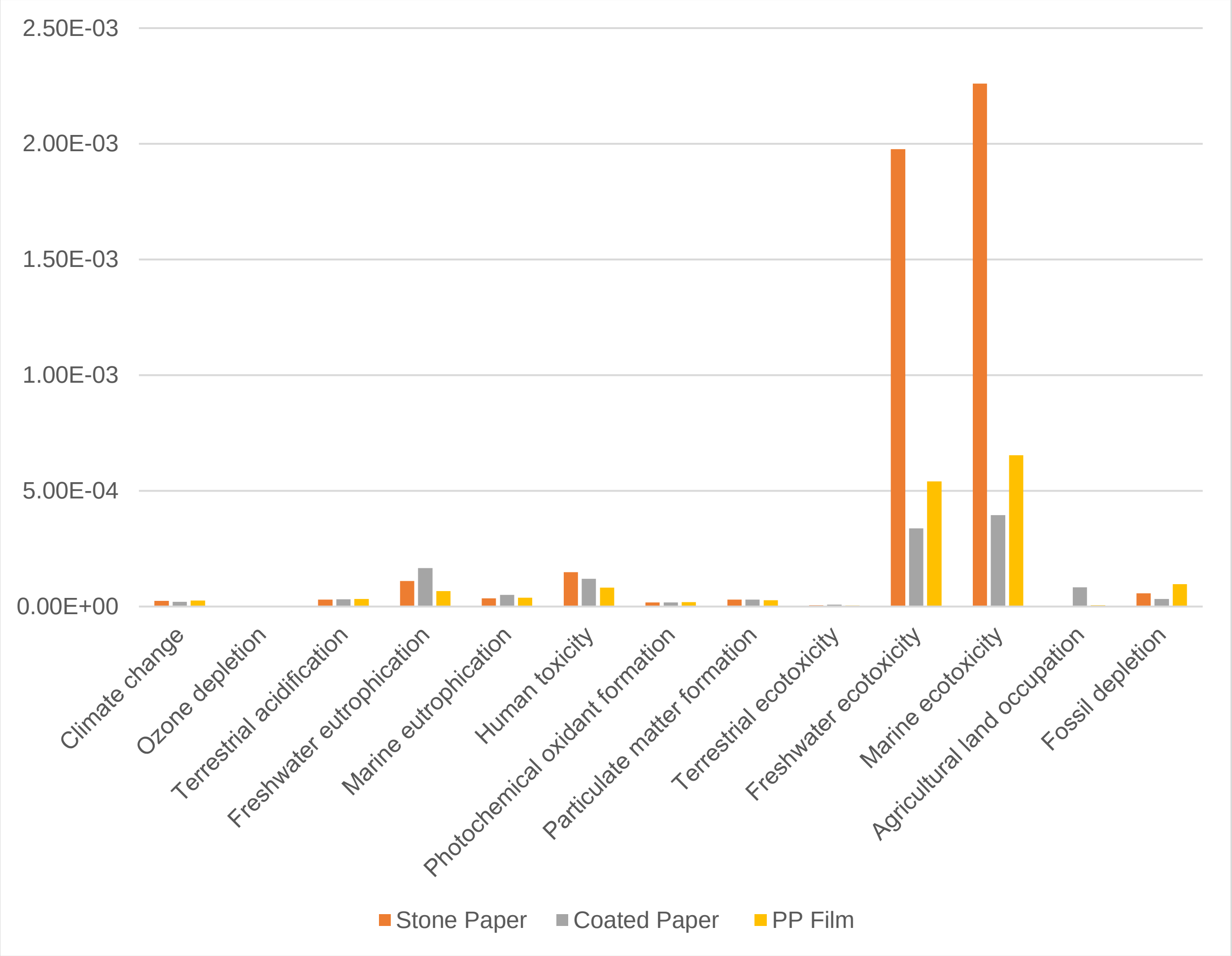
To further analyze life cycle impact assessment results, the life cycle inventory was modeled with the IMPACT 2002+ LCIA method. The IMPACT 2002+ method is a mid-point LCIA approach with novel calculations for human toxicity and aquatic & terrestrial ecotoxicity impact categories[60]. IMPACT 2002+ categories were chosen to closely match the categories of the TRACI method. It is notable that the normalized relative impacts across categories show ecotoxicity categories lower than the global warming and respiratory inorganics categories. Additionally, coated paper has the highest normalized impact in the terrestrial ecotoxicity category according to the IMPACT 2002+ method. This directly contradicts the findings from the TRACI LCIA results, which calculate the ecotoxicity impacts as the highest normalized impact among category and Stone Paper with the highest normalized ecotoxicity impact across products. This finding is important, because there is more than one way to calculate the LCIA results, and the choice of impact assessment method greatly affects the results in the case of this study. It must be recognized that secondary data were used to model the end of life impacts which contribute to the ecotoxicity category. To provide more confidence in the result, primary data would need to be collected for the end of life processes.

Figure 13. Normalized IMPACT 2002+ LCIA Results



To further assess the effect of choosing different LCIA methods, additional categories that closely match the TRACI impact categories were calculated using ReCiPe method. Figure 14 shows the normalized results of the impact categories. Note that the LCIA calculations used by the ReCiPe method provide a similar result to the TRACI results, in that the ecotoxicity categories provide the highest relative normalized impacts across categories and Stone Paper has the highest relative normalized impacts across products.

Figure 14. Normalized ReCiPe LCIA Results – Expanded Categories List



4.2.3 Ozone Depletion

Ozone within the stratosphere provides protection from radiation, which can lead to increased frequency of skin cancers and cataracts in the human populations. Additionally, ozone has been documented to have effects on crops, other plants, marine life, and human-built materials. There is international consensus on the use of ozone depletion potentials (ODPs) for calculating the relative importance of substances expected to contribute significantly to the breakdown of the ozone layer. Within TRACI 2.1, the most recent sources of ODPs were used for each substance[61].

For the ozone depletion impact category, coated paper has the highest impact while stone paper only has a slightly smaller impact compared with coated paper. PP film has the lowest impact among the three materials. However, the impact on ozone depletion is relatively small across the impact categories for all three materials after normalization. Production and transportation combined contribute to more than 95% of the impact while end-of-life has a negligible contribution to ozone depletion for all three materials.

For Stone Paper, the largest contributions to ozone depletion impacts come from the production of the electricity used during the manufacturing process. The next largest contributions come from ocean freight transportation and freight train transportation. Regarding coated paper, the largest contributor is the paper production process followed by ocean freight shipping and rail freight shipping. For PP film, the impacts stem from the extrusion process, first, followed by ocean freight shipping and rail freight shipping. For all products, the ozone depletion impacts stem from air emissions of halogenated methane and ethane substances.

4.2.4 Global warming

“Global warming is an average increase in the temperature of the atmosphere near the Earth’s surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human induced. In common usage, “global warming” often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities. During the last 200 years, the sources of greenhouse gases have increased (mostly caused from the increased combustion of fossil fuels), while the sinks have decreased (e.g., deforestation and land use changes). TRACI 2.1 utilizes global warming potentials (GWPs) for the calculation of the potency of greenhouse gases relative to CO2 consistent with the guidance of the United Nations Framework Convention on Climate Change with 100-year time horizons”[62].

The global warming potential is the highest for PP film while the lowest for coated paper. Same as ozone depletion, the impact on global warming for all three materials after normalization is relatively small. The production phase of all three materials dominates the global warming impact.

For all three products, the top contributors to global warming impacts are carbon dioxide air emissions released from fossil fuel sources and methane air emissions released from biogenic and fossil fuel sources. For Stone Paper, electricity production used in the manufacturing process, the production of HDPE granulate material, and the treatment of MSW by landfill are the largest contributing processes. For coated paper, the paper production process, treatment of waste graphic paper in a landfill, and transportation by freight rail contribute the most. For PP film, the production of polypropylene granulate, plastic film extrusion, and treatment of waste polypropylene by municipal incineration are largest contributing processes.

4.2.5 Photochemical Smog Formation

“Ground level ozone is created by various chemical reactions, which occur between nitrogen oxides and volatile organic compounds in sunlight. Human health effects can result in a variety of respiratory issues including increasing symptoms of bronchitis, asthma, and emphysema. Permanent lung damage may result from prolonged exposure to ozone. Ecological impacts include damage to various ecosystems and crop damage. The primary sources of ozone precursors are motor vehicles, electric power utilities and industrial facilities.” TRACI 2.1 uses Maximum Incremental Reactivity values for nearly 1,200 substances to model smog formation impacts[63].

Stone paper has the highest smog impact among the three materials. The normalized impact for all three materials is small relative to other impact categories. Transportation dominates the smog impact for Stone Paper while for coated paper and PP film production phase contributes the most.

99.7% of the smog category impacts result from emissions of nitrogen oxides for all three products. The top contributions to smog impacts for Stone Paper derive from ocean freight shipping, rail freight shipping, and electricity production in Taiwan used in the manufacturing process, in order of contribution. For coated paper, the largest contributor to smog impacts come from the paper production process, followed by ocean freight shipping and rail freight shipping. And for PP film, polypropylene granulate production, ocean freight shipping, and plastic film extrusion contribute the most to smog impacts.

Transportation is an important factor in the product life cycles in terms of smog impacts, and this is a category in which the differing densities between products becomes important. Stone Paper is the densest material in the comparison, followed by coated paper and PP film. When the equivalent size products are shipped across the globe, the difference in density creates different energy requirements to ship. This ultimately results in the burning of more fuel to ship denser products, and hence the creation of more emissions and transportation emission impacts. A similar result can be seen in other impact categories with notable transportation contributions.

4.2.6 Acidification

“Acidification is the increasing concentration of hydrogen ion within a local environment. Substances, which cause acidification, can cause damage to building materials, paints, and other human-built structures, lakes, streams, rivers, and various plants and animals. TRACI 2.1 uses an acidification model which incorporates the increasing hydrogen ion potential within the environment without incorporation of site-specific characteristics such as the ability for certain environments to provide buffering capability”[64].

There is not much practical difference in the acidification impact among coated paper, Stone Paper, and PP film. The normalized impact of all three materials is also small across impact categories. Production for coated paper and PP film is most important in contributing to acidification while production and transportation are equally important for stone paper.

98% of acidification impacts for all three categories derive from the air emissions of sulfur dioxide and nitrogen dioxides. The chief contributing process for Stone Paper are ocean freight transport, electricity production in Taiwan, and rail freight transport, in order of impact. For coated paper, the paper production process, ocean freight transport, and rail freight transport are the main contributors. For PP film, polypropylene granulate production, plastic film extrusion, and ocean freight transport are main contributors.

4.2.7 Eutrophication

“Eutrophication is the enrichment of an aquatic ecosystem with nutrients (nitrates, phosphates) that accelerate biological productivity (growth of algae and weeds) and an undesirable accumulation of algal biomass.” TRACI 2.1 characterizes nitrogen, phosphorus and additional substances, which have the potential to cause eutrophication[65].

The eutrophication impact is highest for coated paper and lowest for Stone Paper, although they have a very similar level of impact. This is a surprising result. As expected, the majority of the coated paper eutrophication impact comes from the production phase. End-of-life is important for coated paper, stone paper and PP film. For Stone Paper and PP film, end-of-life contributes to more than 60% of the total eutrophication impact while for coated paper end-of-life contributes to 40%. Production phase in coated paper is the most dominant contributing to more than 50% of the total eutrophication impact.

Eutrophication impacts occur from releases to water in the product life cycles. For Stone Paper, chemical oxygen demand (COD), phosphate, and biological oxygen demand (BOD) provide the largest impact, in order. 92% of impacts are from treatment of MSW in a landfill, treatment of waste polyethylene in a landfill, and electricity production in Taiwan used in the manufacturing process. For coated paper, phosphate, COD, and nitrate releases provide the largest impacts, in order of impacts. 98% of impacts are from the paper production process, treatment of waste graphical paper in a landfill, and the production offset printing ink, in order of impact. And for PP film, COD, nitrates, and BOD contribute the most to eutrophication impacts. 95% of impacts are from treatment of waste polypropylene in a landfill, plastic film extrusion process, and production of offset printing ink, in order of impact.

4.2.8 Human Health Cancer (Carcinogenics)

Various international multimedia model developers created a global consensus model known as USEtox, which was used to develop human health cancer and noncancer toxicity potentials and freshwater ecotoxicity potentials for over 3,000 substances, including organic and inorganic substances. The USEtox model is the basis for the TRACI impact categories of human health cancer, noncancer, and ecotoxicity. EPA notes that some of the characterization factors included within the USEtox model are recommended while others are simply interim and should be used with caution.

The LCIA carcinogenics category shows that Stone Paper has the highest relative impact, whereas PP film has the lowest relative impact. The difference between them is not remarkably large; the impacts of PP film are still 79% of the impacts of Stone Paper and the impacts of coated paper are 88% of the Stone Paper impacts. The normalized effects show that carcinogenics have a relatively large effect compared to other impact categories – the effects are the second highest for each respective material. The production phase is the main area of contribution towards carcinogenics in all three materials. Production phase accounts for over 75% in PP film and coated paper, whereas in Stone Paper production phase only accounts for just over 50% of impacts, with the difference coming from increased impacts from end of life processes. The large normalized effect makes it important for the impact category to be further studied, especially in the case of Stone Paper and why the life cycle stages differ compared to the other materials.

98.5% of modeled impacts for Stone Paper stem from the release of chromium VI to water, nickel to water, and chromium to air, in order of contribution. The largest contributing processes are electricity from electricity production in Taiwan, treatment of MSW in a landfill, and production of HDPE, in order. 98% of the modeled impacts for coated paper come from the release of chromium VI to water, chromium to air, and nickel to water, in order of contribution to impacts. Impacts stem from the paper production process, rail freight transport, and treatment of waste graphical paper by municipal incineration, followed by other processes. 98.7% of modeled carcinogenics impacts from PP film derive from the release of chromium VI to water, chromium to air, and arsenic to water, in order of contribution to impacts. The major contributing processes are the production of polypropylene, extrusion of plastic film, and rail freight transport.

4.2.9 Human Health Noncancer (Non carcinogenics)

Non carcinogenic effects on human health are highest in stone paper. Coated paper non carcinogenic effects are halved compared to stone paper, whereas PP film effects are under 30% of the effects of stone paper. The effects as seen from normalized data show relatively large impact compared to other impact categories, especially for stone paper. The end of life phase is dominant in this category for both stone paper and polypropylene film, whereas in coated paper, the production phase is the main factor in producing these effects. This difference between materials is notable, and thus should have further investigation done on its processes. Moreover, relatively high normalized effects for this impact category further suggests that one should look deeper into its processes.

97% of modeled impacts for Stone Paper are from the emission of zinc, arsenic, and lead to water, in order of contribution to impacts. Major contributing processes are the treatment of MSW in a landfill, treatment of MSW by incineration, and electricity production in Taiwan. 90% of modeled impacts for coated paper are from emissions of zinc to water and soil, and arsenic to water, in order of contribution to impacts. Major contributing processes are paper production, treatment of graphical paper in a landfill, and treatment of solid waste in a landfill. 93% of modeled impacts for PP film are from emissions of zinc, arsenic, and vanadium to water, in order of contribution to impacts. The major contributing processes are treatment of waste polypropylene in a landfill, extrusion of plastic film, and treatment of MSW in a landfill.

4.2.10 Human Health Particulate (Respiratory effects)

This category deals with particulate matter and precursors to particulates. Particulate matter is a collection of small particles in ambient air which have the ability to cause negative human health effects including respiratory illness and death. Particulate matter may be emitted as particulates, or may be the product of chemical reactions in the air. Common sources of primary and secondary particulates are fossil fuel combustion, wood combustion, and dust particles from roads and fields. The method for calculation of human health impacts includes the modeling of the fate and exposure into intake fractions[66].

The respiratory effects impact category results show very similar levels between coated paper and Stone Paper, and PP film has lower impacts compared to the other two. All three materials show the production phase as being the major contributor to respiratory effects impacts from air emissions. The normalized graph shows a low impact from respiratory effects on human health compared the normalized results of other impact categories.

For all three products, the modeled respiratory effects impacts for all three products are at least 96% from the release of PM2.5 to air, sulfur dioxide to air, and PM10 to air, in order of contribution to impacts. For Stone Paper, the top three contributing processes are electricity production in Taiwan, ocean freight transportation, and rail freight transportation. For coated paper, the top three contributing processes are paper production, ocean freight transportation, and rail freight transportation. For PP film, the top three contributing processes are extrusion of plastic film, production of polypropylene granulate, and ocean freight transportation.

4.2.11 Ecotoxicity

Ecotoxicity impacts show stone paper as having the largest impact, with PP film having less than half the impact that stone paper has, and coated paper having less than 20% of stone paper. The vast majority of this impact in stone paper and PP film comes from the end of life phase, while for coated paper the effects are more equally concentrated around production and end of life phases. The transportation phase has the least effect across all three materials. These observations alone could warrant extra research into processes, but the largest reason that this impact category is mandatory to understand better is due to the normalization, where it has by far the largest impact on human health.

Ecotoxicity impacts primarily stem from the release of toxic heavy metals to water. 97% of modeled impacts for Stone Paper are from the release of copper, zinc, and vanadium to water, in order. 96% of modeled impacts for coated paper are from the release of copper, zinc, and nickel to water, in order. 97% of modeled impacts for PP film are from the release of vanadium, zinc, and copper to water, in order.

The ecotoxicity impacts are primarily caused by emissions during the production and end of life stages. For Stone Paper, 97% of impacts derive from the treatment of solid waste in a landfill, the treatment of polyethylene waste in a landfill, and the treatment of MSW by incineration. For coated paper, 95% of impacts result from paper production, the treatment of waste graphical paper in a landfill, and the treatment of MSW in a landfill. For PP film, 95% of impacts are from the treatment of waste polypropylene in a landfill, the treatment of waste polypropylene by incineration, and plastic film extrusion.

EPA has noted that there is a dominance of metals to the human and ecotoxicity categories and that there is a need to refine the characterization factors within the USEtox model. For example, a paper by the TRACI creators notes that soil emissions of metals are significantly higher than expected[67].

4.2.12 Fossil Fuel Depletion

A non site-specific fossil fuel use characterization is used in TRACI to model fossil fuel resource depletion.

Fossil fuel depletion impacts are the highest in PP film, whereas stone paper has slightly over half the effect, and coated paper has just under 30%. This is presumably due to its nature as a plastic, which is produced from fossil fuels. This also explains why stone paper has higher impact than coated paper, due to its use of HDPE. Fossil fuel depletion is dominated by the production phase for each material, with end of life being the least significant in each case. While normalization shows that impacts of fossil fuel depletion are but not negligible relative to other impact categories, further study into the processes of each material will not be necessary due to the predictability of this impact category, based on materials used.

For Stone Paper, coated paper, and PP film, 99% of modeled fossil fuel depletion impacts come from the use of crude oil, natural gas, and hard coal, in order. For Stone Paper, the production of HDPE granulate, production of electricity in Taiwan, and rail freight transportation provide the largest share of fossil resource depletion impacts. For coated paper, paper production, rail freight transportation, and ocean freight transportation contribute the most. And for PP film, the largest fossil fuel depletion impacts come from the production of polypropylene granulate, plastic film extrusion, and the production of offset printing ink.

4.2.13 Water Depletion

As expected, coated paper dominates the water depletion impact category, which stems almost entirely from the production phase. In fact, the production phase contributes more than 90% of water depletion impacts for each of the products. Comparatively, the water depletion impacts of PP Film are characterized at 69% of coated paper’s impacts and the water depletion impacts of Stone Paper are characterized at 21% of coated paper’s impacts. Water depletion impacts modeled in the Ecoinvent process stem from hydropower generation and water used for various processes, including cooling. The Normalization factors for the water depletion impact category are not included in the ReCiPe method, so the relative impacts compared to the other categories are unknown.

4.2.14 Agricultural Land Occupation

The agricultural land occupation impacts are also dominated by the production phase for each of the products, contributing to more than 90% of impacts. Also as anticipated, given the use of wood as a primary feedstock, coated paper completely dominates this impact category. The Ecoinvent production process models a number of land occupation categories for coated paper, and the largest process is land occupation from intensive forestry. Agricultural land occupation impacts are modeled at 7% of coated paper's for PP Film and 3% of coated paper's for Stone Paper. This makes sense, because both products are made primarily from materials that are mined or extracted. A small amount of arable and forest land occupation is modeled for the production of both products in the Ecoinvent processes. The TRACI normalization method shows the coated paper agricultural land occupation impact as the next highest relative category after three of the health and toxicity categories.

4.2.15 Urban Land Occupation

As with agricultural land occupation, the urban land occupation impact category is dominated by coated paper, but to a lesser degree. The processes modeled by the Ecoinvent data include railways, roads, and industrial areas. The urban land occupation impact of Stone Paper is calculated at 65% of the impact of coated paper, and impact of PP film is calculated at 41% of coated paper. This impact category represents one piece of the footprint of a product life cycle. For coated paper, a majority of the impact derives from production land occupation, but for Stone Paper and PP film the transportation phase provides the largest share of urban land occupation impacts.

5 Sensitivity Analysis

5.1 Transportation Scenarios

A sensitivity analysis was carried out investigating the two transportation scenarios described in 3.2.2.1 and 3.2.2.2. This analysis was carried out for TRACI categories and investigated the impact categories for which the transportation life cycle stage consistently had a large effect, relative to other impact categories. The impacts from the categories of ozone depletion, smog, and acidification all had over 30% contribution from the transportation life cycle across the three materials, with the exception of acidification in PP film, which had 28%.

Figure 15. High Transportation Characterization Results for Selected Impact Categories

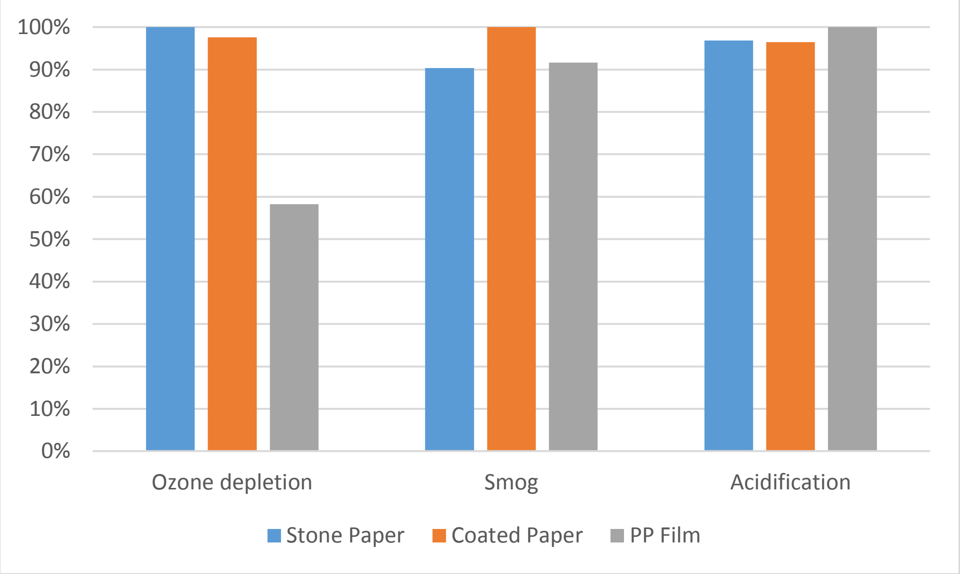
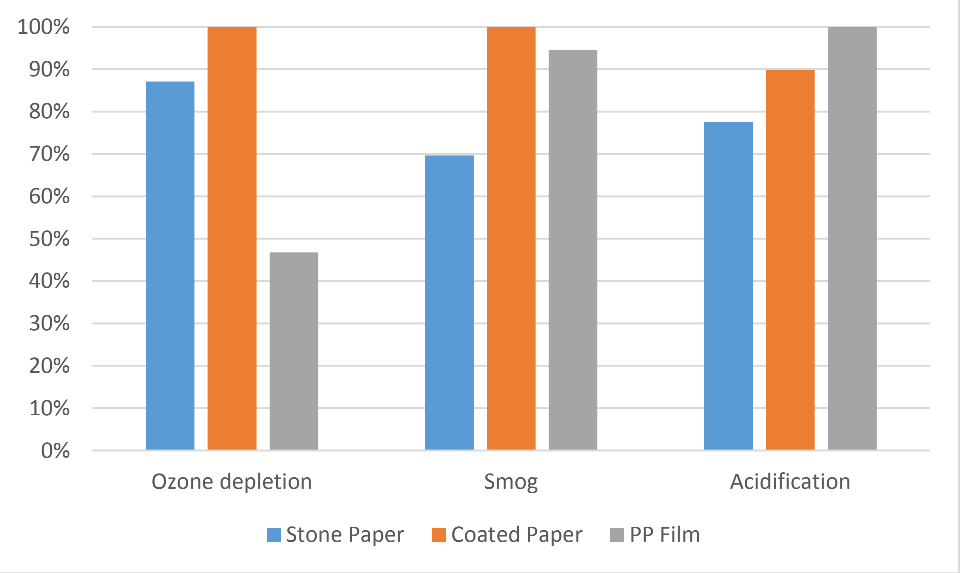


Figure 16. Low Transportation Characterization Results for Selected Impact Categories



The figures show that Stone Paper benefits the most from a low transportation scenario. In the low transportation scenario, Stone Paper has a lower ozone depletion impact compared to coated paper, and also clearly has the lowest impact of all three materials in both the smog and acidification categories.

However, in the high transportation scenario, it is now the highest impact material in ozone depletion. In smog and acidification, it is not the highest impact, but is now comparable to the other materials in its impact, rather than being clearly the lowest impact.
For both PP film and coated paper, based on the three selected impact categories, they do not perform definitely better or worse between the two transportation scenarios, relative to the other products. PP film performs better in the acidification impact category in a high transportation scenario, where although it is still the worst option, the other materials are much closer in their impact. However, its impact in the ozone depletion category in low transportation is relatively

better at 47% of the highest impact material, compared to the high transportation scenario of 58%. A similar story can be seen for coated paper, where relative impact decreases in the acidification category in low transportation compared to high, but the ozone depletion category shows an increased relative impact in low transportation compared to high.

Thus, it can be concluded that only Stone Paper clearly prefers one scenario over another, whereas for the other materials, one would have to make judgments about which impact category to prioritize before making deciding which scenario is more preferable. It should be noted that in order to make a more comprehensive claim about whether Stone Paper prefers one option to another, one could also investigate more impact categories.

5.2 End-of-Life Scenarios

A sensitivity analysis was carried out to investigate the two transportation scenarios described in 3.2.3.1 and 3.2.3.2. This analysis was carried out for TRACI categories and investigated the impact categories for which the end of life phase consistently had a large effect, relative to other impact categories. The impacts from the categories of eutrophication, non carcinogenics, and ecotoxicity all had over 25% contribution from the end of life phase across the three materials. In some materials, the contribution from the end of life phase was over 90% of the impact for the category.

Figure 17. Japan End of Life Scenario Results for Selected Impact Categories

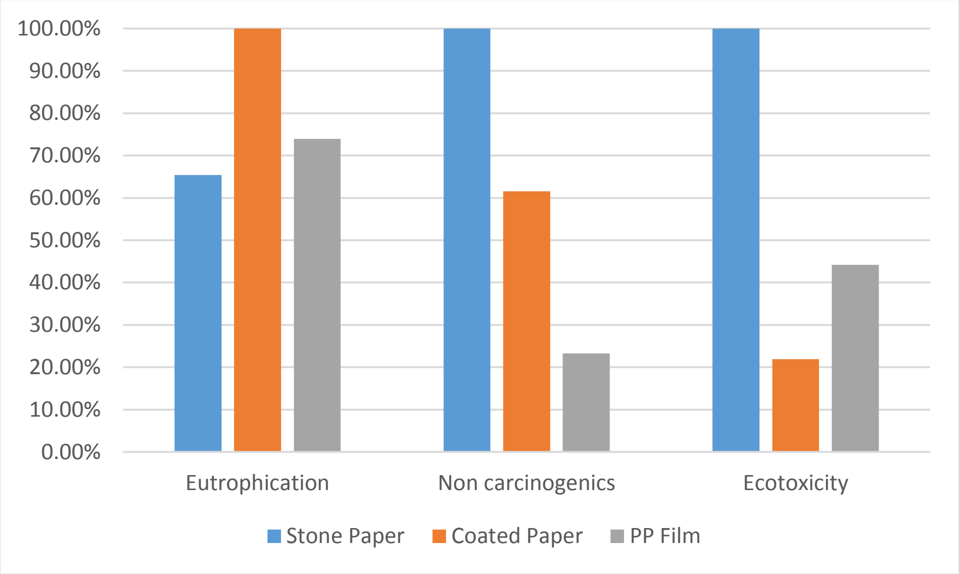
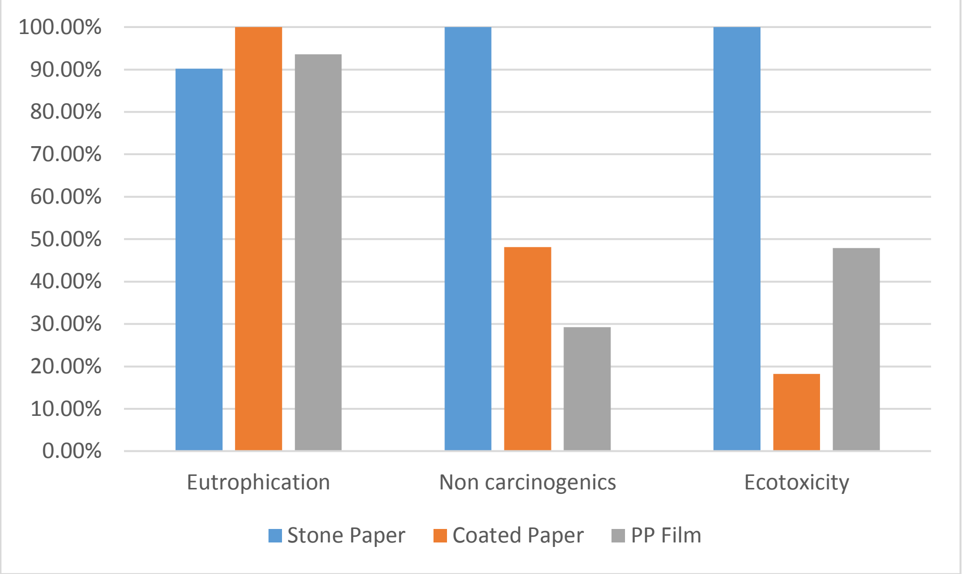


Figure 18. Europe End of Life Scenario Results for Selected Impact Categories



Compared to coated paper, Stone Paper performs better in the Japan scenario for non carcinogenics and ecotoxicity compared to the Europe scenario. Coated paper has 60% of the effect of Stone Paper in non carcinogenics in the Japan scenario, as compared to under 50% in the Europe scenario. A similar case can be seen in the ecotoxicity category, where impacts of coated paper drop from 22% of Stone Paper in Japan, to 18% in Europe.

This finding is supported by the results in the eutrophication impact category. Stone Paper eutrophication impact is only around 65% of the impact of coated paper in the Japan scenario, whereas it increases to 90% in the Europe scenario.

However, the opposite effect takes place compared to PP film, where Stone Paper performs relatively better in Europe compared to Japan in the impact categories of non carcinogenics and ecotoxicity. The relative impact of PP film compared to Stone Paper from the Japan to Europe scenarios increases from 23% to 29% in non carcinogenics, and from 44% to 48% in ecotoxicity.

Coated paper in fact performs better relatively in every impact category in the Europe scenario, compared to the Japan scenario. Coated paper in the eutrophication category performs in the Europe scenario (the materials are 90-95% of its impacts) compared to the Japan scenario (where the other materials are 60-75% of its impacts). A decrease in relative impact is seen in both non carcinogenics and ecotoxicity going from the Japan to Europe scenarios as well.

PP Film in this case is similar to coated paper in the sense that it is clearly better in one scenario relative to the other, except for the fact that it prefers the Japan scenario. Its impacts relative to the highest impact material in all three cases is lower in the Japan scenario than the Europe scenario.

It can be concluded that coated paper seems to prefer the landfill option more than the other materials based on the selected impact categories, as the difference between landfilling and incineration are the main differences in the end of life strategy for both scenarios. On the other hand, PP film prefers the Japan scenario with higher incineration in order to reduce end of life impacts. Meanwhile, Stone Paper is neutral between the two scenarios, until determinations are made about weighting of importance of impact categories. As with the transportation sensitivity, including more impact categories would allow for more comprehensive conclusions.

6 Improvement Analysis

6.1 Introduction

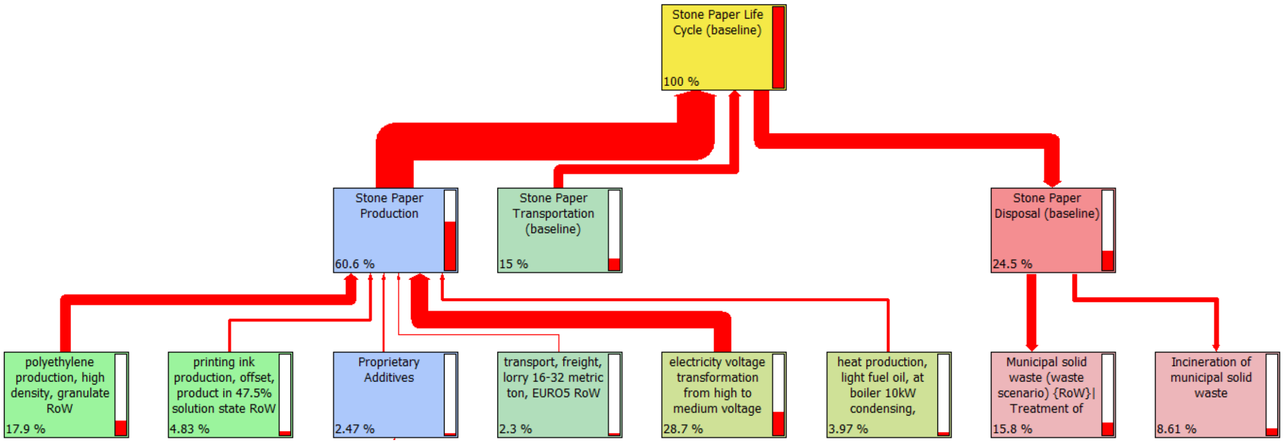
This section provides an improvement analysis focused on Stone Paper's life cycle. The improvement analysis has two focuses. The first focus is to analyze opportunities to reduce life cycle greenhouse gas emissions according to the TRACI Global Warming impact characterization. The strategies will then also be used to analyze opportunities to reduce life cycle photochemical oxidation potential emissions according to the TRACI Smog impact characterization.

6.2 Opportunities for Improvement

Figure 19 displays a network diagram with characterization results of the Stone Paper life cycle for the TRACI Global Warming indicator. The diagram shows the relative contributions of processes to modeled life cycle of a Stone Paper label. The diagram is displayed with 1% of contributing processes cut off.

The network diagram allows an interpretation of the processes that may be prioritized for life cycle improvements. Considering the network diagram for Stone Paper Global Warming life cycle impacts, the three largest contributing processes are the electricity used in the manufacturing process at 28.7%, the HDPE granulate material input at 17.9%, and the disposal in landfill at the end of life at 15.8%. The first part of this improvement analysis will focus on changes that could be made in the production process to improve the impact profile of the electricity and HDPE inputs. Changes to the production process are much more feasible for TLM to control compared to changes in the end-of-life processes. End-of-life improvement considerations will be discussed later in the improvement analysis.

Figure 19. Network diagram of Stone Paper life cycle



6.2.1 Electricity

The electricity life cycle inventory has relatively high data quality in this model. TLM receives electricity from the grid from TaiPower, which is Taiwan’s only major electric utility. Ecoinvent 3 includes a process that models the Taiwan grid mix, so the data quality can be considered high. Overall, the electricity used in production contributes heavily to a number of the impact categories studied in this LCA. The next sections develop scenarios to test improvement effects on life cycle greenhouse gas releases.

6.2.1.1 Energy Efficiency

The energy efficiency scenario assumes that a 20% electricity use reduction is feasible from energy efficiency efforts. This was modeled by reducing the electricity process in the life cycle inventory. Table 15 shows the new electricity inventory value.

Background research shows that a 10% to 30% reduction is feasible in typical processes. For example, major areas for improvement in the petrochemical industry are utilities, fired heaters, process optimization, heat exchangers, motor and motor applications, and other areas. Optimization of utilities is among the opportunities that require the lowest investment costs and experiences of various companies show that required investments are modest[68]. A U.K. industry report describes 10-20% energy use reductions to pelletizing and extrusion processes without major capital outlay[69]. A 10% per year reduction is considered achievable for U.S. plastic manufacturers[70], and other general industry energy efficiency reports show opportunities for reductions up to 30%[71,72].

Table 15. Energy Efficiency Scenario Life Cycle Process Changes

Processes	**Value**	**Unit**	**Life Cycle Process Name**	**Life Cycle Data Source**
Electricity	0.0751	kWh	Electricity, medium voltage {TW}| electricity voltage transformation from high to medium voltage	Ecoinvent 3

In addition to the 20% reduction scenario, the life cycle kgCO2 equivalent reductions per 1% electricity use reduction was calculated. For each 1% reduction in electricity use, the life cycle GHGs are decreased by 0.3% for Stone Paper.

6.2.1.2 Renewable Electricity from Rooftop PV Solar Panels

At the time of the report, TLM was researching the use of roof top photovoltaic solar panels to provide electricity to the manufacturing facility. Ecoinvent 3 includes processes for electricity from roof top photovoltaic solar panels, and two renewable electricity scenarios were tested. The scenarios are a 50% production process electricity from roof top PV solar scenario and 100% production process electricity from PV solar scenario. Table 16 shows the inventory values and life cycle processes used to calculate the scenarios.

Table 16. Renewable Electricity Scenario Life Cycle Process Changes

Processes	Value	Unit	Life Cycle Process Name	Life Cycle Data Source
50% Scenario				
Roof-top Solar	0.0469	kWh	Electricity, low voltage {RoW}| electricity production, photovoltaic, 3kWp flat-roof installation, single-Si	Ecoinvent 3
Electricity	0.0469	kWh	Electricity, medium voltage {TW}| electricity voltage transformation from high to medium voltage	Ecoinvent 3
100% Scenario				
Roof-top Solar	0.0938	kWh	Electricity, low voltage {RoW}| electricity production, photovoltaic, 3kWp flat-roof installation, single-Si	Ecoinvent 3

6.2.2 Materials

6.2.2.1 Recycled HDPE

The life cycle impacts from the HDPE granulate material inputs contribute the second highest share of life cycle Global Warming impacts. TLM have developed a version of Stone Paper with recycled material inputs, and this is modeled in the improvement analysis using a U.S. Life Cycle Inventory recycled postconsumer HDPE pellet process. Table 17 shows the new process used to model the recycled HDPE scenario.

Table 17. Recycle HDPE Scenario Life Cycle Process Changes

Materials	Value	Unit	Life Cycle Process Name	Life Cycle Data Source
Recycled HDPE	0.0255	kg	Recycled postconsumer HDPE pellet/RNA	USLCI

6.2.2.2 Material Density

Stone Paper is the densest material compared in this LCA. If one picks up a Stone Paper notebook and paper notebook, the difference in the weight of the materials is apparent. This stems from the composition of the Stone Paper material, which is mostly calcium carbonate. In terms of the life cycle assessment, the material density results in a higher mass reference flow for the same area and thickness product functional unit. This requires higher mass-distance factors for transportation and more mass treated for waste disposal.

Dematerialization may be one strategy to consider to produce a similar thickness product with a lower density. It is unknown if this strategy is feasible, but it would certainly result in lower life cycle impacts, especially compared with competing products.

6.2.3 Improvement Scenario Results

Figure 20 exhibits life cycle improvement results from the electricity and material improvement scenarios compared to the baseline scenario. In ascending order of reduction from the baseline are the energy efficiency, recycled HDPE, 50% solar, and 100% solar improvement scenarios. Combining improvement scenarios results in additional reductions from the baseline, although there is a notable diminishing returns effect when the energy efficiency reductions are completed in addition to the implementation of 100% solar and recycled HDPE.

Figure 20. Global Warming Impact Category Life Cycle Improvement Results for Stone Paper

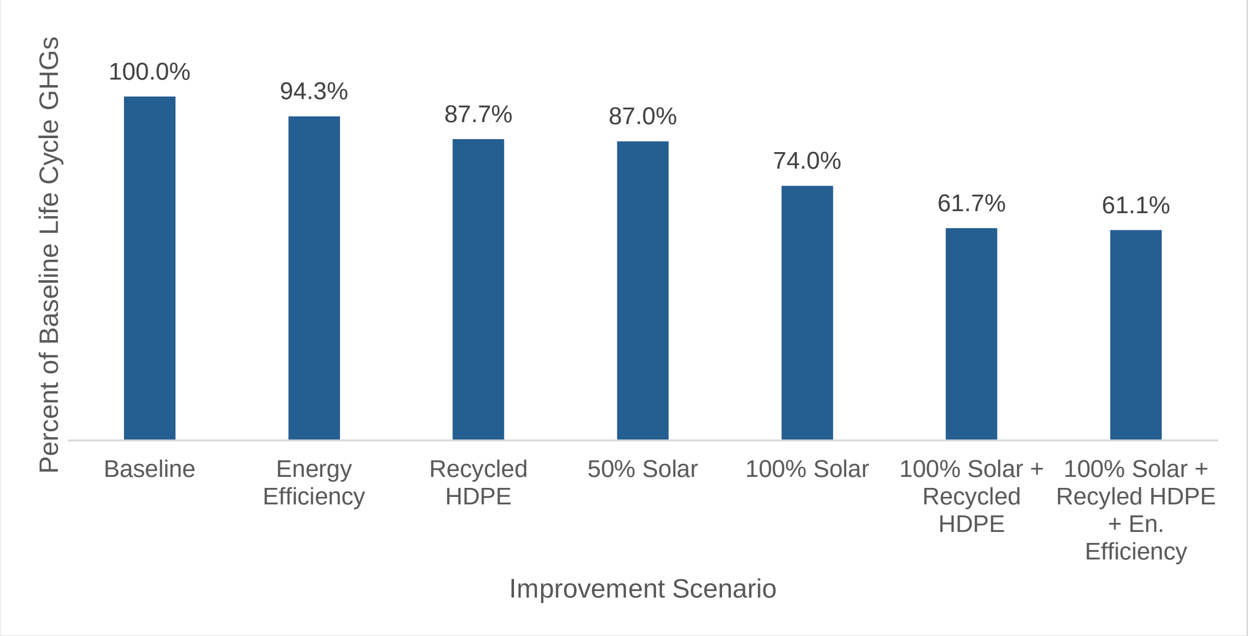


Figure 21 shows the life cycle results for the electricity and material improvement scenarios for the Smog impact category compared to the baseline scenario.

Figure 21. Smog Impact Category Life Cycle Improvement Results for Stone Paper

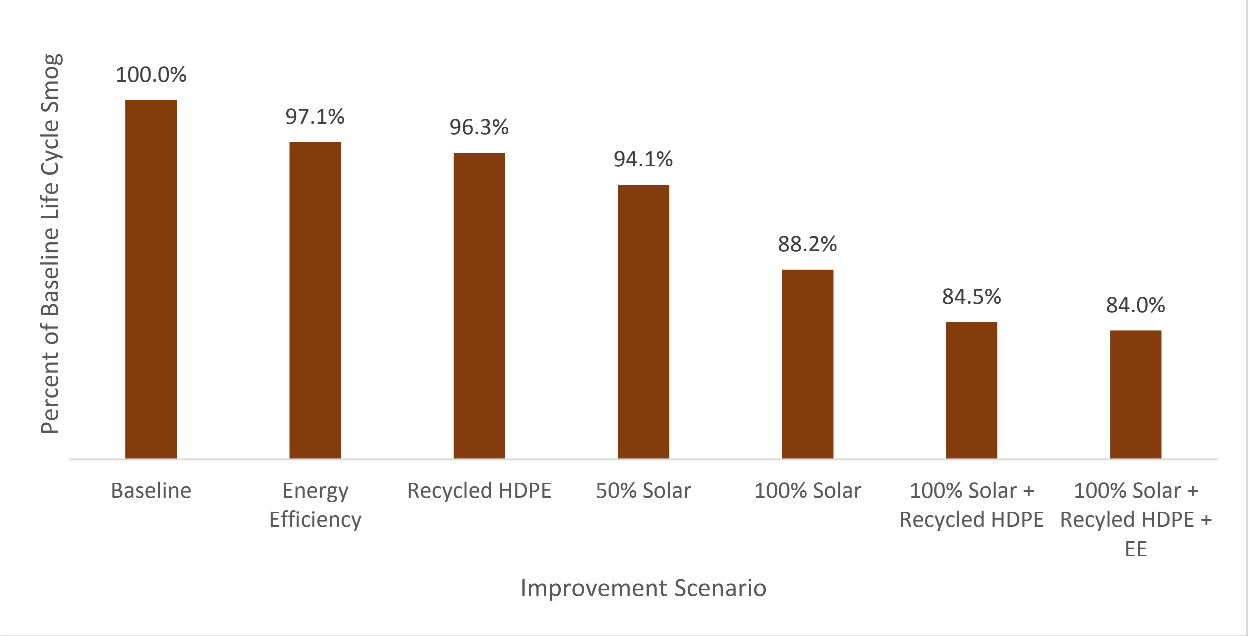
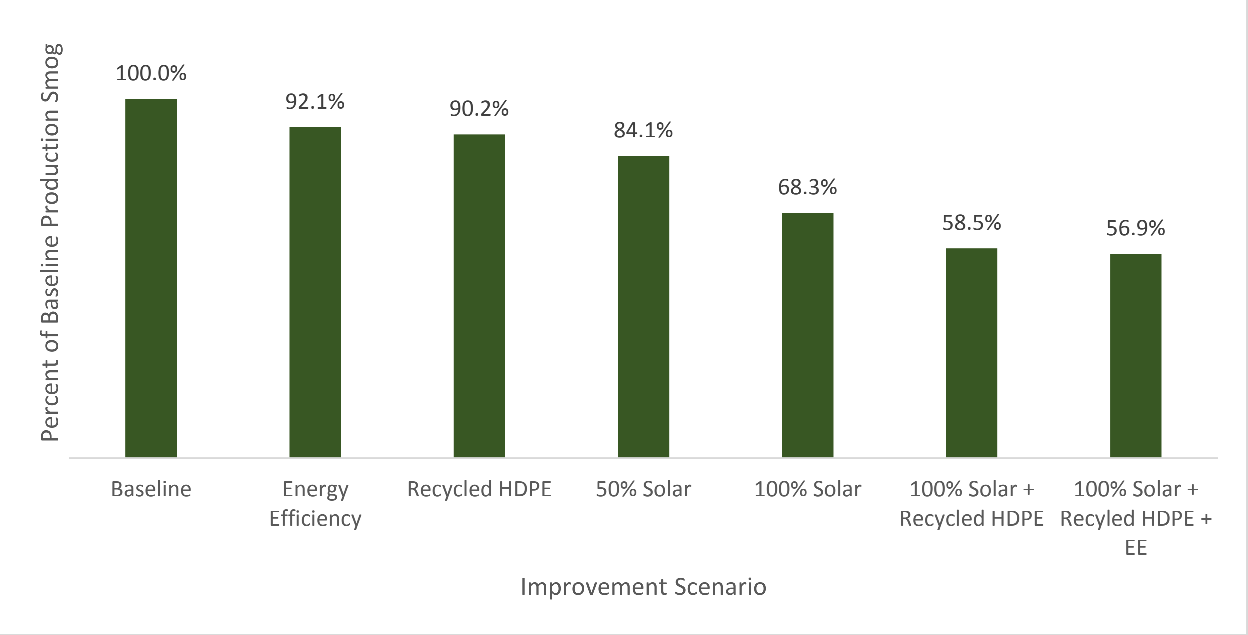


Figure 22 displays the production results for the electricity and material improvement scenarios for the Smog impact category compared to the baseline scenario.

Figure 22. Smog Impact Category Production Improvement Results for Stone Paper



Electricity production and virgin HDPE production contribute a significant share of impacts to several LCIA categories for Stone Paper, including smog formation. The results from Figures 21 and 22 show the reductions that can be achieved by the improvement scenarios in the smog formation category. Figure 22 specifically shows reductions in the production phase, which is important to consider. The energy and materials are sourced from Taiwan, and smog formation is an environmental concern in urban and industrial areas. Notable improvements can be made in the production phase.

7 Conclusions

The results of this analysis show that it cannot be stated that one product is better than another across the full range of life cycle impacts studied. The use of each product involves tradeoffs compared to the use of the other products. This LCA can help inform material selection and provide information about relative impacts. Each decision maker should decide what attributes matter, including life cycle impacts, and this study can help to inform those decision makers.

Future studies of Stone Paper could work to refine the life cycle inventory and compare different product systems, because Stone Paper material can be used in numerous ways. Future work could also include modeling the implementation of the improvement analysis scenarios. The scenarios show that the Stone Paper life cycle could be significantly improved by focusing on improving the profile of the electricity used in production through energy efficiency or the use of renewable energy. Improvement analysis also shows that the Stone Paper life cycle could be improved by incorporating postconsumer recycled HDPE content.

Appendix A – Stone Paper Life Cycle Inventory Emissions

No	Substance	Compartment	Unit	Total
1	1-Butanol	Air	kg	4.61E-11
2	1-Butanol	Water	kg	1.72E-09
3	1-Pentanol	Air	kg	7.82E-12
4	1-Pentanol	Water	kg	1.88E-11
5	1-Pentene	Air	kg	6.05E-12
6	1-Pentene	Water	kg	1.42E-11
7	1-Propanol	Air	kg	1.98E-09
8	1-Propanol	Water	kg	6.92E-11
9	1,4-Butanediol	Air	kg	8.11E-11
10	1,4-Butanediol	Water	kg	1.86E-10
11	2-Aminopropanol	Air	kg	9.17E-12
12	2-Aminopropanol	Water	kg	2.21E-11
13	2-Butene, 2-methyl-	Air	kg	1.46E-14
14	2-Butene, 2-methyl-	Water	kg	3.51E-14
15	2-Methyl-1-propanol	Air	kg	2.56E-11
16	2-Methyl-1-propanol	Water	kg	6.14E-11
17	2-Methyl-4-chlorophenoxyacetic acid	Soil	kg	8.10E-13
18	2-Nitrobenzoic acid	Air	kg	2.01E-11
19	2-Propanol	Air	kg	3.12E-09
20	2-Propanol	Water	kg	8.66E-11
21	2,4-D	Air	kg	1.48E-09
22	2,4-D	Soil	kg	4.08E-07
23	4-Methyl-2-pentanone	Water	kg	2.60E-11
24	Acenaphthene	Air	kg	2.54E-12
25	Acenaphthene	Water	kg	6.37E-12
26	Acenaphthylene	Air	kg	9.36E-14
27	Acenaphthylene	Water	kg	3.98E-13
28	Acephate	Air	kg	1.58E-10
29	Acephate	Soil	kg	6.88E-11
30	Acetaldehyde	Air	kg	1.92E-07
31	Acetaldehyde	Water	kg	9.22E-09
32	Acetamide	Air	kg	3.88E-11
33	Acetamide	Soil	kg	9.99E-12
34	Acetic acid	Air	kg	6.11E-07
35	Acetic acid	Water	kg	1.17E-08
36	Acetochlor	Soil	kg	1.69E-11
37	Acetone	Air	kg	1.68E-07
38	Acetone	Water	kg	2.28E-10
39	Acetonitrile	Air	kg	3.33E-08
40	Acetonitrile	Water	kg	3.04E-11

41	Acetyl chloride	Water	kg	1.47E-11
42	Acidity, unspecified	Water	kg	5.67E-08
43	Acifluorfen	Air	kg	2.17E-11
44	Acifluorfen	Soil	kg	9.28E-13
45	Aclonifen	Soil	kg	1.27E-13
46	Acrolein	Air	kg	1.52E-08
47	Acrylate	Water	kg	7.82E-13
48	Acrylic acid	Air	kg	3.30E-13
49	Actinides, radioactive, unspecified	Air	Bq	9.59E-03
50	Actinides, radioactive, unspecified	Water	Bq	2.76E-04
51	Aerosols, radioactive, unspecified	Air	Bq	8.44E-06
52	Alachlor	Air	kg	1.53E-10
53	Alachlor	Soil	kg	1.69E-11
54	Aldehydes, unspecified	Air	kg	5.17E-09
55	Aldicarb	Soil	kg	2.09E-10
56	Aldrin	Soil	kg	2.25E-09
57	Allyl chloride	Water	kg	2.44E-12
58	Aluminium	Raw	kg	5.28E-05
59	Aluminium	Air	kg	5.06E-06
60	Aluminium	Water	kg	1.26E-03
61	Aluminium	Soil	kg	6.07E-07
62	Amidosulfuron	Soil	kg	5.06E-15
63	Ammonia	Air	kg	4.91E-06
64	Ammonium carbonate	Air	kg	3.13E-11
65	Ammonium, ion	Water	kg	1.26E-04
66	Anhydrite	Raw	kg	9.67E-08
67	Aniline	Air	kg	5.92E-11
68	Aniline	Water	kg	1.42E-10
69	Anthranilic acid	Air	kg	1.56E-11
70	Anthraquinone	Soil	kg	2.08E-13
71	Antimony	Air	kg	5.14E-07
72	Antimony	Water	kg	1.27E-06
73	Antimony	Soil	kg	5.89E-11
74	Antimony-122	Water	Bq	6.84E-06
75	Antimony-124	Air	Bq	2.62E-08
76	Antimony-124	Water	Bq	3.37E-03
77	Antimony-125	Air	Bq	1.77E-07
78	Antimony-125	Water	Bq	3.35E-04
79	AOX, Adsorbable Organic Halogen as Cl	Water	kg	1.33E-08
80	Argon	Raw	kg	3.35E-06
81	Argon-40	Air	kg	8.84E-07
82	Argon-41	Air	Bq	1.58E-02
83	Arsenic	Air	kg	1.69E-08

84	Arsenic	Water	kg	3.93E-07
85	Arsenic	Soil	kg	5.02E-10
86	Arsine	Air	kg	3.84E-18
87	Asulam	Soil	kg	1.40E-11
88	Atrazine	Air	kg	1.21E-10
89	Atrazine	Soil	kg	7.15E-10
90	Azoxystrobin	Air	kg	7.17E-11
91	Azoxystrobin	Soil	kg	1.39E-11
92	Barite	Raw	kg	8.63E-05
93	Barite	Water	kg	1.80E-06
94	Barium	Air	kg	2.46E-07
95	Barium	Water	kg	2.53E-05
96	Barium	Soil	kg	2.70E-07
97	Barium-140	Air	Bq	1.95E-05
98	Barium-140	Water	Bq	5.08E-05
99	Basalt	Raw	kg	6.00E-06
100	Benomyl	Soil	kg	2.31E-11
101	Bentazone	Air	kg	6.63E-11
102	Bentazone	Soil	kg	3.06E-12
103	Benzal chloride	Air	kg	2.94E-15
104	Benzaldehyde	Air	kg	1.06E-08
105	Benzene	Air	kg	1.38E-06
106	Benzene	Water	kg	1.07E-07
107	Benzene, 1-methyl-2-nitro-	Air	kg	1.74E-11
108	Benzene, 1,2-dichloro-	Air	kg	1.45E-10
109	Benzene, 1,2-dichloro-	Water	kg	1.12E-08
110	Benzene, chloro-	Water	kg	1.72E-08
111	Benzene, ethyl-	Air	kg	3.28E-08
112	Benzene, ethyl-	Water	kg	2.52E-08
113	Benzene, hexachloro-	Air	kg	1.47E-11
114	Benzene, pentachloro-	Air	kg	1.52E-11
115	Benzo(a)anthracene	Air	kg	1.81E-15
116	Benzo(a)pyrene	Air	kg	3.43E-09
117	Benzo(b)fluoranthene	Air	kg	2.14E-15
118	Benzo(g,h,i)perylene	Air	kg	1.32E-16
119	Benzo(k)fluoranthene	Air	kg	1.55E-15
120	Beryllium	Air	kg	1.89E-10
121	Beryllium	Water	kg	8.34E-06
122	Bifenox	Soil	kg	5.34E-14
123	Bifenthrin	Soil	kg	6.16E-14
124	Bitertanol	Soil	kg	2.24E-14
125	BOD5, Biological Oxygen Demand	Water	kg	3.41E-03
126	Borate	Water	kg	2.64E-09

127	Borax	Raw	kg	1.37E-08
128	Boric acid	Air	kg	4.20E-15
129	Boron	Air	kg	3.74E-07
130	Boron	Water	kg	3.62E-06
131	Boron	Soil	kg	5.80E-09
132	Boron trifluoride	Air	kg	2.82E-11
133	Bromate	Water	kg	3.14E-08
134	Bromide	Water	kg	1.63E-07
135	Bromine	Raw	kg	1.86E-07
136	Bromine	Air	kg	1.86E-07
137	Bromine	Water	kg	6.16E-06
138	Bromine	Soil	kg	5.88E-10
139	Bromoxynil	Soil	kg	3.19E-13
140	Bromuconazole	Soil	kg	1.64E-17
141	Butadiene	Air	kg	5.04E-12
142	Butane	Air	kg	1.43E-06
143	Butene	Air	kg	2.71E-08
144	Butene	Water	kg	3.30E-10
145	Butyl acetate	Water	kg	2.10E-09
146	Butyrolactone	Air	kg	7.56E-13
147	Butyrolactone	Water	kg	1.81E-12
148	Cadmium	Raw	kg	1.64E-07
149	Cadmium	Air	kg	4.07E-09
150	Cadmium	Water	kg	1.75E-06
151	Cadmium	Soil	kg	7.07E-10
152	Calcite	Raw	kg	9.65E-02
153	Calcium	Air	kg	2.01E-06
154	Calcium	Water	kg	2.57E-03
155	Calcium	Soil	kg	2.89E-06
156	Carbaryl	Air	kg	1.81E-11
157	Carbaryl	Soil	kg	9.58E-13
158	Carbendazim	Soil	kg	1.06E-10
159	Carbetamide	Soil	kg	1.68E-11
160	Carbofuran	Soil	kg	1.26E-08
161	Carbon	Air	kg	1.19E-11
162	Carbon	Water	kg	4.08E-11
163	Carbon	Soil	kg	1.75E-06
164	Carbon-14	Air	Bq	1.22E+00
165	Carbon-14	Water	Bq	3.39E-04
166	Carbon dioxide, biogenic	Air	kg	2.74E-02
167	Carbon dioxide, fossil	Air	kg	2.11E-01
168	Carbon dioxide, in air	Raw	kg	6.38E-03
169	Carbon dioxide, land transformation	Air	kg	3.34E-03

170	Carbon disulfide	Air	kg	1.30E-07
171	Carbon disulfide	Water	kg	4.69E-11
172	Carbon monoxide, biogenic	Air	kg	8.37E-06
173	Carbon monoxide, fossil	Air	kg	5.25E-04
174	Carbon monoxide, land transformation	Air	kg	1.92E-05
175	Carbon, organic, in soil or biomass stock	Raw	kg	9.06E-04
176	Carbonate	Water	kg	9.98E-07
177	Carbonyl sulfide	Air	kg	6.96E-09
178	Carboxylic acids, unspecified	Water	kg	4.33E-06
179	Carfentrazone-ethyl	Air	kg	1.99E-12
180	Carfentrazone-ethyl	Soil	kg	8.73E-14
181	Carnallite	Raw	kg	1.08E-07
182	Cerium	Raw	kg	8.51E-10
183	Cerium-141	Air	Bq	4.73E-06
184	Cerium-141	Water	Bq	1.94E-05
185	Cerium-144	Water	Bq	3.65E-06
186	Cesium	Water	kg	1.02E-09
187	Cesium-134	Air	Bq	2.27E-07
188	Cesium-134	Water	Bq	1.16E-04
189	Cesium-136	Water	Bq	2.13E-06
190	Cesium-137	Air	Bq	3.98E-06
191	Cesium-137	Water	Bq	3.71E-02
192	Chloramine	Air	kg	4.97E-11
193	Chloramine	Water	kg	4.44E-10
194	Chlorate	Water	kg	2.46E-07
195	Chloridazon	Soil	kg	1.46E-15
196	Chloride	Water	kg	2.10E-03
197	Chloride	Soil	kg	2.04E-06
198	Chlorides, unspecified	Water	kg	4.80E-07
199	Chlorimuron-ethyl	Air	kg	3.62E-11
200	Chlorimuron-ethyl	Soil	kg	9.95E-10
201	Chlorinated solvents, unspecified	Air	kg	6.95E-11
202	Chlorinated solvents, unspecified	Water	kg	1.68E-09
203	Chlorine	Air	kg	1.49E-07
204	Chlorine	Water	kg	1.54E-08
205	Chlorine	Soil	kg	1.53E-08
206	Chlormequat	Soil	kg	1.77E-11
207	Chloroacetic acid	Air	kg	5.75E-10
208	Chloroacetic acid	Water	kg	2.77E-08
209	Chloroacetyl chloride	Water	kg	2.95E-11
210	Chloroform	Air	kg	9.52E-10
211	Chloroform	Water	kg	2.35E-11

212	Chlorosilane, trimethyl-	Air	kg	3.58E-12
213	Chlorosulfonic acid	Air	kg	4.43E-11
214	Chlorosulfonic acid	Water	kg	1.10E-10
215	Chlorothalonil	Soil	kg	3.13E-10
216	Chlorpyrifos	Air	kg	7.22E-10
217	Chlorpyrifos	Soil	kg	3.34E-09
218	Chlorsulfuron	Soil	kg	2.26E-17
219	Chlortoluron	Soil	kg	3.06E-12
220	Choline chloride	Soil	kg	3.12E-15
221	Chromium	Raw	kg	1.87E-05
222	Chromium	Air	kg	7.73E-08
223	Chromium	Water	kg	1.37E-08
224	Chromium	Soil	kg	7.37E-09
225	Chromium-51	Air	Bq	3.03E-07
226	Chromium-51	Water	Bq	3.68E-03
227	Chromium IV	Air	kg	2.08E-17
228	Chromium VI	Air	kg	2.71E-09
229	Chromium VI	Water	kg	8.84E-07
230	Chromium VI	Soil	kg	2.61E-09
231	Chrysene	Air	kg	1.97E-16
232	Chrysotile	Raw	kg	1.09E-08
233	Cinidon-ethyl	Soil	kg	6.13E-15
234	Cinnabar	Raw	kg	1.58E-10
235	Clay, bentonite	Raw	kg	2.86E-05
236	Clay, unspecified	Raw	kg	7.02E-04
237	Clethodim	Air	kg	1.07E-10
238	Clethodim	Soil	kg	1.42E-09
239	Clodinafop-propargyl	Soil	kg	3.35E-16
240	Clomazone	Soil	kg	1.70E-11
241	Clopyralid	Soil	kg	4.00E-13
242	Cloquintocet-mexyl	Soil	kg	8.09E-17
243	Cloransulam-methyl	Air	kg	1.88E-11
244	Cloransulam-methyl	Soil	kg	4.27E-10
245	Coal, brown	Raw	kg	6.20E-03
246	Coal, hard	Raw	kg	3.53E-02
247	Cobalt	Raw	kg	1.34E-09
248	Cobalt	Air	kg	7.73E-09
249	Cobalt	Water	kg	1.17E-06
250	Cobalt	Soil	kg	4.36E-10
251	Cobalt-57	Water	Bq	6.75E-05
252	Cobalt-58	Air	Bq	3.36E-07
253	Cobalt-58	Water	Bq	9.49E-03
254	Cobalt-60	Air	Bq	3.33E-06

255	Cobalt-60	Water	Bq	1.19E-02
256	COD, Chemical Oxygen Demand	Water	kg	1.20E-02
257	Colemanite	Raw	kg	1.55E-07
258	Copper	Air	kg	3.05E-07
259	Copper	Water	kg	1.16E-04
260	Copper	Soil	kg	-3.34E-08
261	Copper, 0.52% in sulfide, Cu 0.27% and Mo 8.2E-3% in crude ore	Raw	kg	2.51E-06
262	Copper, 0.59% in sulfide, Cu 0.22% and Mo 8.2E-3% in crude ore	Raw	kg	1.98E-06
263	Copper, 0.97% in sulfide, Cu 0.36% and Mo 4.1E-2% in crude ore	Raw	kg	1.09E-06
264	Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore	Raw	kg	9.82E-06
265	Copper, 1.13% in sulfide, Cu 0.76% and Ni 0.76% in crude ore	Raw	kg	7.22E-08
266	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore	Raw	kg	2.58E-06
267	Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore	Raw	kg	2.39E-07
268	Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore	Raw	kg	7.98E-07
269	Copper, Cu 0.2%, in mixed ore	Raw	kg	1.27E-09
270	Copper, Cu 0.38%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Pb 0.014%, in ore	Raw	kg	2.39E-06
271	Copper, Cu 3.2E+0%, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0% in ore	Raw	kg	7.55E-08
272	Copper, Cu 5.2E-2%, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2% in ore	Raw	kg	2.59E-09
273	Cu-HDO	Water	kg	5.73E-16
274	Cumene	Air	kg	4.17E-09
275	Cumene	Water	kg	9.97E-09
276	Cyanide	Air	kg	8.45E-07
277	Cyanide	Water	kg	1.12E-08
278	Cyanoacetic acid	Air	kg	3.63E-11
279	Cyclohexane	Air	kg	9.05E-13
280	Cycloxydim	Soil	kg	1.67E-16
281	Cyfluthrin	Air	kg	3.78E-12
282	Cyfluthrin	Soil	kg	6.91E-13
283	Cyhalothrin, gamma-	Air	kg	4.33E-11
284	Cyhalothrin, gamma-	Soil	kg	1.86E-12
285	Cypermethrin	Air	kg	9.17E-12
286	Cypermethrin	Soil	kg	1.80E-09
287	Cyproconazole	Soil	kg	9.16E-14

288	Cyprodinil	Soil	kg	8.46E-13
289	Deltamethrin	Soil	kg	7.32E-13
290	Diatomite	Raw	kg	4.36E-10
291	Dibenz(a,h)anthracene	Air	kg	1.00E-15
292	Dicamba	Air	kg	1.21E-11
293	Dicamba	Soil	kg	1.43E-12
294	Dichlorprop-P	Soil	kg	2.30E-13
295	Dichromate	Water	kg	2.69E-10
296	Diclofop	Soil	kg	3.31E-13
297	Diclofop-methyl	Soil	kg	3.33E-13
298	Dicrotophos	Soil	kg	1.14E-11
299	Diethyl ether	Air	kg	2.99E-14
300	Diethylamine	Air	kg	2.89E-11
301	Diethylamine	Water	kg	6.93E-11
302	Diethylene glycol	Air	kg	2.98E-13
303	Difenoconazole	Soil	kg	1.56E-12
304	Diflubenzuron	Air	kg	1.99E-12
305	Diflubenzuron	Soil	kg	2.83E-07
306	Diflufenican	Soil	kg	8.05E-12
307	Diflufenzopyr-sodium	Soil	kg	5.48E-14
308	Dimethachlor	Soil	kg	4.14E-11
309	Dimethenamid	Soil	kg	3.94E-12
310	Dimethoate	Soil	kg	5.26E-13
311	Dimethyl malonate	Air	kg	4.55E-11
312	Dimethylamine	Air	kg	8.98E-14
313	Dimethylamine	Water	kg	4.54E-10
314	Dinitrogen monoxide	Air	kg	7.76E-06
315	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	Air	kg	7.14E-14
316	Dipropylamine	Air	kg	1.32E-11
317	Dipropylamine	Water	kg	3.17E-11
318	Diquat	Soil	kg	3.55E-12
319	Diquat dibromide	Soil	kg	4.66E-14
320	Dithianone	Soil	kg	5.06E-14
321	Diuron	Soil	kg	1.75E-11
322	DOC, Dissolved Organic Carbon	Water	kg	1.05E-02
323	Dolomite	Raw	kg	4.19E-05
324	Endosulfan	Soil	kg	5.87E-08
325	Endothall	Soil	kg	4.25E-13
326	Energy, geothermal, converted	Raw	MJ	1.62E-03
327	Energy, gross calorific value, in biomass	Raw	MJ	8.72E-02
328	Energy, gross calorific value, in biomass, primary forest	Raw	MJ	9.62E-03
329	Energy, kinetic (in wind), converted	Raw	MJ	2.03E-03

330	Energy, potential (in hydropower reservoir), converted	Raw	MJ	4.29E-02
331	Energy, solar, converted	Raw	MJ	8.60E-06
332	Epoxiconazole	Soil	kg	1.12E-13
333	Esfenvalerate	Air	kg	2.26E-11
334	Esfenvalerate	Soil	kg	9.69E-13
335	Ethalfluralin	Soil	kg	1.38E-11
336	Ethane	Air	kg	1.82E-06
337	Ethane, 1,1-difluoro-, HFC-152a	Air	kg	9.83E-10
338	Ethane, 1,1,1-trichloro-, HCFC-140	Air	kg	9.25E-11
339	Ethane, 1,1,1-trichloro-, HCFC-140	Water	kg	7.02E-17
340	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	kg	8.88E-10
341	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	kg	9.52E-11
342	Ethane, 1,2-dichloro-	Air	kg	4.00E-09
343	Ethane, 1,2-dichloro-	Water	kg	5.21E-10
344	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	kg	2.07E-09
345	Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	Air	kg	8.50E-11
346	Ethane, hexafluoro-, HFC-116	Air	kg	1.36E-10
347	Ethanol	Air	kg	5.58E-08
348	Ethanol	Water	kg	1.24E-08
349	Ethene	Air	kg	5.87E-07
350	Ethene	Water	kg	2.79E-09
351	Ethene, chloro-	Air	kg	1.93E-09
352	Ethene, chloro-	Water	kg	1.62E-11
353	Ethene, tetrachloro-	Air	kg	2.06E-10
354	Ethephon	Soil	kg	2.72E-11
355	Ethofumesate	Soil	kg	6.96E-11
356	Ethyl acetate	Air	kg	1.51E-08
357	Ethyl acetate	Water	kg	5.49E-11
358	Ethyl cellulose	Air	kg	2.98E-11
359	Ethylamine	Air	kg	3.39E-11
360	Ethylamine	Water	kg	8.15E-11
361	Ethylene diamine	Air	kg	8.51E-12
362	Ethylene diamine	Water	kg	2.04E-11
363	Ethylene oxide	Air	kg	2.38E-09
364	Ethylene oxide	Water	kg	2.37E-10
365	Ethyne	Air	kg	2.33E-08
366	Europium	Raw	kg	2.13E-12
367	Feldspar	Raw	kg	1.91E-10
368	Fenbuconazole	Soil	kg	1.32E-14
369	Fenoxaprop	Air	kg	2.96E-11

370	Fenoxaprop	Soil	kg	8.53E-10
371	Fenoxaprop-P ethyl ester	Soil	kg	1.54E-14
372	Fenoxaprop ethyl ester	Soil	kg	2.76E-14
373	Fenpiclonil	Soil	kg	1.19E-11
374	Fenpropidin	Soil	kg	8.88E-13
375	Fenpropimorph	Soil	kg	2.19E-11
376	Fipronil	Soil	kg	6.82E-11
377	Florasulam	Soil	kg	5.64E-15
378	Fluazifop-p-butyl	Air	kg	4.24E-11
379	Fluazifop-P-butyl	Soil	kg	2.94E-10
380	Flucarbazone sodium salt	Soil	kg	1.41E-18
381	Fludioxonil	Soil	kg	4.75E-14
382	Flufenacet	Air	kg	1.59E-11
383	Flufenacet	Soil	kg	9.07E-13
384	Flumetsulam	Air	kg	3.72E-12
385	Flumetsulam	Soil	kg	2.55E-13
386	Flumiclorac-pentyl	Air	kg	6.37E-12
387	Flumiclorac-pentyl	Soil	kg	2.73E-13
388	Flumioxazin	Air	kg	6.44E-11
389	Flumioxazin	Soil	kg	4.96E-10
390	Fluoranthene	Air	kg	1.65E-14
391	Fluorene	Air	kg	1.50E-14
392	Fluoride	Water	kg	1.59E-05
393	Fluoride	Soil	kg	2.84E-08
394	Fluorine	Raw	kg	7.11E-07
395	Fluorine	Air	kg	2.32E-08
396	Fluorine, 4.5% in apatite, 3% in crude ore	Raw	kg	2.40E-06
397	Fluorspar	Raw	kg	2.99E-06
398	Fluosilicic acid	Air	kg	7.01E-10
399	Fluosilicic acid	Water	kg	1.38E-09
400	Flupyrsulfuron-methyl	Soil	kg	2.20E-18
401	Fluquinconazole	Soil	kg	1.15E-14
402	Fluroxypyr	Soil	kg	2.56E-14
403	Flurtamone	Soil	kg	1.93E-11
404	Flusilazole	Soil	kg	7.18E-14
405	Fomesafen	Air	kg	2.40E-10
406	Fomesafen	Soil	kg	3.26E-09
407	Foramsulfuron	Soil	kg	1.03E-14
408	Formaldehyde	Air	kg	4.88E-07
409	Formaldehyde	Water	kg	2.69E-08
410	Formamide	Air	kg	1.43E-11
411	Formamide	Water	kg	3.43E-11
412	Formic acid	Air	kg	2.03E-07

413	Formic acid	Water	kg	9.97E-12
414	Formic acid, thallium(1+) salt	Water	kg	1.08E-08
415	Fosetyl-aluminium	Soil	kg	5.75E-13
416	Fungicides, unspecified	Soil	kg	3.29E-12
417	Furan	Air	kg	8.87E-07
418	Gadolinium	Raw	kg	5.32E-12
419	Gallium	Raw	kg	1.64E-08
420	Gangue, bauxite, in ground	Raw	kg	5.68E-04
421	Gas, mine, off-gas, process, coal mining/m3	Raw	m3	3.06E-04
422	Gas, natural/m3	Raw	m3	2.85E-02
423	Glufosinate	Soil	kg	3.39E-13
424	Glutaraldehyde	Water	kg	2.22E-10
425	Glyphosate	Air	kg	4.79E-08
426	Glyphosate	Soil	kg	7.29E-07
427	Gold	Raw	kg	1.13E-10
428	Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore	Raw	kg	2.05E-11
429	Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore	Raw	kg	4.20E-11
430	Gold, Au 1.8E-4%, in mixed ore	Raw	kg	1.52E-12
431	Gold, Au 2.1E-4%, Ag 2.1E-4%, in ore	Raw	kg	9.07E-12
432	Gold, Au 4.3E-4%, in ore	Raw	kg	2.21E-11
433	Gold, Au 4.9E-5%, in ore	Raw	kg	1.11E-10
434	Gold, Au 5.4E-4%, Ag 1.5E-5%, in ore	Raw	kg	6.60E-13
435	Gold, Au 6.7E-4%, in ore	Raw	kg	1.18E-10
436	Gold, Au 6.8E-4%, Ag 1.5E-4%, in ore	Raw	kg	8.97E-13
437	Gold, Au 7.1E-4%, in ore	Raw	kg	5.48E-11
438	Gold, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore	Raw	kg	5.83E-11
439	Gold, Au 9.7E-5%, Ag 7.6E-5%, in ore	Raw	kg	3.25E-12
440	Granite	Raw	kg	2.31E-13
441	Gravel	Raw	kg	5.42E-02
442	Gypsum	Raw	kg	4.95E-05
443	Heat, waste	Air	MJ	1.89E-01
444	Heat, waste	Water	MJ	4.98E-02
445	Helium	Air	kg	5.45E-08
446	Heptane	Air	kg	2.72E-07
447	Hexane	Air	kg	3.66E-06
448	Hydrocarbons, aliphatic, alkanes, cyclic	Air	kg	2.50E-08

449	Hydrocarbons, aliphatic, alkanes, unspecified	Air	kg	1.50E-06
450	Hydrocarbons, aliphatic, alkanes, unspecified	Water	kg	1.33E-07
451	Hydrocarbons, aliphatic, unsaturated	Air	kg	1.52E-07
452	Hydrocarbons, aliphatic, unsaturated	Water	kg	1.24E-08
453	Hydrocarbons, aromatic	Air	kg	3.25E-06
454	Hydrocarbons, aromatic	Water	kg	5.46E-07
455	Hydrocarbons, chlorinated	Air	kg	5.47E-09
456	Hydrocarbons, unspecified	Air	kg	6.15E-08
457	Hydrocarbons, unspecified	Water	kg	7.13E-07
458	Hydrocarbons, unspecified	Soil	kg	3.18E-11
459	Hydrogen	Air	kg	1.37E-06
460	Hydrogen-3, Tritium	Air	Bq	2.14E+00
461	Hydrogen-3, Tritium	Water	Bq	9.77E+01
462	Hydrogen carbonate	Water	kg	1.54E-07
463	Hydrogen chloride	Air	kg	2.00E-05
464	Hydrogen chloride	Water	kg	4.66E-08
465	Hydrogen fluoride	Air	kg	2.43E-06
466	Hydrogen peroxide	Air	kg	2.15E-11
467	Hydrogen peroxide	Water	kg	6.96E-10
468	Hydrogen sulfide	Air	kg	2.35E-07
469	Hydrogen sulfide	Water	kg	7.06E-06
470	Hydroxide	Water	kg	1.08E-09
471	Hypochlorite	Water	kg	6.17E-08
472	Imazamox	Air	kg	9.53E-12
473	Imazamox	Soil	kg	4.27E-10
474	Imazapyr	Soil	kg	1.37E-15
475	Imazaquin	Air	kg	3.04E-11
476	Imazaquin	Soil	kg	1.30E-12
477	Imazethapyr	Air	kg	6.29E-11
478	Imazethapyr	Soil	kg	1.07E-09
479	Imidacloprid	Soil	kg	6.68E-11
480	Indeno(1,2,3-cd)pyrene	Air	kg	3.95E-16
481	Indium	Raw	kg	2.73E-09
482	Iodide	Water	kg	1.38E-07
483	Iodine	Raw	kg	3.63E-08
484	Iodine	Air	kg	9.30E-08
485	Iodine-129	Air	Bq	1.70E-04
486	Iodine-131	Air	Bq	1.92E-03
487	Iodine-131	Water	Bq	7.03E-04
488	Iodine-133	Air	Bq	1.38E-05
489	Iodine-133	Water	Bq	2.97E-05
490	Iodosulfuron	Soil	kg	7.66E-16

491	Iodosulfuron-methyl-sodium	Soil	kg	1.37E-18
492	Ioxynil	Soil	kg	1.31E-12
493	Iprodione	Soil	kg	1.85E-11
494	Iron	Raw	kg	1.73E-03
495	Iron	Air	kg	1.61E-06
496	Iron	Water	kg	4.42E-04
497	Iron	Soil	kg	1.90E-05
498	Iron-59	Water	Bq	2.77E-03
499	Isocyanic acid	Air	kg	6.14E-09
500	Isoprene	Air	kg	2.96E-09
501	Isopropylamine	Air	kg	1.56E-11
502	Isopropylamine	Water	kg	3.76E-11
503	Isoproturon	Soil	kg	1.23E-11
504	Isoxaflutole	Soil	kg	1.64E-13
505	Kaolinite	Raw	kg	6.01E-04
506	Kieserite	Raw	kg	1.62E-08
507	Kresoxim-methyl	Soil	kg	8.06E-14
508	Krypton	Raw	kg	1.93E-10
509	Krypton-85	Air	Bq	6.32E-02
510	Krypton-85m	Air	Bq	2.29E-01
511	Krypton-87	Air	Bq	6.24E-02
512	Krypton-88	Air	Bq	8.25E-02
513	Krypton-89	Air	Bq	3.51E-02
514	Lactic acid	Air	kg	1.03E-11
515	Lactic acid	Water	kg	2.48E-11
516	Lactofen	Air	kg	3.06E-11
517	Lactofen	Soil	kg	1.31E-12
518	Lambda-cyhalothrin	Soil	kg	1.44E-10
519	Lanthanum	Raw	kg	2.55E-10
520	Lanthanum-140	Air	Bq	1.67E-06
521	Lanthanum-140	Water	Bq	5.15E-05
522	Lead	Raw	kg	2.75E-06
523	Lead	Air	kg	8.94E-08
524	Lead	Water	kg	4.70E-05
525	Lead	Soil	kg	8.78E-09
526	Lead-210	Air	Bq	4.15E-02
527	Lead-210	Water	Bq	6.19E-03
528	Lead, Pb 0.014%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, in ore	Raw	kg	2.89E-07
529	Lead, Pb 3.6E-1%, in mixed ore	Raw	kg	2.29E-09
530	Linuron	Soil	kg	1.70E-08
531	Lithium	Raw	kg	4.47E-09
532	Lithium	Air	kg	2.04E-15

533	Lithium	Water	kg	6.66E-06
534	Lithium	Soil	kg	3.83E-11
535	m-Xylene	Air	kg	8.56E-09
536	m-Xylene	Water	kg	2.15E-10
537	Magnesite	Raw	kg	1.35E-05
538	Magnesium	Air	kg	2.41E-07
539	Magnesium	Water	kg	7.48E-04
540	Magnesium	Soil	kg	5.08E-07
541	Malathion	Soil	kg	3.79E-10
542	Mancozeb	Soil	kg	3.94E-10
543	Manganese	Raw	kg	9.72E-06
544	Manganese	Air	kg	5.00E-08
545	Manganese	Water	kg	5.88E-05
546	Manganese	Soil	kg	7.33E-08
547	Manganese-54	Air	Bq	1.55E-07
548	Manganese-54	Water	Bq	8.66E-04
549	MCPB	Soil	kg	4.87E-11
550	Mecoprop	Soil	kg	1.29E-15
551	Mecoprop-P	Soil	kg	1.73E-12
552	Mefenpyr	Soil	kg	5.75E-14
553	Mefenpyr-diethyl	Soil	kg	3.08E-14
554	Mepiquat chloride	Soil	kg	1.75E-12
555	Mercury	Air	kg	4.11E-09
556	Mercury	Water	kg	1.31E-07
557	Mercury	Soil	kg	1.58E-11
558	Mesosulfuron-methyl (prop)	Soil	kg	7.56E-18
559	Mesotrione	Soil	kg	4.45E-13
560	Metalaxil	Soil	kg	4.55E-11
561	Metaldehyde	Soil	kg	4.99E-11
562	Metam-sodium dihydrate	Soil	kg	1.20E-10
563	Metamitron	Soil	kg	2.62E-10
564	Metamorphous rock, graphite containing	Raw	kg	5.88E-08
565	Metazachlor	Soil	kg	9.78E-11
566	Metconazole	Soil	kg	4.02E-12
567	Methane	Air	kg	3.99E-11
568	Methane, biogenic	Air	kg	1.68E-03
569	Methane, bromo-, Halon 1001	Air	kg	6.73E-16
570	Methane, bromochlorodifluoro-, Halon 1211	Air	kg	5.31E-11
571	Methane, bromotrifluoro-, Halon 1301	Air	kg	1.05E-09
572	Methane, chlorodifluoro-, HCFC-22	Air	kg	2.14E-09
573	Methane, dichloro-, HCC-30	Air	kg	1.45E-09
574	Methane, dichloro-, HCC-30	Water	kg	1.36E-08

575	Methane, dichlorodifluoro-, CFC-12	Air	kg	7.43E-11
576	Methane, dichlorofluoro-, HCFC-21	Air	kg	1.13E-13
577	Methane, fossil	Air	kg	8.35E-04
578	Methane, land transformation	Air	kg	1.26E-06
579	Methane, monochloro-, R-40	Air	kg	2.45E-09
580	Methane, tetrachloro-, CFC-10	Air	kg	3.06E-10
581	Methane, tetrafluoro-, CFC-14	Air	kg	1.85E-09
582	Methane, trichlorofluoro-, CFC-11	Air	kg	1.83E-13
583	Methane, trifluoro-, HFC-23	Air	kg	3.60E-11
584	Methanesulfonic acid	Air	kg	3.67E-11
585	Methanol	Air	kg	6.20E-07
586	Methanol	Water	kg	1.81E-08
587	Methyl acetate	Air	kg	4.66E-12
588	Methyl acetate	Water	kg	1.12E-11
589	Methyl acrylate	Air	kg	3.74E-13
590	Methyl acrylate	Water	kg	7.30E-12
591	Methyl borate	Air	kg	8.89E-12
592	Methyl ethyl ketone	Air	kg	1.51E-08
593	Methyl formate	Air	kg	4.85E-12
594	Methyl formate	Water	kg	1.93E-12
595	Methyl lactate	Air	kg	1.14E-11
596	Methylamine	Air	kg	4.67E-11
597	Methylamine	Water	kg	1.12E-10
598	Metolachlor	Air	kg	5.00E-10
599	Metolachlor	Soil	kg	1.29E-07
600	Metosulam	Soil	kg	4.33E-18
601	Metribuzin	Air	kg	1.98E-10
602	Metribuzin	Soil	kg	3.43E-09
603	Metsulfuron-methyl	Soil	kg	9.67E-11
604	Molybdenum	Raw	kg	1.25E-07
605	Molybdenum	Air	kg	5.39E-08
606	Molybdenum	Water	kg	3.69E-07
607	Molybdenum	Soil	kg	9.27E-11
608	Molybdenum-99	Water	Bq	1.86E-05
609	Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore	Raw	kg	2.32E-08
610	Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore	Raw	kg	4.90E-09
611	Molybdenum, 0.016% in sulfide, Mo 8.2E-3% and Cu 0.27% in crude ore	Raw	kg	6.02E-08
612	Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.22% in crude ore	Raw	kg	4.42E-08
613	Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore	Raw	kg	1.93E-07

614	Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore	Raw	kg	5.15E-08
615	Monocrotophos	Soil	kg	3.46E-08
616	Monoethanolamine	Air	kg	2.98E-09
617	Monoethanolamine	Water	kg	2.06E-12
618	Monosodium acid methanearsonate	Soil	kg	5.81E-12
619	Napropamide	Soil	kg	5.85E-11
620	Neodymium	Raw	kg	1.40E-10
621	Nickel	Air	kg	1.50E-07
622	Nickel	Water	kg	1.36E-05
623	Nickel	Soil	kg	-1.06E-08
624	Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore	Raw	kg	1.40E-07
625	Nickel, 1.98% in silicates, 1.04% in crude ore	Raw	kg	5.34E-05
626	Nickel, Ni 2.3E+0%, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Cu 3.2E+0% in ore	Raw	kg	5.45E-08
627	Nickel, Ni 3.7E-2%, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Cu 5.2E-2% in ore	Raw	kg	3.70E-09
628	Nicosulfuron	Soil	kg	7.53E-14
629	Niobium-95	Air	Bq	3.39E-03
630	Niobium-95	Water	Bq	5.04E-05
631	Nitrate	Air	kg	2.67E-08
632	Nitrate	Water	kg	5.71E-04
633	Nitrate	Soil	kg	4.42E-08
634	Nitrite	Water	kg	4.74E-06
635	Nitrobenzene	Air	kg	9.33E-11
636	Nitrobenzene	Water	kg	3.74E-10
637	Nitrogen	Raw	kg	1.80E-04
638	Nitrogen	Water	kg	2.51E-06
639	Nitrogen	Soil	kg	6.52E-10
640	Nitrogen fluoride	Air	kg	8.22E-14
641	Nitrogen oxides	Air	kg	6.88E-04
642	Nitrogen, atmospheric	Air	kg	9.10E-08
643	Nitrogen, organic bound	Water	kg	1.03E-04
644	NMVOC, non-methane volatile organic compounds, unspecified origin	Air	kg	1.97E-04
645	Noble gases, radioactive, unspecified	Air	Bq	1.63E+03
646	o-Xylene	Air	kg	2.80E-09
647	o-Xylene	Water	kg	1.37E-10
648	Occupation, arable	Raw	m2a	1.11E-03
649	Occupation, arable, irrigated	Raw	m2a	1.11E-03

650	Occupation, arable, irrigated, intensive	Raw	m2a	2.02E-06
651	Occupation, arable, non-irrigated	Raw	m2a	3.94E-08
652	Occupation, arable, non-irrigated, extensive	Raw	m2a	4.67E-06
653	Occupation, arable, non-irrigated, intensive	Raw	m2a	6.34E-03
654	Occupation, construction site	Raw	m2a	3.65E-05
655	Occupation, dump site	Raw	m2a	5.89E-04
656	Occupation, forest, extensive	Raw	m2a	4.36E-05
657	Occupation, forest, intensive	Raw	m2a	2.66E-03
658	Occupation, grassland, not used	Raw	m2a	1.45E-05
659	Occupation, industrial area	Raw	m2a	1.80E-04
660	Occupation, mineral extraction site	Raw	m2a	9.23E-05
661	Occupation, pasture and meadow, extensive	Raw	m2a	4.28E-08
662	Occupation, pasture and meadow, intensive	Raw	m2a	7.76E-07
663	Occupation, permanent crop	Raw	m2a	2.48E-04
664	Occupation, seabed, drilling and mining	Raw	m2a	2.89E-06
665	Occupation, seabed, infrastructure	Raw	m2a	2.86E-08
666	Occupation, shrub land, sclerophyllous	Raw	m2a	3.11E-05
667	Occupation, traffic area, rail network	Raw	m2a	3.30E-04
668	Occupation, traffic area, rail/road embankment	Raw	m2a	4.68E-04
669	Occupation, traffic area, road network	Raw	m2a	9.39E-04
670	Occupation, urban, discontinuously built	Raw	m2a	1.54E-06
671	Occupation, urban/industrial fallow	Raw	m2a	4.38E-09
672	Occupation, water bodies, artificial	Raw	m2a	1.69E-04
673	Oil, crude	Raw	kg	4.68E-02
674	Oils, biogenic	Water	kg	2.66E-07
675	Oils, biogenic	Soil	kg	2.62E-07
676	Oils, unspecified	Water	kg	6.32E-05
677	Oils, unspecified	Soil	kg	6.72E-05
678	Olivine	Raw	kg	4.75E-08
679	Orbencarb	Soil	kg	7.49E-11
680	Organic carbon	Air	kg	2.97E-11
681	Organic carbon	Water	kg	9.65E-11
682	Organic carbon	Soil	kg	9.65E-11
683	Oxydemeton methyl	Soil	kg	5.36E-14
684	Oxygen	Raw	kg	2.70E-02
685	Ozone	Air	kg	4.90E-07

686	PAH, polycyclic aromatic hydrocarbons	Air	kg	2.41E-08
687	PAH, polycyclic aromatic hydrocarbons	Water	kg	6.45E-09
688	PAH, polycyclic aromatic hydrocarbons	Soil	kg	1.15E-10
689	Palladium, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore	Raw	kg	7.21E-12
690	Palladium, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore	Raw	kg	1.72E-11
691	Paraffins	Air	kg	1.87E-10
692	Paraffins	Water	kg	5.42E-10
693	Paraquat	Air	kg	1.28E-10
694	Paraquat	Soil	kg	5.71E-11
695	Parathion	Soil	kg	3.20E-12
696	Parathion, methyl	Air	kg	2.45E-11
697	Parathion, methyl	Soil	kg	1.05E-12
698	Particulates, < 2.5 um	Air	kg	1.14E-04
699	Particulates, > 10 um	Air	kg	1.19E-04
700	Particulates, > 2.5 um, and < 10um	Air	kg	4.62E-05
701	Peat	Raw	kg	6.84E-05
702	Pendimethalin	Air	kg	1.34E-09
703	Pendimethalin	Soil	kg	2.48E-08
704	Pentane	Air	kg	1.82E-06
705	Pentane, 2-methyl-	Air	kg	1.20E-11
706	Perfluoropentane	Air	kg	2.28E-11
707	Perlite	Raw	kg	7.08E-07
708	Permethrin	Air	kg	2.00E-11
709	Permethrin	Soil	kg	8.87E-13
710	Pesticides, unspecified	Soil	kg	2.95E-10
711	Phenanthrene	Air	kg	2.30E-13
712	Phenmedipham	Soil	kg	4.81E-11
713	Phenol	Air	kg	3.11E-09
714	Phenol	Water	kg	1.54E-07
715	Phenol, 2,4-dichloro-	Air	kg	1.39E-10
716	Phenol, pentachloro-	Air	kg	1.49E-09
717	Phenol, pentachloro-	Soil	kg	3.40E-14
718	Phosphate	Water	kg	1.35E-04
719	Phosphine	Air	kg	1.92E-10
720	Phosphoric acid	Air	kg	1.49E-13
721	Phosphorus	Raw	kg	9.87E-06
722	Phosphorus	Air	kg	2.20E-08
723	Phosphorus	Water	kg	1.04E-06

724	Phosphorus	Soil	kg	5.17E-08
725	Phosphorus trichloride	Air	kg	1.31E-11
726	Phosphorus, 18% in apatite, 4% in crude ore	Raw	kg	2.85E-06
727	Picloram	Soil	kg	2.83E-18
728	Picoxystrobin	Soil	kg	7.39E-14
729	Pirimicarb	Soil	kg	3.25E-14
730	Platinum	Air	kg	3.39E-16
731	Platinum, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore	Raw	kg	5.90E-12
732	Platinum, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore	Raw	kg	1.70E-11
733	Plutonium-238	Air	Bq	2.32E-11
734	Plutonium-alpha	Air	Bq	5.31E-11
735	Polonium-210	Air	Bq	7.34E-02
736	Polonium-210	Water	Bq	5.03E-03
737	Polychlorinated biphenyls	Air	kg	1.89E-11
738	Polychlorinated biphenyls	Water	kg	3.67E-15
739	Potassium	Air	kg	6.37E-07
740	Potassium	Water	kg	4.82E-04
741	Potassium	Soil	kg	3.32E-07
742	Potassium-40	Air	Bq	1.34E-02
743	Potassium-40	Water	Bq	4.17E-03
744	Potassium chloride	Raw	kg	6.85E-05
745	Praseodymium	Raw	kg	1.49E-11
746	Primisulfuron	Soil	kg	3.42E-14
747	Prochloraz	Soil	kg	1.24E-13
748	Procymidone	Soil	kg	6.62E-12
749	Profenofos	Soil	kg	9.04E-12
750	Prohexadione-calcium	Soil	kg	1.70E-18
751	Prometryn	Soil	kg	4.85E-12
752	Pronamide	Soil	kg	8.32E-16
753	Propanal	Air	kg	9.53E-10
754	Propanal	Water	kg	2.71E-11
755	Propane	Air	kg	1.66E-06
756	Propene	Air	kg	2.17E-07
757	Propene	Water	kg	9.26E-09
758	Propiconazole	Air	kg	2.35E-11
759	Propiconazole	Soil	kg	1.32E-12
760	Propionic acid	Air	kg	3.92E-09
761	Propionic acid	Water	kg	3.80E-10
762	Propoxycarbazone-sodium (prop)	Soil	kg	9.45E-18

763	Propylamine	Air	kg	4.56E-12
764	Propylamine	Water	kg	1.09E-11
765	Propylene oxide	Air	kg	1.39E-09
766	Propylene oxide	Water	kg	3.32E-09
767	Prosulfuron	Soil	kg	5.06E-14
768	Protactinium-234	Air	Bq	6.83E-04
769	Protactinium-234	Water	Bq	1.94E-03
770	Prothioconazol	Soil	kg	5.24E-12
771	Pumice	Raw	kg	2.34E-06
772	Pyraclostrobin (prop)	Air	kg	5.53E-11
773	Pyraclostrobin (prop)	Soil	kg	2.40E-12
774	Pyrene	Air	kg	1.20E-14
775	Pyrithiobac sodium salt	Soil	kg	3.25E-13
776	Quinoxyfen	Soil	kg	8.26E-17
777	Quizalofop-P	Soil	kg	9.52E-13
778	Quizalofop ethyl ester	Air	kg	7.42E-12
779	Quizalofop ethyl ester	Soil	kg	1.16E-12
780	Radioactive species, alpha emitters	Water	Bq	5.39E-05
781	Radioactive species, Nuclides, unspecified	Water	Bq	1.72E-01
782	Radioactive species, other beta emitters	Air	Bq	7.00E-01
783	Radium-224	Water	Bq	5.12E-02
784	Radium-226	Air	Bq	1.52E-02
785	Radium-226	Water	Bq	1.09E+00
786	Radium-228	Air	Bq	5.03E-03
787	Radium-228	Water	Bq	1.14E-01
788	Radon-220	Air	Bq	2.93E-01
789	Radon-222	Air	Bq	1.40E+04
790	Rhenium	Raw	kg	2.25E-12
791	Rhodium, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore	Raw	kg	4.71E-13
792	Rhodium, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore	Raw	kg	8.50E-13
793	Rimsulfuron	Soil	kg	3.42E-14
794	Rubidium	Water	kg	1.02E-08
795	Ruthenium-103	Air	Bq	4.05E-09
796	Ruthenium-103	Water	Bq	2.44E-06
797	Samarium	Raw	kg	1.06E-11
798	Sand	Raw	kg	2.49E-06
799	Scandium	Air	kg	1.31E-09
800	Scandium	Water	kg	9.45E-08
801	Selenium	Air	kg	1.35E-08

802	Selenium	Water	kg	1.86E-07
803	Selenium	Soil	kg	5.88E-10
804	Sethoxydim	Air	kg	1.60E-11
805	Sethoxydim	Soil	kg	4.98E-12
806	Shale	Raw	kg	2.74E-07
807	Silicon	Air	kg	9.22E-07
808	Silicon	Water	kg	5.94E-04
809	Silicon	Soil	kg	3.20E-07
810	Silicon dioxide	Water	kg	1.04E-10
811	Silicon tetrachloride	Air	kg	1.22E-11
812	Silicon tetrafluoride	Air	kg	1.90E-11
813	Silthiofam	Soil	kg	1.27E-16
814	Silver	Air	kg	5.54E-11
815	Silver	Water	kg	8.65E-08
816	Silver	Soil	kg	2.95E-12
817	Silver-110	Air	Bq	2.37E-08
818	Silver-110	Water	Bq	1.35E-02
819	Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In	Raw	kg	3.99E-09
820	Silver, 3.2ppm in sulfide, Ag 1.2ppm, Cu and Te, in crude ore	Raw	kg	1.56E-13
821	Silver, Ag 1.5E-4%, Au 6.8E-4%, in ore	Raw	kg	2.01E-13
822	Silver, Ag 1.5E-5%, Au 5.4E-4%, in ore	Raw	kg	1.84E-14
823	Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore	Raw	kg	9.24E-12
824	Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore	Raw	kg	7.68E-10
825	Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore	Raw	kg	1.50E-11
826	Silver, Ag 5.4E-3%, in mixed ore	Raw	kg	3.46E-11
827	Silver, Ag 7.6E-5%, Au 9.7E-5%, in ore	Raw	kg	2.54E-12
828	Silver, Ag 9.7E-4%, Au 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore	Raw	kg	2.95E-09
829	Simazine	Soil	kg	6.92E-13
830	Sodium	Air	kg	6.68E-07
831	Sodium	Water	kg	1.38E-03
832	Sodium	Soil	kg	1.20E-06
833	Sodium-24	Water	Bq	8.87E-05
834	Sodium chlorate	Air	kg	7.64E-11
835	Sodium chlorate	Water	kg	1.33E-12
836	Sodium chloride	Raw	kg	2.27E-04
837	Sodium dichromate	Air	kg	1.35E-10
838	Sodium formate	Air	kg	2.99E-12

839	Sodium formate	Water	kg	7.18E-12
840	Sodium hydroxide	Air	kg	7.97E-11
841	Sodium nitrate	Raw	kg	1.11E-11
842	Sodium sulfate	Raw	kg	7.73E-07
843	Sodium tetrahydroborate	Air	kg	5.46E-11
844	Solids, inorganic	Water	kg	2.36E-05
845	Spiroxamine	Soil	kg	3.80E-13
846	Spodumene	Raw	kg	1.58E-09
847	Stibnite	Raw	kg	4.53E-11
848	Strontium	Air	kg	4.39E-08
849	Strontium	Water	kg	1.78E-05
850	Strontium	Soil	kg	5.81E-09
851	Strontium-89	Water	Bq	2.95E-04
852	Strontium-90	Water	Bq	3.68E-02
853	Styrene	Air	kg	4.14E-09
854	Sulfate	Air	kg	9.23E-07
855	Sulfate	Water	kg	3.53E-03
856	Sulfate	Soil	kg	7.37E-08
857	Sulfentrazone	Air	kg	1.53E-10
858	Sulfentrazone	Soil	kg	5.13E-09
859	Sulfide	Water	kg	9.29E-08
860	Sulfite	Water	kg	1.64E-07
861	Sulfosate	Soil	kg	2.11E-08
862	Sulfosulfuron	Soil	kg	3.39E-17
863	Sulfur	Raw	kg	1.61E-06
864	Sulfur	Water	kg	7.08E-07
865	Sulfur	Soil	kg	3.64E-07
866	Sulfur dioxide	Air	kg	6.57E-04
867	Sulfur hexafluoride	Air	kg	2.94E-09
868	Sulfur oxides	Air	kg	8.41E-09
869	Sulfur trioxide	Air	kg	6.30E-10
870	Sulfuric acid	Air	kg	1.73E-11
871	Sulfuric acid	Soil	kg	4.27E-16
872	Suspended solids, unspecified	Water	kg	1.16E-03
873	t-Butyl methyl ether	Air	kg	5.37E-10
874	t-Butyl methyl ether	Water	kg	1.50E-11
875	t-Butylamine	Air	kg	3.49E-11
876	t-Butylamine	Water	kg	8.38E-11
877	Talc	Raw	kg	6.01E-08
878	Tantalum	Raw	kg	2.83E-09
879	Tebuconazole	Soil	kg	3.20E-11
880	Tebufenpyrad	Soil	kg	5.48E-15
881	Tebupirimphos	Soil	kg	2.88E-13

882	Tebutam	Soil	kg	4.68E-11
883	Technetium-99m	Water	Bq	4.13E-04
884	Teflubenzuron	Soil	kg	9.25E-13
885	Tefluthrin	Soil	kg	2.26E-13
886	Tellurium	Raw	kg	2.34E-14
887	Tellurium-123m	Water	Bq	1.26E-05
888	Tellurium-132	Water	Bq	6.38E-07
889	Terbufos	Soil	kg	1.46E-12
890	Terpenes	Air	kg	2.77E-08
891	Tetramethyl ammonium hydroxide	Air	kg	1.97E-09
892	Thallium	Air	kg	5.84E-11
893	Thallium	Water	kg	1.68E-08
894	Thiamethoxam	Soil	kg	5.58E-13
895	Thidiazuron	Soil	kg	5.69E-13
896	Thifensulfuron	Air	kg	2.18E-12
897	Thifensulfuron-methyl	Soil	kg	9.44E-14
898	Thiodicarb	Air	kg	7.75E-12
899	Thiodicarb	Soil	kg	3.32E-13
900	Thiram	Soil	kg	2.60E-10
901	Thorium	Air	kg	4.65E-11
902	Thorium-228	Air	Bq	2.04E-03
903	Thorium-228	Water	Bq	2.05E-01
904	Thorium-230	Air	Bq	1.09E-03
905	Thorium-230	Water	Bq	2.55E-01
906	Thorium-232	Air	Bq	2.87E-03
907	Thorium-232	Water	Bq	7.51E-04
908	Thorium-234	Air	Bq	6.83E-04
909	Thorium-234	Water	Bq	1.94E-03
910	Tin	Raw	kg	4.43E-08
911	Tin	Air	kg	3.71E-08
912	Tin	Water	kg	7.17E-06
913	Tin	Soil	kg	4.15E-12
914	TiO2, 54% in ilmenite, 18% in crude ore	Raw	kg	2.72E-07
915	TiO2, 54% in ilmenite, 2.6% in crude ore	Raw	kg	3.54E-06
916	TiO2, 95% in rutile, 0.40% in crude ore	Raw	kg	5.44E-07
917	Titanium	Air	kg	8.43E-08
918	Titanium	Water	kg	4.15E-05
919	Titanium	Soil	kg	1.46E-08
920	TOC, Total Organic Carbon	Water	kg	1.05E-02
921	Toluene	Air	kg	6.43E-07
922	Toluene	Water	kg	1.42E-07

923	Toluene, 2-chloro-	Air	kg	4.83E-11
924	Toluene, 2-chloro-	Water	kg	7.60E-11
925	Tralkoxydim	Soil	kg	5.26E-13
926	Transformation, from arable	Raw	m2	1.16E-02
927	Transformation, from arable, non-irrigated	Raw	m2	9.61E-06
928	Transformation, from arable, non-irrigated, extensive	Raw	m2	8.42E-06
929	Transformation, from arable, non-irrigated, intensive	Raw	m2	9.73E-04
930	Transformation, from cropland fallow (non-use)	Raw	m2	9.31E-09
931	Transformation, from dump site, inert material landfill	Raw	m2	6.08E-07
932	Transformation, from dump site, residual material landfill	Raw	m2	1.57E-07
933	Transformation, from dump site, sanitary landfill	Raw	m2	5.17E-06
934	Transformation, from dump site, slag compartment	Raw	m2	2.84E-07
935	Transformation, from forest	Raw	m2	2.33E-05
936	Transformation, from forest, extensive	Raw	m2	4.51E-07
937	Transformation, from forest, intensive	Raw	m2	3.12E-05
938	Transformation, from forest, primary	Raw	m2	1.73E-05
939	Transformation, from grassland, not used	Raw	m2	8.00E-08
940	Transformation, from heterogeneous, agricultural	Raw	m2	4.11E-11
941	Transformation, from industrial area	Raw	m2	6.84E-08
942	Transformation, from mineral extraction site	Raw	m2	1.32E-06
943	Transformation, from pasture and meadow	Raw	m2	8.06E-06
944	Transformation, from pasture and meadow, extensive	Raw	m2	8.56E-10
945	Transformation, from pasture and meadow, intensive	Raw	m2	2.21E-07
946	Transformation, from permanent crop	Raw	m2	6.06E-06
947	Transformation, from permanent crops, non-irrigated, intensive	Raw	m2	6.85E-10
948	Transformation, from sea and ocean	Raw	m2	2.89E-06
949	Transformation, from seabed, infrastructure	Raw	m2	4.04E-11
950	Transformation, from shrub land, sclerophyllous	Raw	m2	6.52E-05
951	Transformation, from traffic area, rail/road embankment	Raw	m2	2.35E-07

952	Transformation, from traffic area, road network	Raw	m2	5.38E-10
953	Transformation, from unknown	Raw	m2	1.38E-05
954	Transformation, from wetland, inland (non-use)	Raw	m2	1.22E-08
955	Transformation, to arable	Raw	m2	8.36E-05
956	Transformation, to arable, fallow	Raw	m2	1.72E-08
957	Transformation, to arable, irrigated, intensive	Raw	m2	3.30E-07
958	Transformation, to arable, non-irrigated	Raw	m2	1.06E-07
959	Transformation, to arable, non-irrigated, extensive	Raw	m2	8.49E-06
960	Transformation, to arable, non-irrigated, intensive	Raw	m2	1.26E-02
961	Transformation, to dump site	Raw	m2	3.43E-06
962	Transformation, to dump site, inert material landfill	Raw	m2	6.08E-07
963	Transformation, to dump site, residual material landfill	Raw	m2	1.57E-07
964	Transformation, to dump site, sanitary landfill	Raw	m2	5.17E-06
965	Transformation, to dump site, slag compartment	Raw	m2	2.84E-07
966	Transformation, to forest	Raw	m2	7.11E-06
967	Transformation, to forest, extensive	Raw	m2	3.35E-07
968	Transformation, to forest, intensive	Raw	m2	3.14E-05
969	Transformation, to forest, secondary (non-use)	Raw	m2	6.34E-10
970	Transformation, to heterogeneous, agricultural	Raw	m2	6.80E-07
971	Transformation, to industrial area	Raw	m2	3.29E-06
972	Transformation, to mineral extraction site	Raw	m2	2.48E-05
973	Transformation, to pasture and meadow	Raw	m2	4.76E-08
974	Transformation, to pasture and meadow, extensive	Raw	m2	2.03E-07
975	Transformation, to pasture and meadow, intensive	Raw	m2	1.15E-07
976	Transformation, to permanent crop	Raw	m2	1.24E-05
977	Transformation, to permanent crops, irrigated, intensive	Raw	m2	2.57E-08
978	Transformation, to permanent crops, non-irrigated	Raw	m2	6.34E-10
979	Transformation, to permanent crops, non-irrigated, intensive	Raw	m2	6.85E-10

980	Transformation, to seabed, drilling and mining	Raw	m2	2.89E-06
981	Transformation, to seabed, infrastructure	Raw	m2	3.93E-09
982	Transformation, to seabed, unspecified	Raw	m2	4.04E-11
983	Transformation, to shrub land, sclerophyllous	Raw	m2	6.21E-06
984	Transformation, to traffic area, rail network	Raw	m2	7.63E-07
985	Transformation, to traffic area, rail/road embankment	Raw	m2	1.29E-06
986	Transformation, to traffic area, road network	Raw	m2	2.92E-06
987	Transformation, to unknown	Raw	m2	1.44E-07
988	Transformation, to urban, discontinuously built	Raw	m2	3.08E-08
989	Transformation, to urban/industrial fallow	Raw	m2	5.85E-11
990	Transformation, to water bodies, artificial	Raw	m2	1.87E-06
991	Transformation, to wetland, inland (non-use)	Raw	m2	2.01E-09
992	Triadimenol	Soil	kg	2.78E-14
993	Triallate	Soil	kg	7.64E-17
994	Triasulfuron	Soil	kg	2.26E-17
995	Tribenuron	Soil	kg	2.89E-15
996	Tribenuron-methyl	Soil	kg	6.49E-14
997	Tribufos	Soil	kg	5.32E-12
998	Tributyltin compounds	Water	kg	1.49E-08
999	Triclopyr	Soil	kg	7.50E-12
1000	Triethylene glycol	Water	kg	7.00E-10
1001	Trifloxystrobin	Air	kg	1.39E-12
1002	Trifloxystrobin	Soil	kg	9.02E-14
1003	Trifluralin	Air	kg	2.20E-09
1004	Trifluralin	Soil	kg	3.00E-08
1005	Trimethylamine	Air	kg	9.71E-12
1006	Trimethylamine	Water	kg	2.33E-11
1007	Trinexapac-ethyl	Soil	kg	6.58E-13
1008	Tungsten	Air	kg	1.44E-10
1009	Tungsten	Water	kg	4.66E-08
1010	Ulexite	Raw	kg	8.88E-09
1011	Uranium	Raw	kg	6.63E-07
1012	Uranium	Air	kg	6.16E-11
1013	Uranium-234	Air	Bq	2.48E-03
1014	Uranium-234	Water	Bq	2.33E-03

1015	Uranium-235	Air	Bq	5.95E-05
1016	Uranium-235	Water	Bq	3.85E-03
1017	Uranium-238	Air	Bq	1.06E-02
1018	Uranium-238	Water	Bq	8.05E-03
1019	Uranium alpha	Air	Bq	7.14E-03
1020	Uranium alpha	Water	Bq	1.18E-01
1021	Urea	Water	kg	4.34E-11
1022	Vanadium	Air	kg	1.30E-07
1023	Vanadium	Water	kg	1.58E-05
1024	Vanadium	Soil	kg	1.29E-10
1025	Vermiculite	Raw	kg	7.88E-07
1026	Vinclozolin	Soil	kg	2.21E-12
1027	VOC, volatile organic compounds, unspecified origin	Water	kg	3.63E-07
1028	Volume occupied, final repository for low-active radioactive waste	Raw	m3	4.04E-09
1029	Volume occupied, final repository for radioactive waste	Raw	m3	1.42E-10
1030	Volume occupied, reservoir	Raw	m3y	3.10E-04
1031	Volume occupied, underground deposit	Raw	m3	7.29E-10
1032	Water, AT	Water	m3	1.39E-03
1033	Water, AU	Water	m3	5.54E-04
1034	Water, BA	Water	m3	1.12E-04
1035	Water, BE	Water	m3	3.70E-05
1036	Water, BG	Water	m3	1.95E-04
1037	Water, BR	Water	m3	2.97E-03
1038	Water, CA	Water	m3	9.77E-03
1039	Water, CH	Water	m3	2.05E-03
1040	Water, CL	Water	m3	1.00E-03
1041	Water, CN	Water	m3	1.01E-02
1042	Water, CO	Water	m3	4.52E-08
1043	Water, cooling, unspecified natural origin, AT	Raw	m3	1.20E-06
1044	Water, cooling, unspecified natural origin, AU	Raw	m3	1.22E-05
1045	Water, cooling, unspecified natural origin, BA	Raw	m3	4.60E-07
1046	Water, cooling, unspecified natural origin, BE	Raw	m3	5.31E-06
1047	Water, cooling, unspecified natural origin, BG	Raw	m3	3.14E-06
1048	Water, cooling, unspecified natural origin, BR	Raw	m3	4.89E-06
1049	Water, cooling, unspecified natural origin, CA	Raw	m3	2.19E-05

1050	Water, cooling, unspecified natural origin, CH	Raw	m3	8.80E-06
1051	Water, cooling, unspecified natural origin, CL	Raw	m3	1.98E-06
1052	Water, cooling, unspecified natural origin, CN	Raw	m3	1.14E-04
1053	Water, cooling, unspecified natural origin, CZ	Raw	m3	6.02E-06
1054	Water, cooling, unspecified natural origin, DE	Raw	m3	3.39E-05
1055	Water, cooling, unspecified natural origin, DK	Raw	m3	1.72E-06
1056	Water, cooling, unspecified natural origin, ES	Raw	m3	1.75E-05
1057	Water, cooling, unspecified natural origin, Europe without Switzerland	Raw	m3	1.39E-05
1058	Water, cooling, unspecified natural origin, FI	Raw	m3	3.71E-06
1059	Water, cooling, unspecified natural origin, FR	Raw	m3	4.79E-05
1060	Water, cooling, unspecified natural origin, GB	Raw	m3	2.62E-05
1061	Water, cooling, unspecified natural origin, GLO	Raw	m3	4.15E-06
1062	Water, cooling, unspecified natural origin, GR	Raw	m3	3.66E-06
1063	Water, cooling, unspecified natural origin, HR	Raw	m3	5.88E-07
1064	Water, cooling, unspecified natural origin, HU	Raw	m3	4.12E-06
1065	Water, cooling, unspecified natural origin, ID	Raw	m3	7.27E-06
1066	Water, cooling, unspecified natural origin, IE	Raw	m3	1.93E-06
1067	Water, cooling, unspecified natural origin, IN	Raw	m3	5.09E-05
1068	Water, cooling, unspecified natural origin, IR	Raw	m3	1.46E-05
1069	Water, cooling, unspecified natural origin, IT	Raw	m3	1.95E-05
1070	Water, cooling, unspecified natural origin, JP	Raw	m3	5.46E-05
1071	Water, cooling, unspecified natural origin, KR	Raw	m3	2.52E-05
1072	Water, cooling, unspecified natural origin, LU	Raw	m3	1.49E-07
1073	Water, cooling, unspecified natural origin, MA	Raw	m3	2.30E-08
1074	Water, cooling, unspecified natural origin, MK	Raw	m3	4.38E-07

1075	Water, cooling, unspecified natural origin, MX	Raw	m3	1.05E-05
1076	Water, cooling, unspecified natural origin, MY	Raw	m3	6.27E-06
1077	Water, cooling, unspecified natural origin, NL	Raw	m3	6.82E-06
1078	Water, cooling, unspecified natural origin, NO	Raw	m3	6.92E-08
1079	Water, cooling, unspecified natural origin, PE	Raw	m3	6.37E-07
1080	Water, cooling, unspecified natural origin, PH	Raw	m3	1.24E-09
1081	Water, cooling, unspecified natural origin, PL	Raw	m3	9.08E-06
1082	Water, cooling, unspecified natural origin, PT	Raw	m3	2.27E-06
1083	Water, cooling, unspecified natural origin, RER	Raw	m3	5.91E-05
1084	Water, cooling, unspecified natural origin, RNA	Raw	m3	8.00E-12
1085	Water, cooling, unspecified natural origin, RO	Raw	m3	3.69E-06
1086	Water, cooling, unspecified natural origin, RoW	Raw	m3	1.21E-03
1087	Water, cooling, unspecified natural origin, RS	Raw	m3	1.88E-06
1088	Water, cooling, unspecified natural origin, RU	Raw	m3	9.20E-05
1089	Water, cooling, unspecified natural origin, SA	Raw	m3	1.38E-05
1090	Water, cooling, unspecified natural origin, SE	Raw	m3	6.24E-06
1091	Water, cooling, unspecified natural origin, SI	Raw	m3	1.04E-06
1092	Water, cooling, unspecified natural origin, SK	Raw	m3	1.65E-06
1093	Water, cooling, unspecified natural origin, TH	Raw	m3	7.70E-06
1094	Water, cooling, unspecified natural origin, TR	Raw	m3	8.79E-06
1095	Water, cooling, unspecified natural origin, TW	Raw	m3	4.90E-03
1096	Water, cooling, unspecified natural origin, TZ	Raw	m3	1.46E-07
1097	Water, cooling, unspecified natural origin, UA	Raw	m3	1.61E-05
1098	Water, cooling, unspecified natural origin, US	Raw	m3	1.69E-04
1099	Water, cooling, unspecified natural origin, WEU	Raw	m3	2.43E-10

1100	Water, cooling, unspecified natural origin, ZA	Raw	m3	1.29E-05
1101	Water, CZ	Water	m3	1.01E-04
1102	Water, DE	Water	m3	9.85E-04
1103	Water, DK	Water	m3	3.29E-06
1104	Water, ES	Water	m3	9.64E-04
1105	Water, Europe without Switzerland	Water	m3	6.43E-07
1106	Water, FI	Water	m3	7.53E-04
1107	Water, FR	Water	m3	3.62E-03
1108	Water, GB	Water	m3	3.50E-04
1109	Water, GLO	Water	m3	1.83E-05
1110	Water, GR	Water	m3	2.05E-04
1111	Water, HR	Water	m3	1.68E-05
1112	Water, HU	Water	m3	1.94E-05
1113	Water, IAI Area 1	Water	m3	1.13E-08
1114	Water, IAI Area 2, without Quebec	Water	m3	1.47E-08
1115	Water, IAI Area 3	Water	m3	1.25E-08
1116	Water, IAI Area 4&5 without China	Water	m3	2.07E-08
1117	Water, IAI Area 8	Water	m3	2.52E-08
1118	Water, ID	Water	m3	1.02E-04
1119	Water, IE	Water	m3	6.05E-05
1120	Water, IL	Water	m3	8.85E-13
1121	Water, IN	Water	m3	7.79E-04
1122	Water, IR	Water	m3	2.72E-04
1123	Water, IT	Water	m3	9.40E-04
1124	Water, JP	Water	m3	3.22E-03
1125	Water, KR	Water	m3	1.56E-04
1126	Water, lake, AT	Raw	m3	6.91E-13
1127	Water, lake, BE	Raw	m3	1.37E-12
1128	Water, lake, BG	Raw	m3	1.49E-14
1129	Water, lake, CA	Raw	m3	1.55E-07
1130	Water, lake, CH	Raw	m3	2.44E-08
1131	Water, lake, CN	Raw	m3	2.87E-12
1132	Water, lake, CZ	Raw	m3	2.02E-14
1133	Water, lake, DE	Raw	m3	8.99E-12
1134	Water, lake, DK	Raw	m3	1.87E-12
1135	Water, lake, ES	Raw	m3	1.54E-12
1136	Water, lake, Europe without Switzerland	Raw	m3	1.88E-07
1137	Water, lake, FI	Raw	m3	4.73E-13
1138	Water, lake, FR	Raw	m3	3.59E-12
1139	Water, lake, GB	Raw	m3	2.82E-12
1140	Water, lake, GLO	Raw	m3	1.33E-10
1141	Water, lake, HU	Raw	m3	1.51E-12

1142	Water, lake, IT	Raw	m3	3.21E-12
1143	Water, lake, JP	Raw	m3	4.04E-12
1144	Water, lake, KR	Raw	m3	9.68E-14
1145	Water, lake, LU	Raw	m3	4.64E-14
1146	Water, lake, NL	Raw	m3	2.92E-12
1147	Water, lake, NO	Raw	m3	1.31E-13
1148	Water, lake, PL	Raw	m3	2.60E-13
1149	Water, lake, PT	Raw	m3	5.81E-13
1150	Water, lake, RER	Raw	m3	4.02E-10
1151	Water, lake, RNA	Raw	m3	5.51E-13
1152	Water, lake, RoW	Raw	m3	1.11E-05
1153	Water, lake, RU	Raw	m3	1.27E-12
1154	Water, lake, SE	Raw	m3	3.60E-12
1155	Water, lake, SK	Raw	m3	3.80E-14
1156	Water, lake, TR	Raw	m3	4.30E-14
1157	Water, lake, TW	Raw	m3	1.61E-12
1158	Water, lake, US	Raw	m3	1.51E-12
1159	Water, LU	Water	m3	1.16E-05
1160	Water, MA	Water	m3	1.95E-08
1161	Water, MK	Water	m3	1.11E-05
1162	Water, MX	Water	m3	1.64E-03
1163	Water, MY	Water	m3	8.66E-05
1164	Water, NL	Water	m3	1.19E-05
1165	Water, NO	Water	m3	1.64E-04
1166	Water, NORDEL	Water	m3	7.13E-10
1167	Water, PE	Water	m3	1.40E-05
1168	Water, PG	Water	m3	4.77E-09
1169	Water, PH	Water	m3	1.05E-07
1170	Water, PL	Water	m3	1.33E-04
1171	Water, PT	Water	m3	2.85E-04
1172	Water, RAF	Water	m3	2.21E-06
1173	Water, RAS	Water	m3	3.23E-07
1174	Water, RER	Water	m3	4.68E-05
1175	Water, river, AT	Raw	m3	9.24E-10
1176	Water, river, AU	Raw	m3	3.10E-08
1177	Water, river, BE	Raw	m3	1.72E-09
1178	Water, river, BG	Raw	m3	1.84E-11
1179	Water, river, BR	Raw	m3	1.02E-04
1180	Water, river, CA	Raw	m3	2.40E-06
1181	Water, river, CH	Raw	m3	9.34E-07
1182	Water, river, CN	Raw	m3	2.85E-06
1183	Water, river, CZ	Raw	m3	4.49E-11
1184	Water, river, DE	Raw	m3	8.91E-07

1185	Water, river, DK	Raw	m3	2.33E-09
1186	Water, river, ES	Raw	m3	1.42E-07
1187	Water, river, Europe without Switzerland	Raw	m3	5.32E-06
1188	Water, river, FI	Raw	m3	5.91E-10
1189	Water, river, FR	Raw	m3	2.27E-06
1190	Water, river, GB	Raw	m3	3.89E-09
1191	Water, river, GLO	Raw	m3	8.39E-07
1192	Water, river, GR	Raw	m3	1.42E-11
1193	Water, river, HU	Raw	m3	1.87E-09
1194	Water, river, IE	Raw	m3	9.95E-12
1195	Water, river, IN	Raw	m3	2.49E-06
1196	Water, river, IT	Raw	m3	4.09E-09
1197	Water, river, JP	Raw	m3	5.00E-09
1198	Water, river, KR	Raw	m3	1.27E-10
1199	Water, river, LU	Raw	m3	5.95E-11
1200	Water, river, MX	Raw	m3	9.64E-13
1201	Water, river, MY	Raw	m3	8.02E-06
1202	Water, river, NL	Raw	m3	3.80E-09
1203	Water, river, NO	Raw	m3	1.62E-10
1204	Water, river, PE	Raw	m3	4.82E-11
1205	Water, river, PH	Raw	m3	5.67E-07
1206	Water, river, PL	Raw	m3	3.39E-10
1207	Water, river, PT	Raw	m3	7.23E-10
1208	Water, river, RAS	Raw	m3	6.55E-07
1209	Water, river, RER	Raw	m3	8.02E-05
1210	Water, river, RLA	Raw	m3	1.88E-07
1211	Water, river, RNA	Raw	m3	3.48E-07
1212	Water, river, RoW	Raw	m3	3.23E-04
1213	Water, river, RU	Raw	m3	2.14E-08
1214	Water, river, SE	Raw	m3	3.45E-09
1215	Water, river, SI	Raw	m3	4.72E-12
1216	Water, river, SK	Raw	m3	4.79E-11
1217	Water, river, TH	Raw	m3	6.98E-13
1218	Water, river, TR	Raw	m3	5.51E-11
1219	Water, river, TW	Raw	m3	1.98E-09
1220	Water, river, TZ	Raw	m3	7.39E-10
1221	Water, river, US	Raw	m3	5.76E-06
1222	Water, river, WEU	Raw	m3	2.92E-14
1223	Water, river, ZA	Raw	m3	3.11E-09
1224	Water, RLA	Water	m3	1.28E-07
1225	Water, RME	Water	m3	2.18E-05
1226	Water, RNA	Water	m3	1.28E-06
1227	Water, RO	Water	m3	1.00E-03

1228	Water, RoW	Water	m3	3.41E-02
1229	Water, RS	Water	m3	4.54E-04
1230	Water, RU	Water	m3	5.37E-03
1231	Water, SA	Water	m3	1.39E-05
1232	Water, salt, ocean	Raw	m3	1.22E-05
1233	Water, salt, sole	Raw	m3	1.26E-05
1234	Water, SE	Water	m3	3.28E-03
1235	Water, SI	Water	m3	2.44E-04
1236	Water, SK	Water	m3	1.52E-04
1237	Water, TH	Water	m3	7.28E-05
1238	Water, TR	Water	m3	1.00E-03
1239	Water, turbine use, unspecified natural origin, AT	Raw	m3	1.39E-03
1240	Water, turbine use, unspecified natural origin, AU	Raw	m3	5.42E-04
1241	Water, turbine use, unspecified natural origin, BA	Raw	m3	1.12E-04
1242	Water, turbine use, unspecified natural origin, BE	Raw	m3	3.17E-05
1243	Water, turbine use, unspecified natural origin, BG	Raw	m3	1.92E-04
1244	Water, turbine use, unspecified natural origin, BR	Raw	m3	2.90E-03
1245	Water, turbine use, unspecified natural origin, CA	Raw	m3	9.75E-03
1246	Water, turbine use, unspecified natural origin, CH	Raw	m3	2.04E-03
1247	Water, turbine use, unspecified natural origin, CL	Raw	m3	9.99E-04
1248	Water, turbine use, unspecified natural origin, CN	Raw	m3	9.96E-03
1249	Water, turbine use, unspecified natural origin, CZ	Raw	m3	9.50E-05
1250	Water, turbine use, unspecified natural origin, DE	Raw	m3	9.50E-04
1251	Water, turbine use, unspecified natural origin, DK	Raw	m3	1.54E-06
1252	Water, turbine use, unspecified natural origin, ES	Raw	m3	9.46E-04
1253	Water, turbine use, unspecified natural origin, FI	Raw	m3	7.49E-04
1254	Water, turbine use, unspecified natural origin, FR	Raw	m3	3.57E-03
1255	Water, turbine use, unspecified natural origin, GB	Raw	m3	3.24E-04
1256	Water, turbine use, unspecified natural origin, GLO	Raw	m3	4.72E-09

1257	Water, turbine use, unspecified natural origin, GR	Raw	m3	2.01E-04
1258	Water, turbine use, unspecified natural origin, HR	Raw	m3	1.64E-05
1259	Water, turbine use, unspecified natural origin, HU	Raw	m3	1.52E-05
1260	Water, turbine use, unspecified natural origin, ID	Raw	m3	9.36E-05
1261	Water, turbine use, unspecified natural origin, IE	Raw	m3	5.86E-05
1262	Water, turbine use, unspecified natural origin, IN	Raw	m3	7.30E-04
1263	Water, turbine use, unspecified natural origin, IR	Raw	m3	2.57E-04
1264	Water, turbine use, unspecified natural origin, IT	Raw	m3	9.21E-04
1265	Water, turbine use, unspecified natural origin, JP	Raw	m3	3.16E-03
1266	Water, turbine use, unspecified natural origin, KR	Raw	m3	1.31E-04
1267	Water, turbine use, unspecified natural origin, LU	Raw	m3	1.14E-05
1268	Water, turbine use, unspecified natural origin, MK	Raw	m3	1.07E-05
1269	Water, turbine use, unspecified natural origin, MX	Raw	m3	1.63E-03
1270	Water, turbine use, unspecified natural origin, MY	Raw	m3	7.44E-05
1271	Water, turbine use, unspecified natural origin, NL	Raw	m3	5.01E-06
1272	Water, turbine use, unspecified natural origin, NO	Raw	m3	1.69E-04
1273	Water, turbine use, unspecified natural origin, PE	Raw	m3	1.39E-05
1274	Water, turbine use, unspecified natural origin, PL	Raw	m3	1.23E-04
1275	Water, turbine use, unspecified natural origin, PT	Raw	m3	2.83E-04
1276	Water, turbine use, unspecified natural origin, RER	Raw	m3	6.14E-07
1277	Water, turbine use, unspecified natural origin, RNA	Raw	m3	6.59E-10
1278	Water, turbine use, unspecified natural origin, RO	Raw	m3	1.00E-03
1279	Water, turbine use, unspecified natural origin, RoW	Raw	m3	3.31E-02
1280	Water, turbine use, unspecified natural origin, RS	Raw	m3	4.52E-04
1281	Water, turbine use, unspecified natural origin, RU	Raw	m3	5.27E-03

1282	Water, turbine use, unspecified natural origin, SE	Raw	m3	3.27E-03
1283	Water, turbine use, unspecified natural origin, SI	Raw	m3	2.42E-04
1284	Water, turbine use, unspecified natural origin, SK	Raw	m3	1.50E-04
1285	Water, turbine use, unspecified natural origin, TH	Raw	m3	6.52E-05
1286	Water, turbine use, unspecified natural origin, TR	Raw	m3	9.92E-04
1287	Water, turbine use, unspecified natural origin, TW	Raw	m3	1.52E-01
1288	Water, turbine use, unspecified natural origin, TZ	Raw	m3	2.94E-05
1289	Water, turbine use, unspecified natural origin, UA	Raw	m3	6.53E-04
1290	Water, turbine use, unspecified natural origin, US	Raw	m3	8.69E-03
1291	Water, turbine use, unspecified natural origin, ZA	Raw	m3	1.46E-05
1292	Water, TW	Water	m3	1.57E-01
1293	Water, TZ	Water	m3	2.95E-05
1294	Water, UA	Water	m3	6.69E-04
1295	Water, UCTE	Water	m3	2.08E-11
1296	Water, UCTE without Germany	Water	m3	3.71E-12
1297	Water, UN-EUROPE	Water	m3	4.93E-08
1298	Water, UN-OCEANIA	Water	m3	1.50E-08
1299	Water, unspecified natural origin, AT	Raw	m3	6.77E-09
1300	Water, unspecified natural origin, AU	Raw	m3	2.57E-10
1301	Water, unspecified natural origin, BA	Raw	m3	4.94E-12
1302	Water, unspecified natural origin, BE	Raw	m3	1.33E-08
1303	Water, unspecified natural origin, BG	Raw	m3	1.46E-10
1304	Water, unspecified natural origin, BR	Raw	m3	5.72E-10
1305	Water, unspecified natural origin, CA	Raw	m3	1.86E-07
1306	Water, unspecified natural origin, CH	Raw	m3	1.31E-06
1307	Water, unspecified natural origin, CL	Raw	m3	4.57E-12
1308	Water, unspecified natural origin, CN	Raw	m3	8.64E-08
1309	Water, unspecified natural origin, CZ	Raw	m3	3.19E-10
1310	Water, unspecified natural origin, DE	Raw	m3	8.68E-08
1311	Water, unspecified natural origin, DK	Raw	m3	1.78E-08
1312	Water, unspecified natural origin, ES	Raw	m3	1.49E-08
1313	Water, unspecified natural origin, Europe without Switzerland	Raw	m3	1.78E-07
1314	Water, unspecified natural origin, FI	Raw	m3	4.58E-09
1315	Water, unspecified natural origin, FR	Raw	m3	3.47E-08
1316	Water, unspecified natural origin, GB	Raw	m3	2.69E-08

1317	Water, unspecified natural origin, GLO	Raw	m3	5.71E-06
1318	Water, unspecified natural origin, HR	Raw	m3	2.05E-12
1319	Water, unspecified natural origin, HU	Raw	m3	1.43E-08
1320	Water, unspecified natural origin, IAI Area 1	Raw	m3	6.24E-09
1321	Water, unspecified natural origin, IAI Area 2, without Quebec	Raw	m3	8.58E-09
1322	Water, unspecified natural origin, IAI Area 3	Raw	m3	7.81E-09
1323	Water, unspecified natural origin, IAI Area 4&5 without China	Raw	m3	1.16E-08
1324	Water, unspecified natural origin, IAI Area 8	Raw	m3	1.39E-08
1325	Water, unspecified natural origin, IN	Raw	m3	3.77E-11
1326	Water, unspecified natural origin, IR	Raw	m3	6.04E-11
1327	Water, unspecified natural origin, IT	Raw	m3	3.13E-08
1328	Water, unspecified natural origin, JP	Raw	m3	4.22E-08
1329	Water, unspecified natural origin, KR	Raw	m3	3.08E-09
1330	Water, unspecified natural origin, LU	Raw	m3	4.40E-10
1331	Water, unspecified natural origin, MX	Raw	m3	5.65E-11
1332	Water, unspecified natural origin, NL	Raw	m3	2.82E-08
1333	Water, unspecified natural origin, NO	Raw	m3	1.26E-09
1334	Water, unspecified natural origin, PG	Raw	m3	5.82E-10
1335	Water, unspecified natural origin, PH	Raw	m3	3.11E-10
1336	Water, unspecified natural origin, PL	Raw	m3	2.55E-09
1337	Water, unspecified natural origin, PT	Raw	m3	5.51E-09
1338	Water, unspecified natural origin, RAF	Raw	m3	2.61E-06
1339	Water, unspecified natural origin, RER	Raw	m3	6.48E-06
1340	Water, unspecified natural origin, RME	Raw	m3	2.56E-05
1341	Water, unspecified natural origin, RNA	Raw	m3	3.81E-07
1342	Water, unspecified natural origin, RO	Raw	m3	7.30E-12
1343	Water, unspecified natural origin, RoW	Raw	m3	1.69E-04
1344	Water, unspecified natural origin, RS	Raw	m3	8.99E-12
1345	Water, unspecified natural origin, RU	Raw	m3	3.66E-06
1346	Water, unspecified natural origin, SE	Raw	m3	2.15E-08
1347	Water, unspecified natural origin, SK	Raw	m3	3.98E-10
1348	Water, unspecified natural origin, TH	Raw	m3	4.15E-11
1349	Water, unspecified natural origin, TR	Raw	m3	5.42E-10
1350	Water, unspecified natural origin, TW	Raw	m3	1.01E-07
1351	Water, unspecified natural origin, UA	Raw	m3	2.88E-10

1352	Water, unspecified natural origin, UN-EUROPE	Raw	m3	3.12E-08
1353	Water, unspecified natural origin, UN-OCEANIA	Raw	m3	8.32E-09
1354	Water, unspecified natural origin, US	Raw	m3	1.71E-07
1355	Water, unspecified natural origin, WEU	Raw	m3	3.08E-11
1356	Water, US	Water	m3	8.87E-03
1357	Water, well, in ground, AT	Raw	m3	6.05E-11
1358	Water, well, in ground, AU	Raw	m3	3.24E-07
1359	Water, well, in ground, BE	Raw	m3	1.16E-10
1360	Water, well, in ground, BG	Raw	m3	1.25E-12
1361	Water, well, in ground, BR	Raw	m3	2.35E-05
1362	Water, well, in ground, CA	Raw	m3	1.26E-07
1363	Water, well, in ground, CH	Raw	m3	1.21E-07
1364	Water, well, in ground, CN	Raw	m3	5.85E-06
1365	Water, well, in ground, CZ	Raw	m3	2.50E-12
1366	Water, well, in ground, DE	Raw	m3	7.96E-08
1367	Water, well, in ground, DK	Raw	m3	1.58E-10
1368	Water, well, in ground, ES	Raw	m3	8.28E-08
1369	Water, well, in ground, Europe without Switzerland	Raw	m3	6.76E-07
1370	Water, well, in ground, FI	Raw	m3	3.99E-11
1371	Water, well, in ground, FR	Raw	m3	2.45E-08
1372	Water, well, in ground, GB	Raw	m3	2.53E-10
1373	Water, well, in ground, GLO	Raw	m3	8.89E-07
1374	Water, well, in ground, GR	Raw	m3	6.01E-13
1375	Water, well, in ground, HU	Raw	m3	1.27E-10
1376	Water, well, in ground, ID	Raw	m3	1.40E-06
1377	Water, well, in ground, IE	Raw	m3	4.02E-13
1378	Water, well, in ground, IN	Raw	m3	4.31E-06
1379	Water, well, in ground, IT	Raw	m3	2.75E-10
1380	Water, well, in ground, JP	Raw	m3	3.39E-10
1381	Water, well, in ground, KR	Raw	m3	9.32E-12
1382	Water, well, in ground, LU	Raw	m3	3.96E-12
1383	Water, well, in ground, MA	Raw	m3	8.30E-09
1384	Water, well, in ground, MX	Raw	m3	1.45E-13
1385	Water, well, in ground, MY	Raw	m3	6.97E-07
1386	Water, well, in ground, NL	Raw	m3	2.48E-10
1387	Water, well, in ground, NO	Raw	m3	1.10E-11
1388	Water, well, in ground, NORDEL	Raw	m3	8.38E-10
1389	Water, well, in ground, PE	Raw	m3	7.81E-11
1390	Water, well, in ground, PG	Raw	m3	5.03E-09
1391	Water, well, in ground, PH	Raw	m3	8.86E-08

1392	Water, well, in ground, PL	Raw	m3	3.12E-07
1393	Water, well, in ground, PT	Raw	m3	4.90E-11
1394	Water, well, in ground, RER	Raw	m3	2.62E-06
1395	Water, well, in ground, RLA	Raw	m3	3.78E-08
1396	Water, well, in ground, RNA	Raw	m3	5.57E-07
1397	Water, well, in ground, RoW	Raw	m3	9.88E-05
1398	Water, well, in ground, RU	Raw	m3	1.75E-07
1399	Water, well, in ground, SE	Raw	m3	3.05E-10
1400	Water, well, in ground, SI	Raw	m3	2.10E-13
1401	Water, well, in ground, SK	Raw	m3	3.22E-12
1402	Water, well, in ground, TH	Raw	m3	1.10E-13
1403	Water, well, in ground, TR	Raw	m3	6.43E-12
1404	Water, well, in ground, TW	Raw	m3	1.35E-10
1405	Water, well, in ground, US	Raw	m3	1.20E-05
1406	Water, well, in ground, WEU	Raw	m3	1.77E-07
1407	Water, well, in ground, ZA	Raw	m3	7.94E-08
1408	Water, WEU	Water	m3	1.97E-07
1409	Water, ZA	Water	m3	2.77E-05
1410	Water/m3	Air	m3	8.29E-04
1411	Wood, hard, standing	Raw	m3	1.53E-09
1412	Wood, soft, standing	Raw	m3	1.76E-06
1413	Wood, unspecified, standing/m3	Raw	m3	1.08E-10
1414	Xenon	Raw	kg	2.26E-11
1415	Xenon-131m	Air	Bq	3.28E-01
1416	Xenon-133	Air	Bq	8.86E+00
1417	Xenon-133m	Air	Bq	1.14E-02
1418	Xenon-135	Air	Bq	3.94E+00
1419	Xenon-135m	Air	Bq	3.03E+00
1420	Xenon-137	Air	Bq	9.62E-02
1421	Xenon-138	Air	Bq	7.17E-01
1422	Xylene	Air	kg	7.70E-07
1423	Xylene	Water	kg	1.09E-07
1424	Zeta-cypermethrin	Soil	kg	3.93E-13
1425	Zinc	Raw	kg	5.31E-06
1426	Zinc	Air	kg	2.11E-07
1427	Zinc	Water	kg	1.12E-04
1428	Zinc	Soil	kg	1.23E-07
1429	Zinc-65	Air	Bq	7.75E-07
1430	Zinc-65	Water	Bq	2.13E-03
1431	Zinc, Zn 0.63%, Au 9.7E-4%, Ag 9.7E-4%, Cu 0.38%, Pb 0.014%, in ore	Raw	kg	3.75E-07
1432	Zinc, Zn 3.1%, in mixed ore	Raw	kg	1.97E-08
1433	Zirconium	Raw	kg	5.29E-07

1434	Zirconium	Air	kg	8.30E-13
1435	Zirconium-95	Air	Bq	4.54E-07
1436	Zirconium-95	Water	Bq	1.40E-03

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