

# 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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# 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.

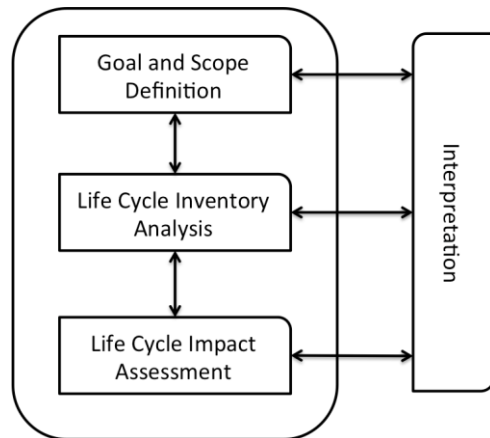
### 1.1.2 LCA Overview

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<sup>1</sup>. 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 from 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”<sup>2</sup>. 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<sup>3</sup>, 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<sup>4</sup>. 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<sup>5</sup>. In 2014 the European pulp and paper industry produced 13 million metric tons of pulp, while using 146 million m<sup>3</sup> of wood as raw materials<sup>6</sup>. Given an assumption that 11,000m<sup>3</sup> of wood can be obtained per square kilometer of forest<sup>7</sup>, 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<sup>8</sup>.

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<sup>3</sup> of water per ton of paper produced, depending on the type of paper<sup>9</sup>. 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<sup>10</sup>. 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<sup>11</sup>. 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<sup>12</sup>. 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<sup>13</sup>. 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<sup>14</sup>.

### **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<sup>15</sup>. 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<sup>16</sup>.

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<sup>17</sup>. 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%<sup>18</sup>. 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<sup>19</sup>.

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<sup>20</sup>.

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<sup>21</sup>.

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<sup>22</sup>. 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<sup>23</sup>. 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”<sup>24</sup>. 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<sup>25</sup>. Calcium carbonate production also has associated energy and carbon dioxide requirements<sup>26</sup>, 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<sup>27,28,29</sup>. 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<sup>30</sup>.

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.

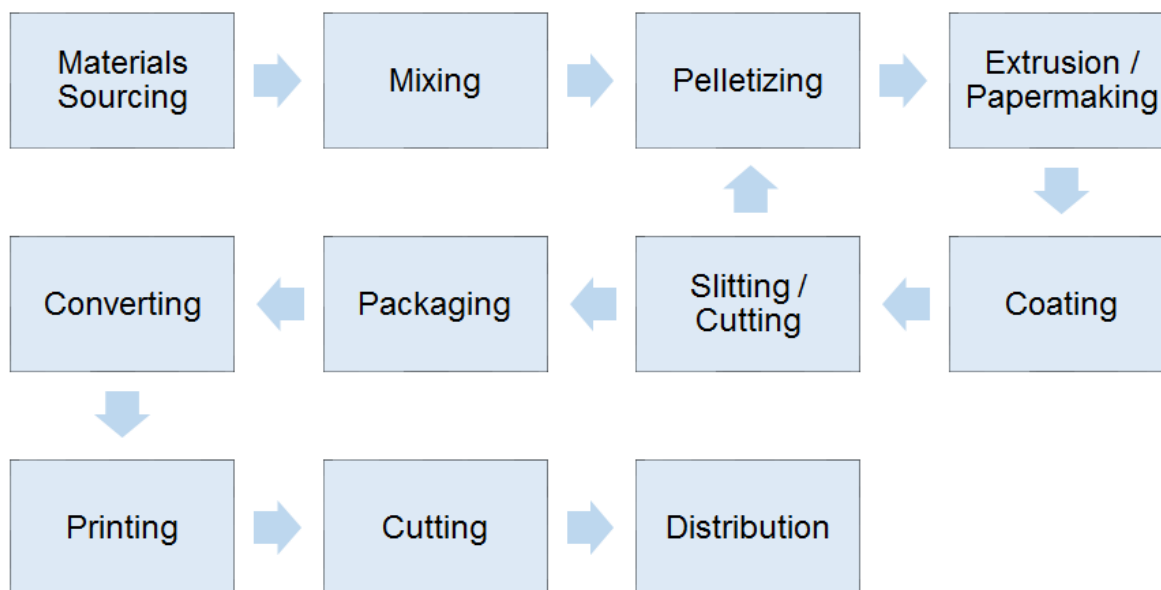
The label roll is then put through the conversion process, which includes slitting and die-cutting. Slitting cuts a large roll into multiple more narrow rolls, whereas die-cutting cuts the slit rolls into the desired final form or shape.

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<sup>31</sup> 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<sup>32</sup>.

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<sup>33</sup>.

#### 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<sup>34</sup> 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<sup>35</sup>. 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<sup>36</sup>.

#### 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 <sup>2</sup> ) | Weight at 100 microns (g/m <sup>2</sup> ) |
|----------------------------|---------------------|----------------------------|---|
| Stone Paper                | 100                 | 120                        | 120                                       |
| Coated Paper <sup>37</sup> | 100                 | 90                         | 90  |
| PP (Yupo) <sup>38</sup>    | 95                  | 73                         | 77  |
| PP (Yupo)                  | 110                 | 85                         |   |

#### 2.2.4 System Boundary

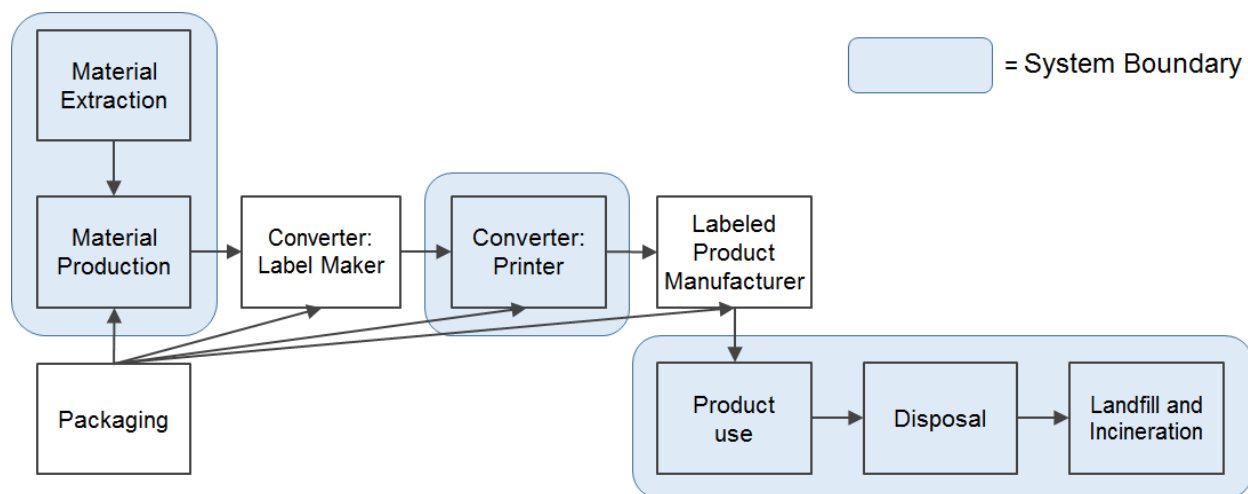
Figure 3 represents the general system boundary used for the life cycle of a product label in this LCA. The highlighted process stages are included in the analysis and the other processes are excluded. Life cycle material inputs, energy requirements, and emissions to the environment of

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.

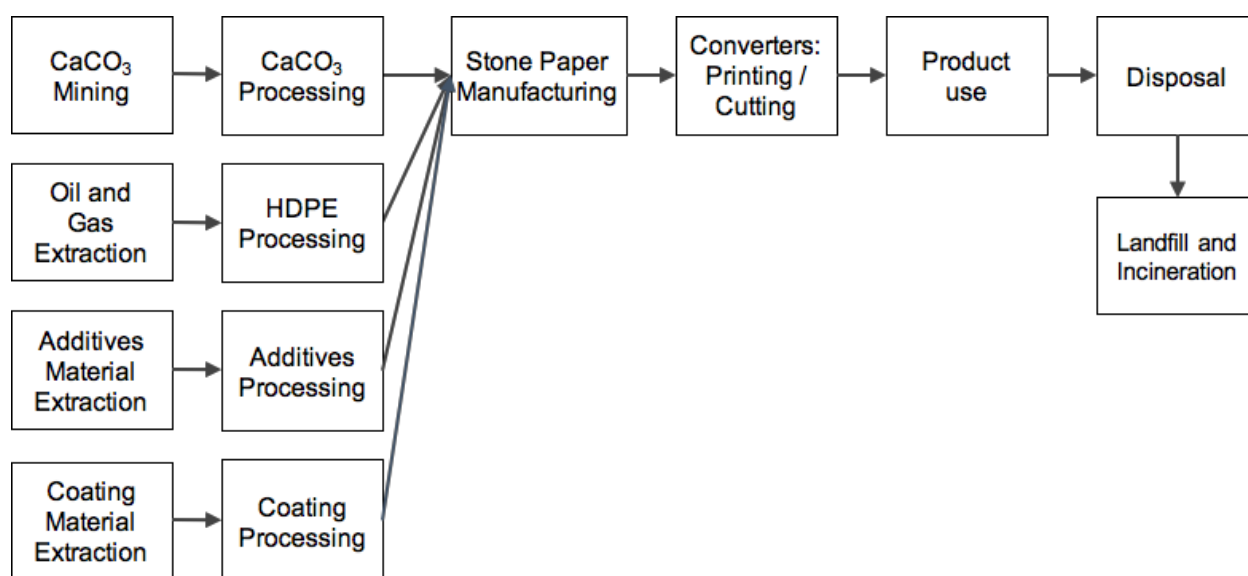
The materials extraction and processing phases refer to the transportation and processing of materials needed for manufacturing Stone Paper. The Stone Paper manufacturing phase refers to the manufacturing processes for the product. This includes the inputs and emissions associated with the transportation 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<sup>39</sup>, and Stone Paper uses 20 percent more ink than the other materials<sup>40</sup>.

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.

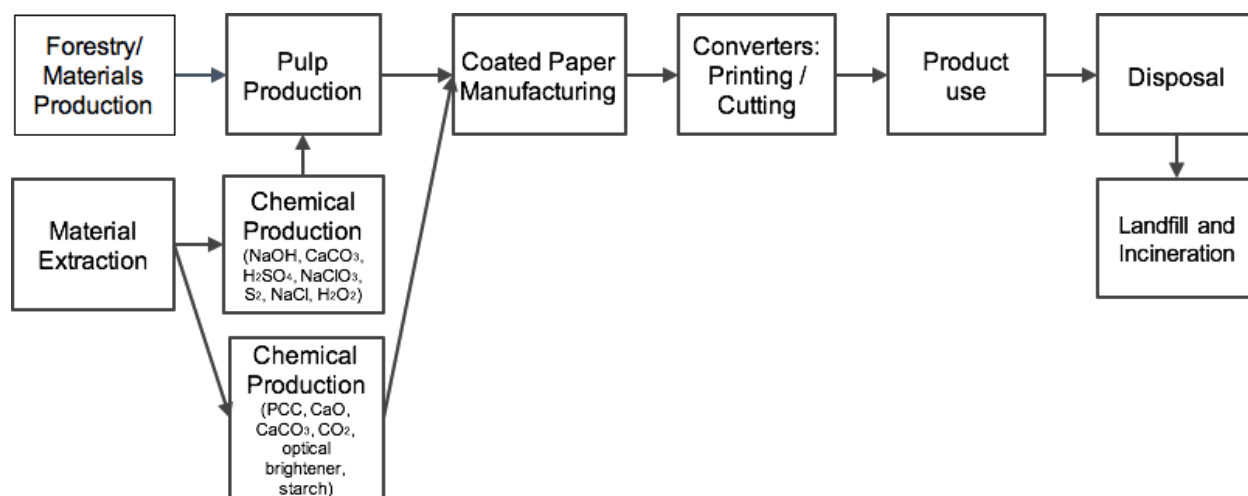
The materials extraction and production phases include the transportation and processing of materials needed for manufacturing coated paper. The coated paper manufacturing phase refers to the manufacturing processes for the product. This includes the inputs and emissions associated with the transportation 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



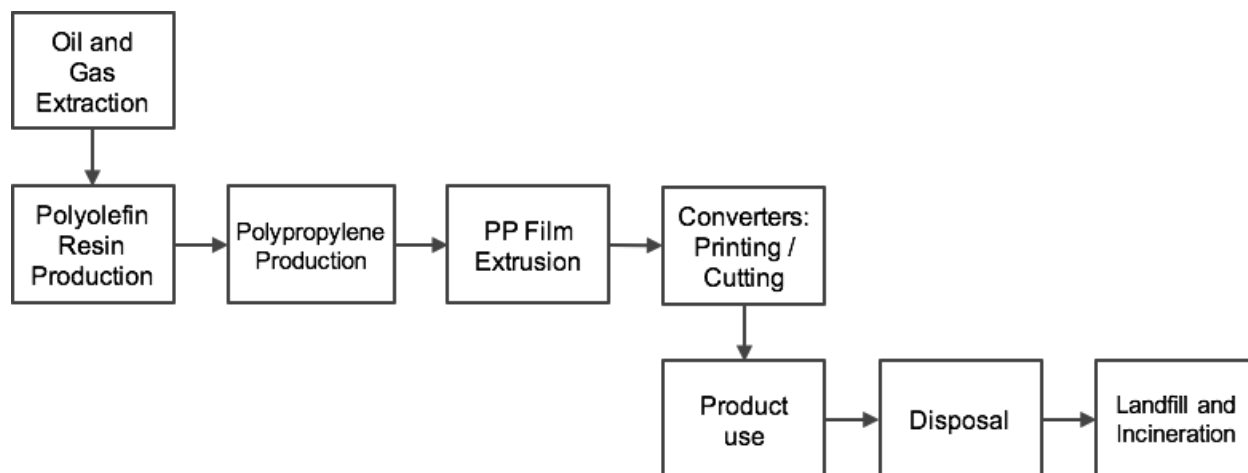
#### 2.2.4.3 Polypropylene Film System

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.<sup>4142</sup>
- 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.<sup>43</sup>
- 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 Shimizu 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 Shimizu to Tokyo was modeled. Shimizu 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<sup>44</sup>. 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<sup>45</sup>.

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<sup>46</sup>.

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<sup>47</sup>.

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<sup>48</sup>. 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<sup>49</sup>. 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 CO <sub>2</sub> eq   |
| Photochemical Smog Formation                   | TRACI 2.1   | kg O <sub>3</sub> eq    |
| Acidification                                  | TRACI 2.1   | kg SO <sub>2</sub> 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 PM <sub>2.5</sub> eq |
| Ecotoxicity                                    | TRACI 2.1   | CTUe                    |
| Fossil Fuel Depletion                          | TRACI 2.1   | MJ surplus              |
| Water Depletion                                | ReCiPe 1.12 | m <sup>3</sup>          |
| Agricultural Land Occupation                   | ReCiPe 1.12 | m <sup>2</sup> a        |
| Urban Land Occupation                          | ReCiPe 1.12 | m <sup>2</sup> a        |

## 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

| <b>Materials</b>      |              |             |               |  |                               |
|-----------------------|--------------|-------------|---------------|--|-------------------------------|
|                       | <b>Value</b> | <b>Unit</b> | <b>Source</b> | <b>Life Cycle Process Name</b>   | <b>Life Cycle Data Source</b> |
| CaCO <sub>3</sub>     | 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                   |
| <b>Processes</b>      |              |             |               |  |                               |
| 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

| <b>Process</b>   | <b>Value</b> | <b>Unit</b> | <b>Source</b> | <b>Life Cycle Process Name</b>   | <b>Life Cycle Data Source</b> |
|------------------|--------------|-------------|---------------|--|-------------------------------|
| 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

| <b>Materials</b>                   |              |             |               |  |                               |
|------------------------------------|--------------|-------------|---------------|--|-------------------------------|
|                                    | <b>Value</b> | <b>Unit</b> | <b>Source</b> | <b>Life Cycle Process Name</b>   | <b>Life Cycle Data Source</b> |
| 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                   |
| <b>Processes</b>                   |              |             |               |  |                               |
| 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

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

Table 8. Transportation Life Cycle Processes

| <b>Process</b> | <b>Stone paper (kg-km)</b> | <b>Coated paper (kg-km)</b> | <b>PP film (kg-km)</b> | <b>Life Cycle Process Name</b>   | <b>Life Cycle Data Source</b> |
|----------------|----------------------------|-----------------------------|------------------------|--|-------------------------------|
| 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 <sup>53</sup>    |
| Truck         | Port of Barcelona | Manufacturer (Frankfurt) | 1339          | Maps.google.com <sup>54</sup> |
| Truck         | Distributor       | User                     | 122           | Eurostat <sup>55</sup>        |

### 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 <sup>56</sup>    |
| Truck         | Port of Shimizu   | Tokyo, Japan      | 167           | Maps.google.com <sup>57</sup> |

### 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 indicators 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

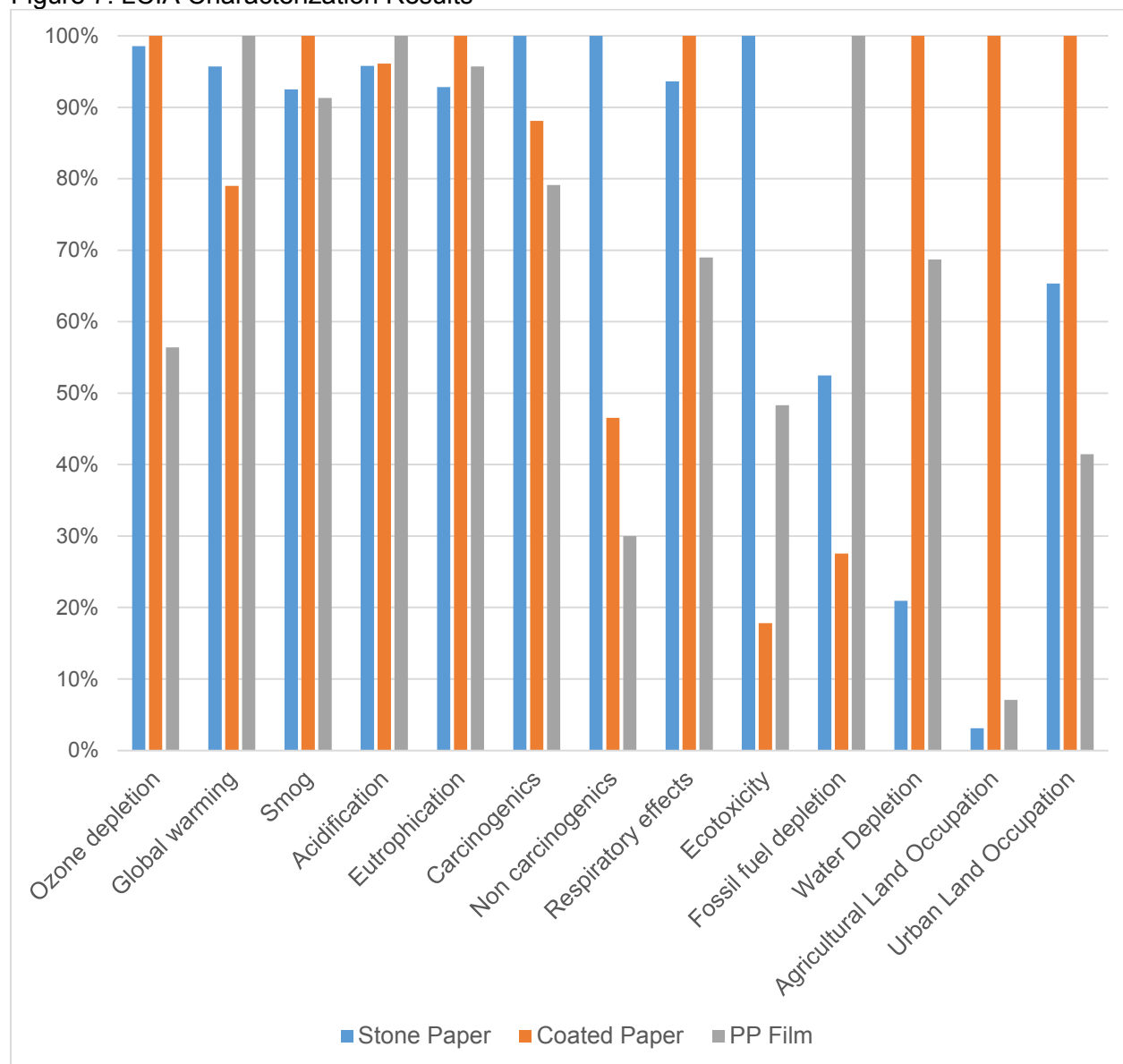
Table 14 below lists the TRACI and ReCiPe LCIA characterization results by impact category. The characterization and normalization results are also visualized below.

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 CO <sub>2</sub> eq   | 2.75E-01    | 2.27E-01     | 2.88E-01 |
| Smog Formation                                 | TRACI 2.1   | kg O <sub>3</sub> eq    | 1.71E-02    | 1.85E-02     | 1.69E-02 |
| Acidification                                  | TRACI 2.1   | kg SO <sub>2</sub> 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 PM <sub>2.5</sub> 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 | m <sup>3</sup>          | 9.56E-04    | 4.56E-03     | 3.14E-03 |
| Agricultural Land Occupation                   | ReCiPe 1.12 | m <sup>2</sup> a        | 1.15E-02    | 3.73E-01     | 2.64E-02 |
| Urban Land Occupation                          | ReCiPe 1.12 | m <sup>2</sup> a        | 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.

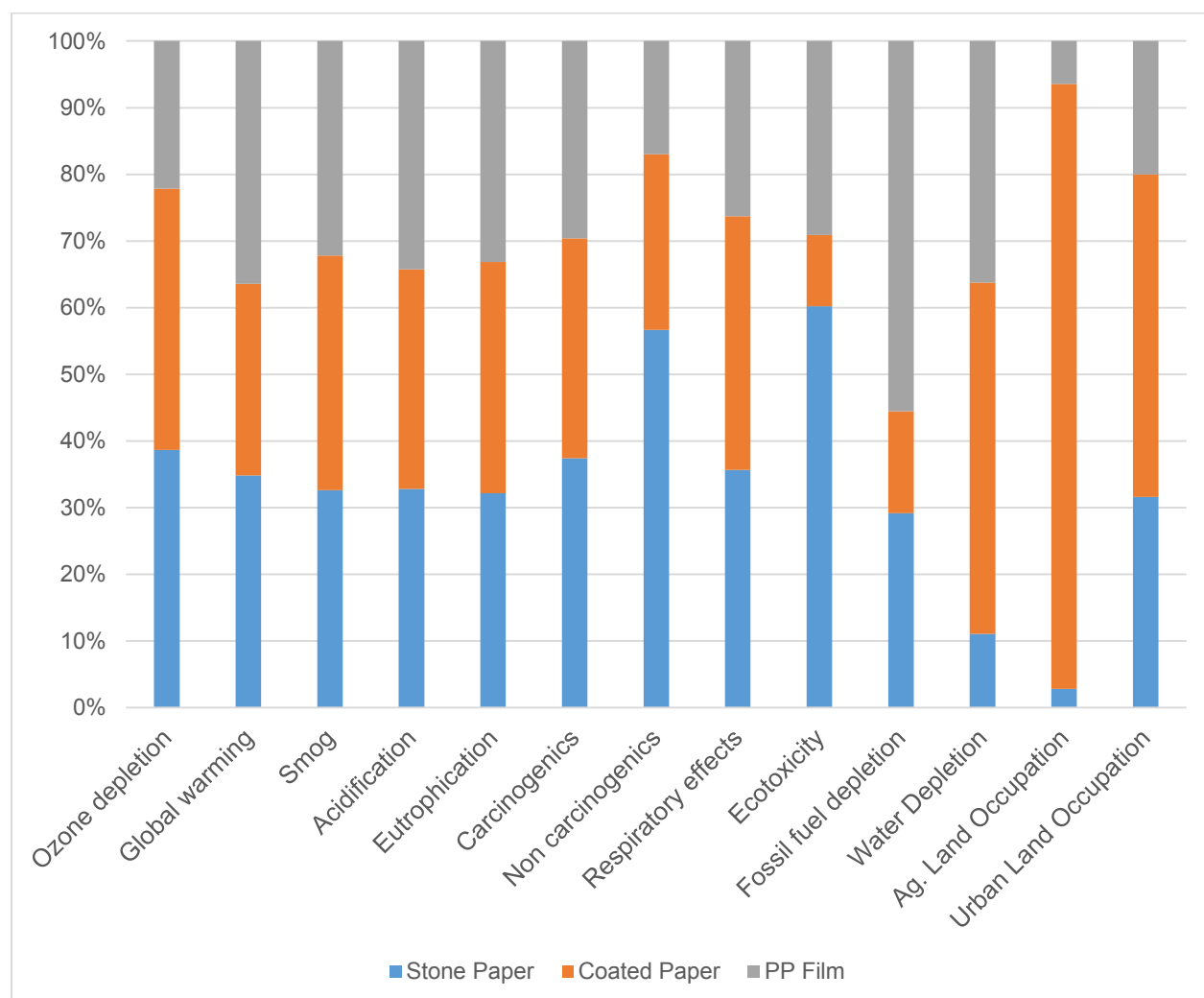
Figure 7. LCIA Characterization Results



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

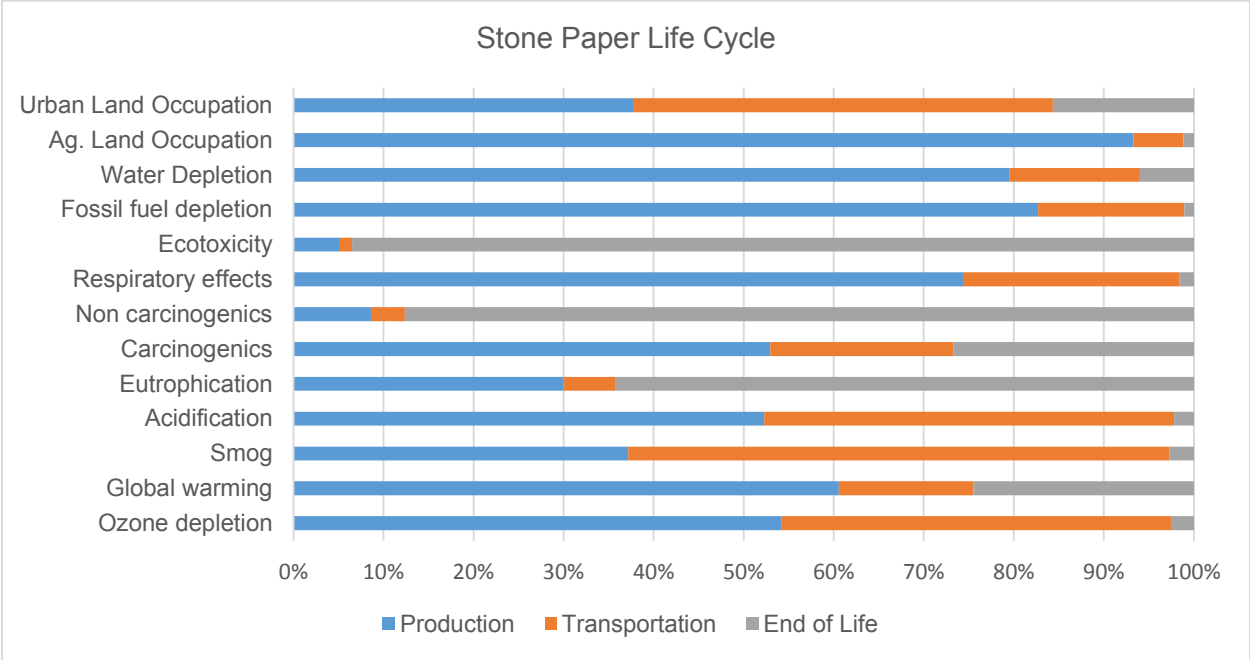


Figure 10. Coated Paper LCIA Results by Life Cycle Stage

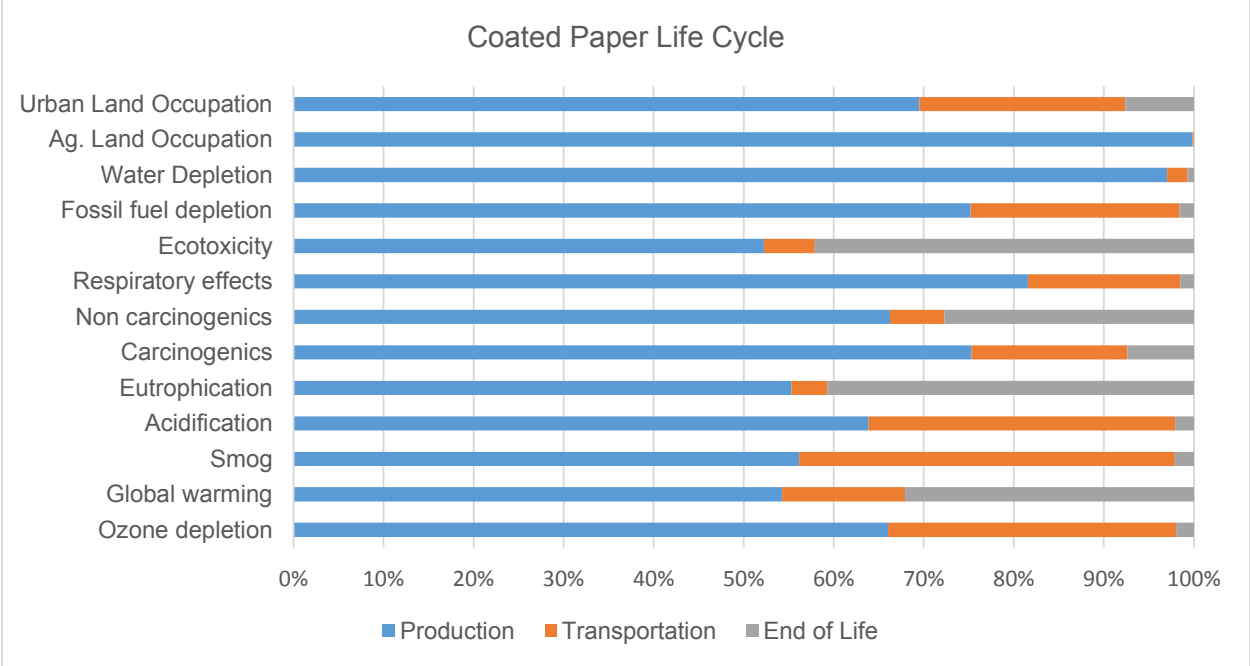
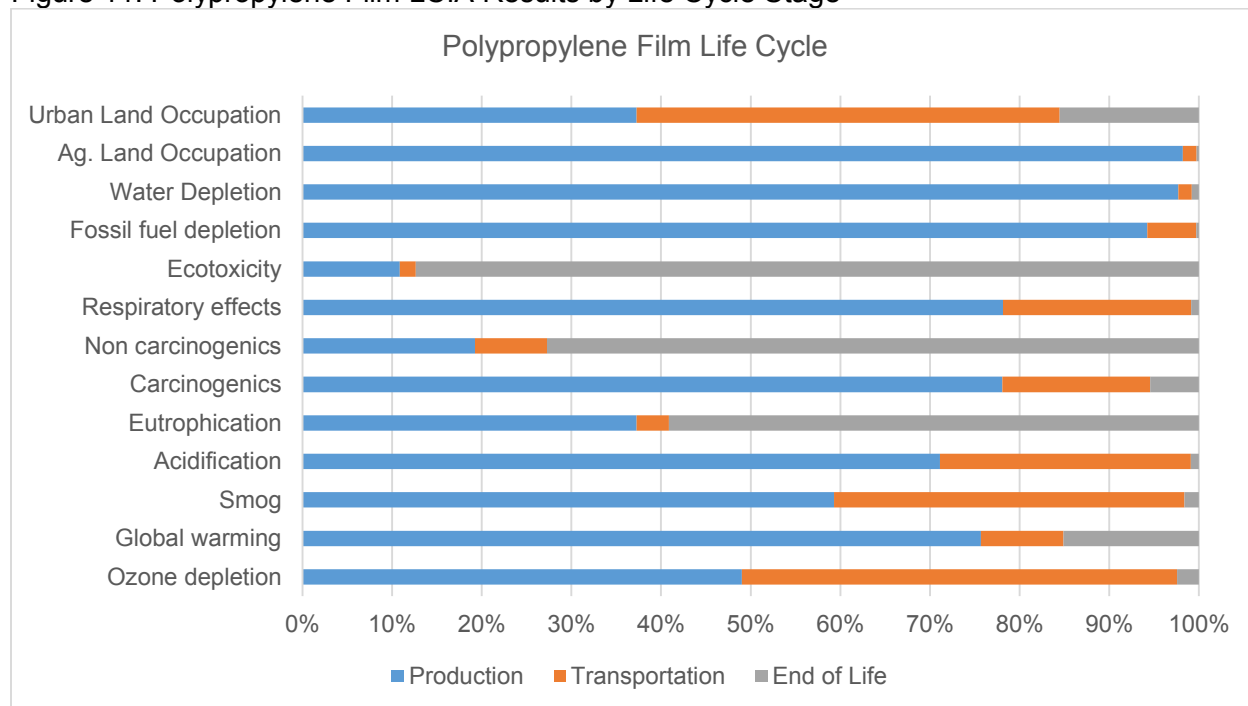


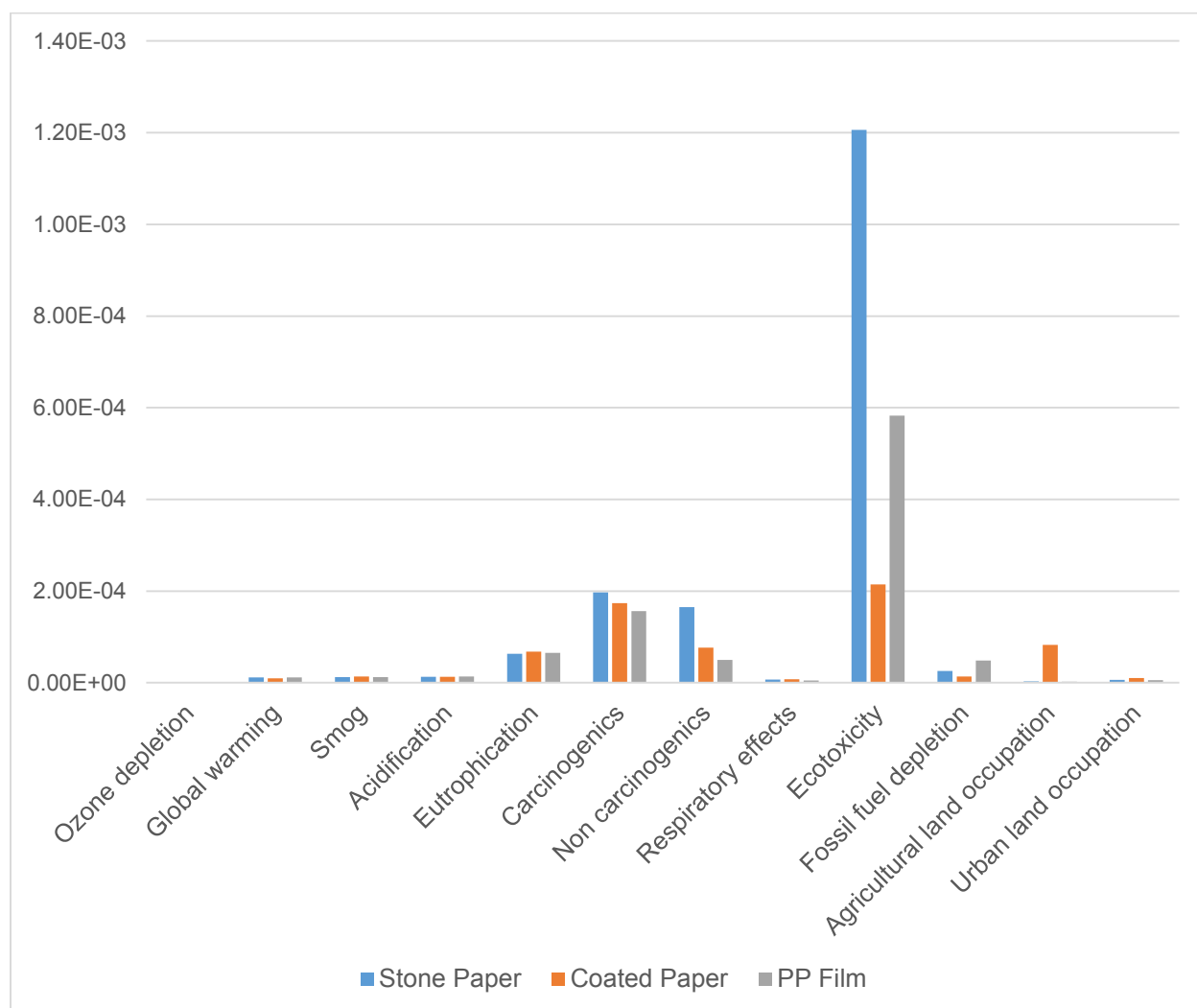
Figure 11. Polypropylene Film LCIA Results by Life Cycle Stage



#### 4.2.2 Normalized LCIA Results

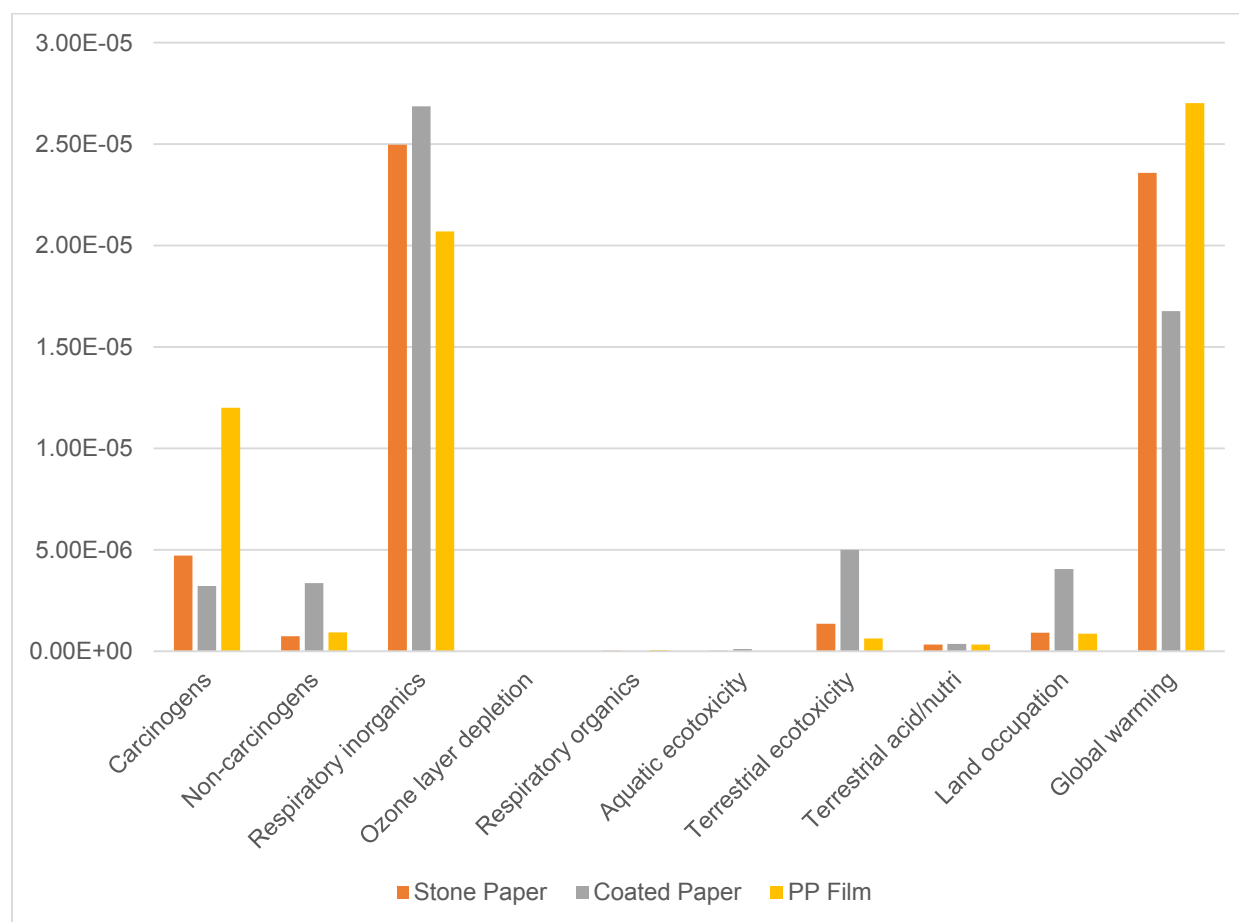
The SimaPro software was used to calculate the normalization of the LCIA characterization results. Normalization involves a calculation that translates the impact results to the proportion of average impacts caused by one person in one year. Normalization factors are important for relating LCIA results 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<sup>58</sup>. The ReCiPe impacts are normalized according to the impacts of the average person in Europe in the year 2000<sup>59</sup>.

Figure 12. Normalized TRACI and ReCiPe LCIA Results



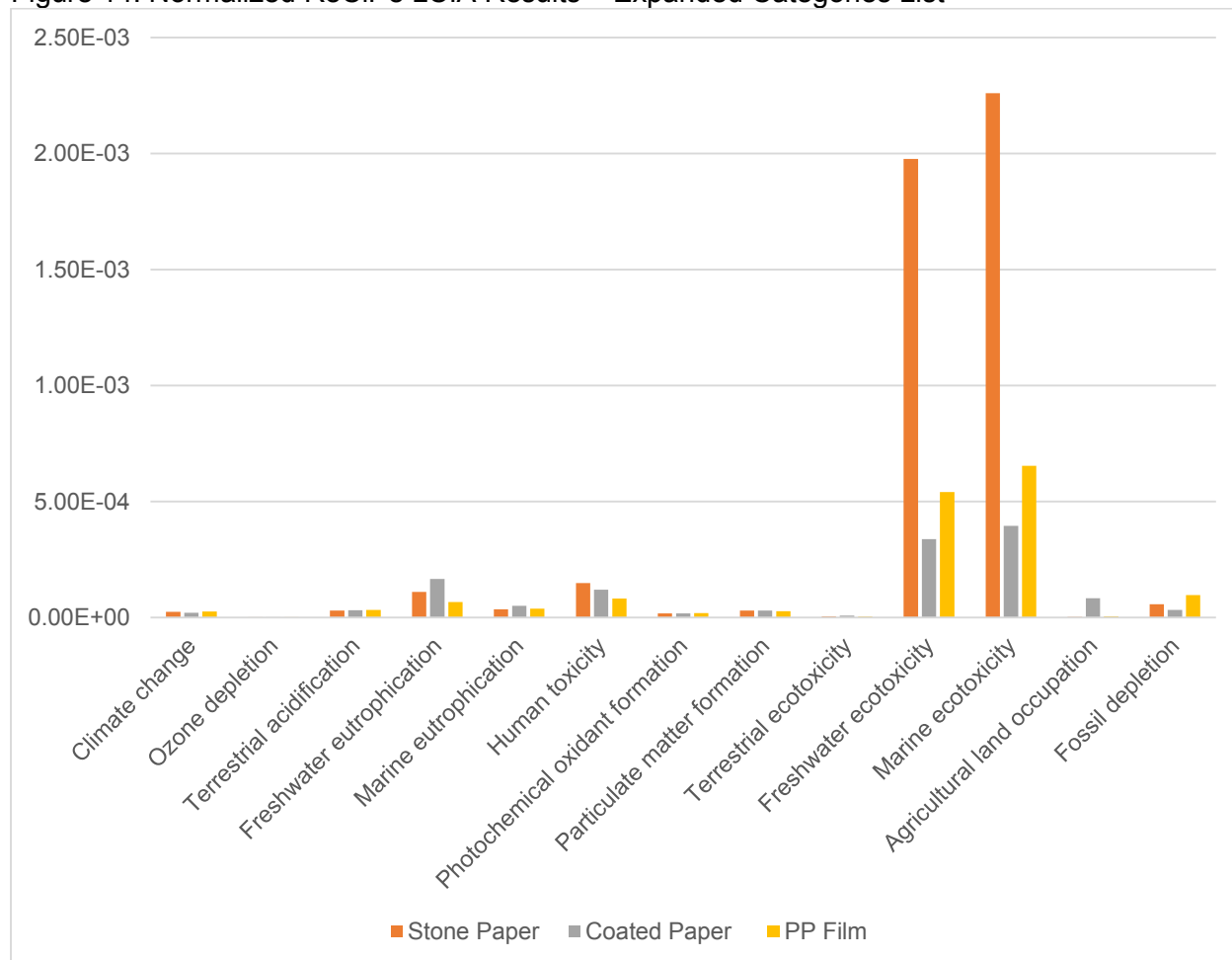
To further analyze life cycle impact assessment results, the life cycle inventory was modeled with the IMPACT 2002+ LCIA method. The IMPACT 2002+ method is a mid-point LCIA approach with novel calculations for human toxicity and aquatic & terrestrial ecotoxicity impact categories<sup>60</sup>. IMPACT 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<sup>61</sup>.

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 CO<sub>2</sub> consistent with the guidance of the United Nations Framework Convention on Climate Change with 100-year time horizons”<sup>62</sup>.

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<sup>63</sup>.

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”<sup>64</sup>.

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<sup>65</sup>.

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<sup>66</sup>.

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 PM<sub>2.5</sub> to air, sulfur dioxide to air, and PM<sub>10</sub> 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<sup>67</sup>.

#### **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

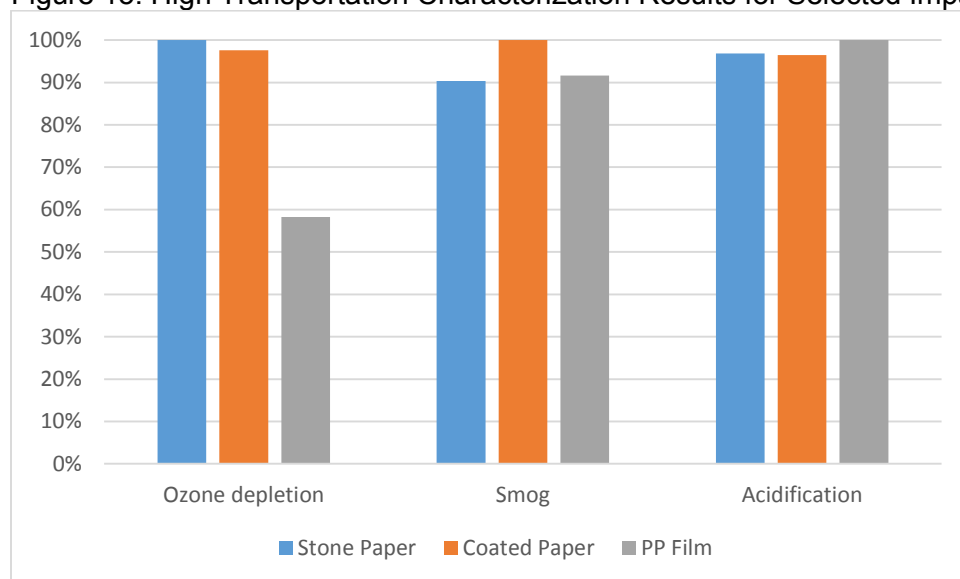
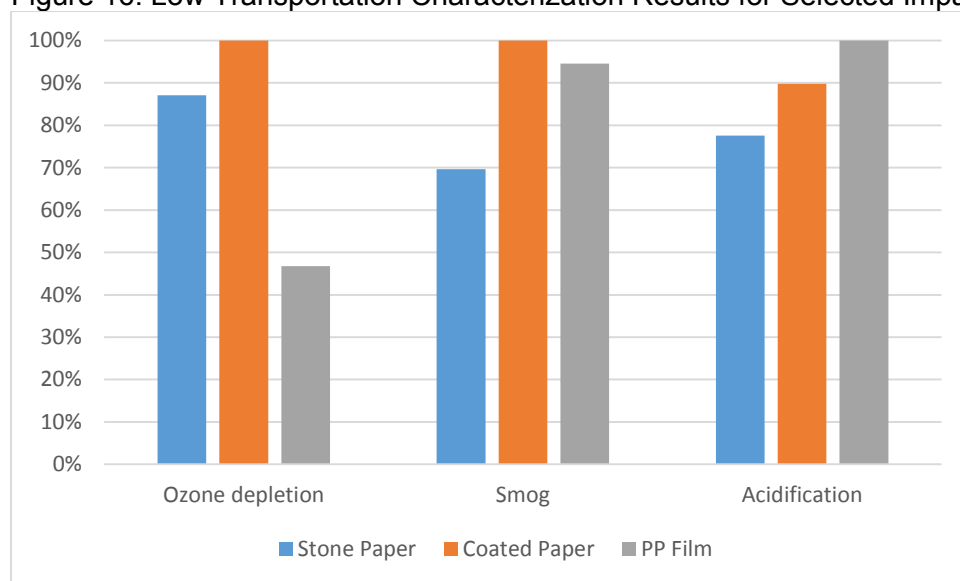


Figure 16. Low Transportation Characterization Results for Selected Impact Categories



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

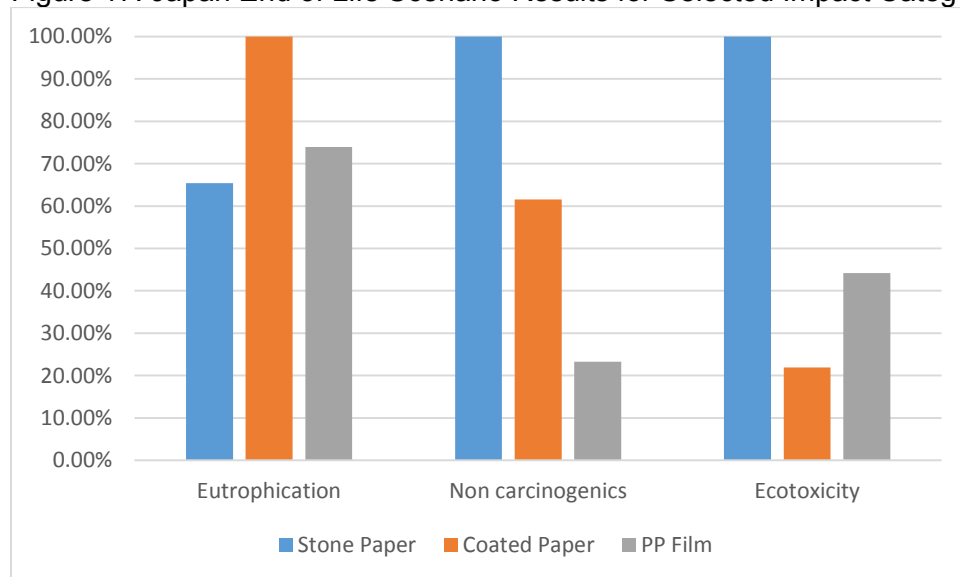
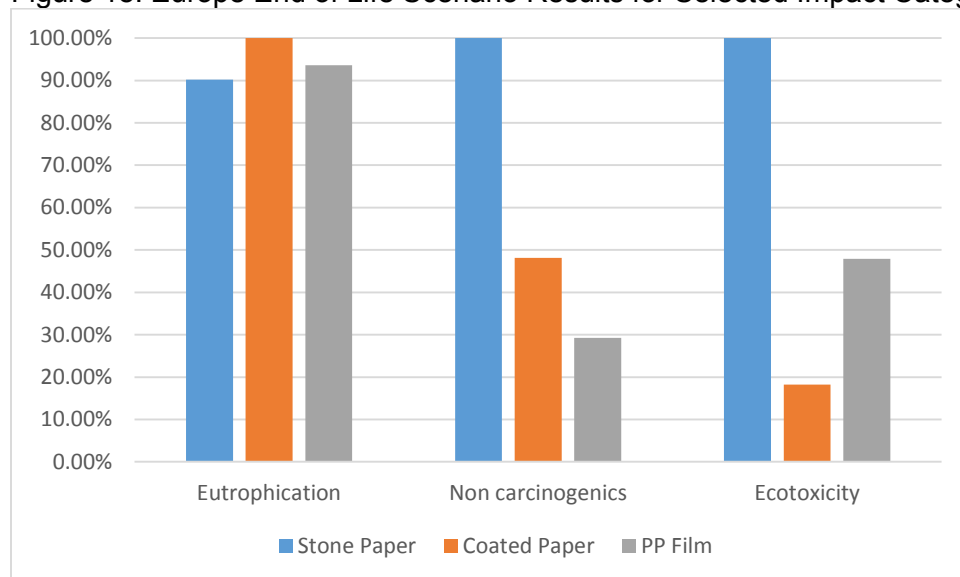


Figure 18. Europe End of Life Scenario Results for Selected Impact Categories



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

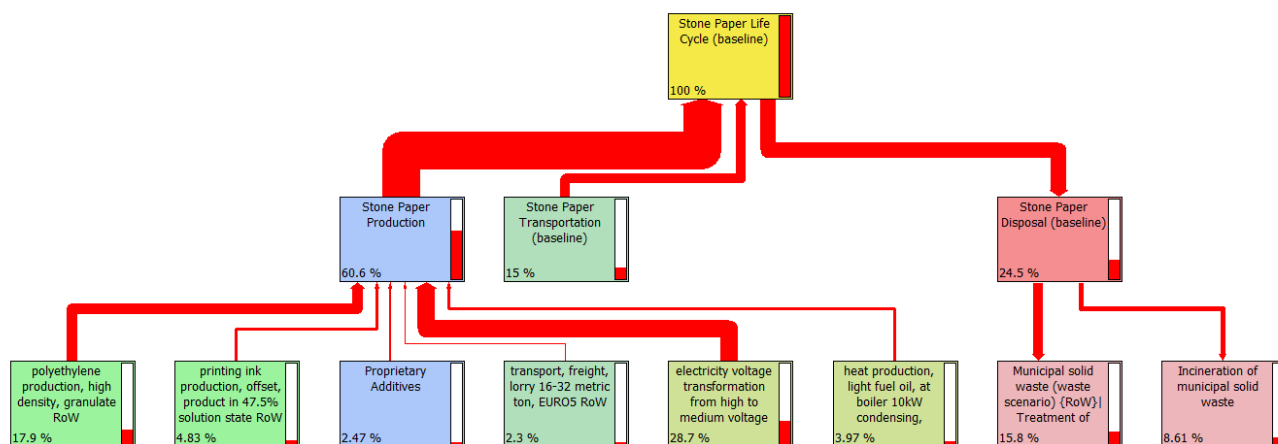
This section provides an improvement analysis focused on Stone Paper's life cycle. The improvement analysis has two focuses. The first focus is to analyze opportunities to reduce life cycle greenhouse gas emissions according to the TRACI Global Warming impact characterization. The strategies will then 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<sup>68</sup>. A U.K. industry report describes 10-20% energy use reductions to pelletizing and extrusion processes without major capital outlay<sup>69</sup>. A 10% per year reduction is considered achievable for U.S. plastic manufacturers<sup>70</sup>, and other general industry energy efficiency reports show opportunities for reductions up to 30%<sup>71,72</sup>.

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}<br>electricity voltage transformation from high to medium voltage | Ecoinvent 3            |

In addition to the 20% reduction scenario, the life cycle kgCO<sub>2</sub> 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

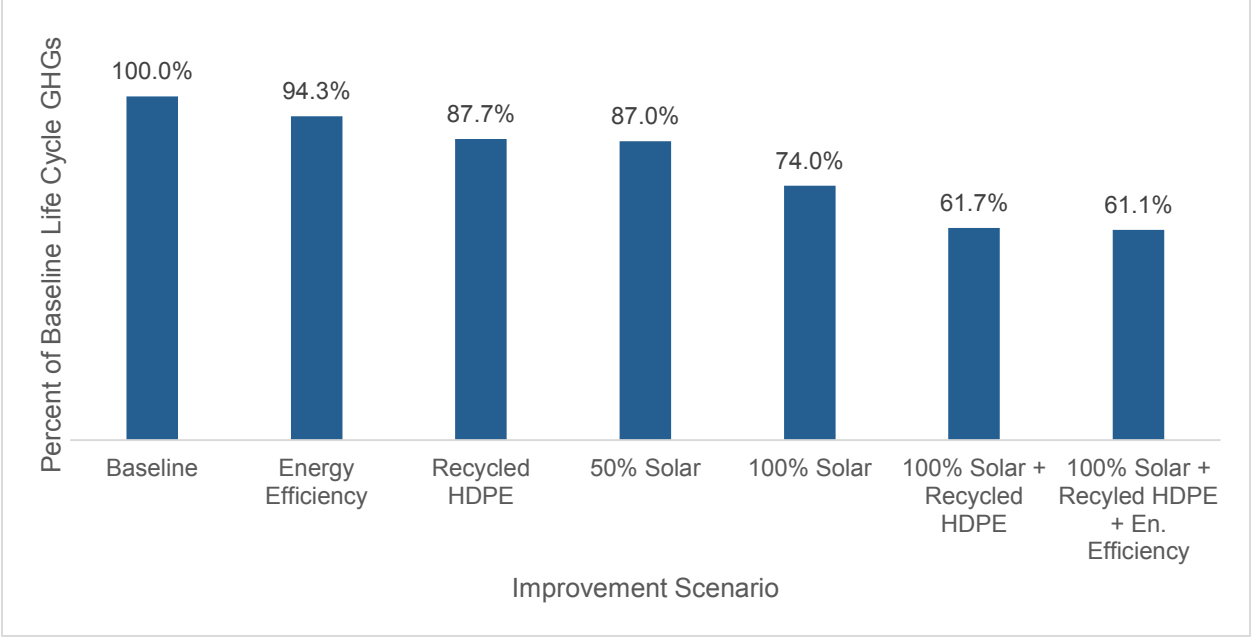


Figure 21 shows the life cycle results for the electricity and material improvement scenarios for the Smog impact category compared to the baseline scenario.

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

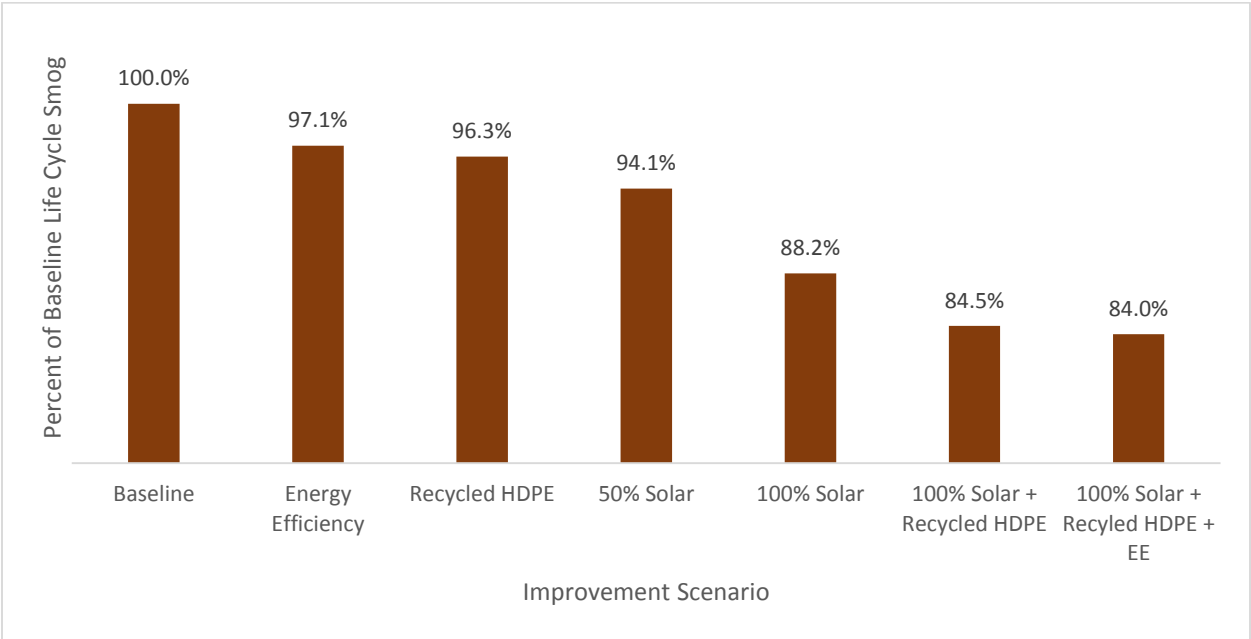
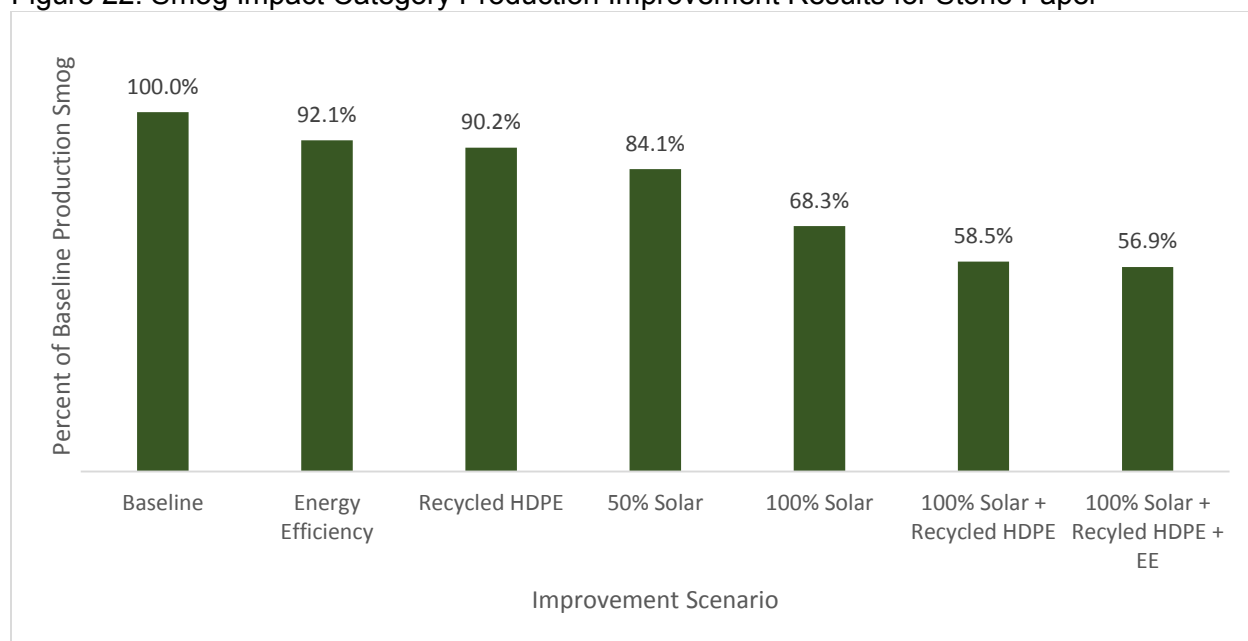


Figure 22 displays the production results for the electricity and material improvement scenarios for the Smog impact category compared to the baseline scenario.

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<br>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  |

|            |   |       |    |          |
|------------|---|-------|----|----------|
| <b>288</b> | Cyprodinil  | Soil  | kg | 8.46E-13 |
| <b>289</b> | Deltamethrin  | Soil  | kg | 7.32E-13 |
| <b>290</b> | Diatomite   | Raw   | kg | 4.36E-10 |
| <b>291</b> | Dibenz(a,h)anthracene                                     | Air   | kg | 1.00E-15 |
| <b>292</b> | Dicamba   | Air   | kg | 1.21E-11 |
| <b>293</b> | Dicamba   | Soil  | kg | 1.43E-12 |
| <b>294</b> | Dichlorprop-P   | Soil  | kg | 2.30E-13 |
| <b>295</b> | Dichromate  | Water | kg | 2.69E-10 |
| <b>296</b> | Diclofop  | Soil  | kg | 3.31E-13 |
| <b>297</b> | Diclofop-methyl   | Soil  | kg | 3.33E-13 |
| <b>298</b> | Dicrotophos   | Soil  | kg | 1.14E-11 |
| <b>299</b> | Diethyl ether   | Air   | kg | 2.99E-14 |
| <b>300</b> | Diethylamine  | Air   | kg | 2.89E-11 |
| <b>301</b> | Diethylamine  | Water | kg | 6.93E-11 |
| <b>302</b> | Diethylene glycol   | Air   | kg | 2.98E-13 |
| <b>303</b> | Difenoconazole  | Soil  | kg | 1.56E-12 |
| <b>304</b> | Diffubenzuron   | Air   | kg | 1.99E-12 |
| <b>305</b> | Diffubenzuron   | Soil  | kg | 2.83E-07 |
| <b>306</b> | Diffufenican  | Soil  | kg | 8.05E-12 |
| <b>307</b> | Diffufenzopyr-sodium                                      | Soil  | kg | 5.48E-14 |
| <b>308</b> | Dimethachlor  | Soil  | kg | 4.14E-11 |
| <b>309</b> | Dimethenamid  | Soil  | kg | 3.94E-12 |
| <b>310</b> | Dimethoate  | Soil  | kg | 5.26E-13 |
| <b>311</b> | Dimethyl malonate   | Air   | kg | 4.55E-11 |
| <b>312</b> | Dimethylamine   | Air   | kg | 8.98E-14 |
| <b>313</b> | Dimethylamine   | Water | kg | 4.54E-10 |
| <b>314</b> | Dinitrogen monoxide                                       | Air   | kg | 7.76E-06 |
| <b>315</b> | Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-                     | Air   | kg | 7.14E-14 |
| <b>316</b> | Dipropylamine   | Air   | kg | 1.32E-11 |
| <b>317</b> | Dipropylamine   | Water | kg | 3.17E-11 |
| <b>318</b> | Diquat  | Soil  | kg | 3.55E-12 |
| <b>319</b> | Diquat dibromide  | Soil  | kg | 4.66E-14 |
| <b>320</b> | Dithianone  | Soil  | kg | 5.06E-14 |
| <b>321</b> | Diuron  | Soil  | kg | 1.75E-11 |
| <b>322</b> | DOC, Dissolved Organic Carbon                             | Water | kg | 1.05E-02 |
| <b>323</b> | Dolomite  | Raw   | kg | 4.19E-05 |
| <b>324</b> | Endosulfan  | Soil  | kg | 5.87E-08 |
| <b>325</b> | Endothall   | Soil  | kg | 4.25E-13 |
| <b>326</b> | Energy, geothermal, converted                             | Raw   | MJ | 1.62E-03 |
| <b>327</b> | Energy, gross calorific value, in biomass                 | Raw   | MJ | 8.72E-02 |
| <b>328</b> | Energy, gross calorific value, in biomass, primary forest | Raw   | MJ | 9.62E-03 |
| <b>329</b> | 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 | Ethalfuralin   | 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 | Pyriothion sodium salt   | Soil  | kg | 3.25E-13 |
| 776 | Quinoxifen   | 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 |



|            |   |       |    |          |
|------------|---|-------|----|----------|
| <b>802</b> | Selenium  | Water | kg | 1.86E-07 |
| <b>803</b> | Selenium  | Soil  | kg | 5.88E-10 |
| <b>804</b> | Sethoxydim  | Air   | kg | 1.60E-11 |
| <b>805</b> | Sethoxydim  | Soil  | kg | 4.98E-12 |
| <b>806</b> | Shale   | Raw   | kg | 2.74E-07 |
| <b>807</b> | Silicon   | Air   | kg | 9.22E-07 |
| <b>808</b> | Silicon   | Water | kg | 5.94E-04 |
| <b>809</b> | Silicon   | Soil  | kg | 3.20E-07 |
| <b>810</b> | Silicon dioxide   | Water | kg | 1.04E-10 |
| <b>811</b> | Silicon tetrachloride   | Air   | kg | 1.22E-11 |
| <b>812</b> | Silicon tetrafluoride   | Air   | kg | 1.90E-11 |
| <b>813</b> | Silthiofam  | Soil  | kg | 1.27E-16 |
| <b>814</b> | Silver  | Air   | kg | 5.54E-11 |
| <b>815</b> | Silver  | Water | kg | 8.65E-08 |
| <b>816</b> | Silver  | Soil  | kg | 2.95E-12 |
| <b>817</b> | Silver-110  | Air   | Bq | 2.37E-08 |
| <b>818</b> | Silver-110  | Water | Bq | 1.35E-02 |
| <b>819</b> | Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In                  | Raw   | kg | 3.99E-09 |
| <b>820</b> | Silver, 3.2ppm in sulfide, Ag 1.2ppm, Cu and Te, in crude ore         | Raw   | kg | 1.56E-13 |
| <b>821</b> | Silver, Ag 1.5E-4%, Au 6.8E-4%, in ore                                | Raw   | kg | 2.01E-13 |
| <b>822</b> | Silver, Ag 1.5E-5%, Au 5.4E-4%, in ore                                | Raw   | kg | 1.84E-14 |
| <b>823</b> | Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore                                | Raw   | kg | 9.24E-12 |
| <b>824</b> | Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore                                | Raw   | kg | 7.68E-10 |
| <b>825</b> | Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore                                | Raw   | kg | 1.50E-11 |
| <b>826</b> | Silver, Ag 5.4E-3%, in mixed ore                                      | Raw   | kg | 3.46E-11 |
| <b>827</b> | Silver, Ag 7.6E-5%, Au 9.7E-5%, in ore                                | Raw   | kg | 2.54E-12 |
| <b>828</b> | 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 |
| <b>829</b> | Simazine  | Soil  | kg | 6.92E-13 |
| <b>830</b> | Sodium  | Air   | kg | 6.68E-07 |
| <b>831</b> | Sodium  | Water | kg | 1.38E-03 |
| <b>832</b> | Sodium  | Soil  | kg | 1.20E-06 |
| <b>833</b> | Sodium-24   | Water | Bq | 8.87E-05 |
| <b>834</b> | Sodium chlorate   | Air   | kg | 7.64E-11 |
| <b>835</b> | Sodium chlorate   | Water | kg | 1.33E-12 |
| <b>836</b> | Sodium chloride   | Raw   | kg | 2.27E-04 |
| <b>837</b> | Sodium dichromate   | Air   | kg | 1.35E-10 |
| <b>838</b> | 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 | TiO <sub>2</sub> , 54% in ilmenite, 18% in crude ore  | Raw   | kg | 2.72E-07 |
| 915 | TiO <sub>2</sub> , 54% in ilmenite, 2.6% in crude ore | Raw   | kg | 3.54E-06 |
| 916 | TiO <sub>2</sub> , 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 |

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

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

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



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

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

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

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

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

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



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

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

|             |              |       |    |          |
|-------------|--------------|-------|----|----------|
| <b>1434</b> | Zirconium    | Air   | kg | 8.30E-13 |
| <b>1435</b> | Zirconium-95 | Air   | Bq | 4.54E-07 |
| <b>1436</b> | Zirconium-95 | Water | Bq | 1.40E-03 |

## References

- <sup>1</sup> International Organization for Standardization (2006), ISO14040: Environmental Management – Life Cycle Assessment – Principles and Framework
- <sup>2</sup> International Organization for Standardization (2006), ISO14040: Environmental Management – Life Cycle Assessment – Principles and Framework
- <sup>3</sup> US Department of Commerce – Bureau of Economic Commerce (2014). Gross-Domestic-Product-(GDP)-by-Industry Data. Retrieved April 02, 2016, from [http://www.bea.gov/industry/gdpbyind\\_data.htm](http://www.bea.gov/industry/gdpbyind_data.htm)
- <sup>4</sup> US EIA. (2014). Energy Use in Industry. Retrieved April 03, 2016, from [http://www.eia.gov/Energyexplained/?page=us\\_energy\\_industry](http://www.eia.gov/Energyexplained/?page=us_energy_industry)
- <sup>5</sup> Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., . . . Townshend, J. R. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science*, 342(6160), 850-853. doi:10.1126/science.1244693
- <sup>6</sup> Confederation of European Paper Industries (2014). Key Statistics 2014 European Pulp and Paper Industry. Retrieved April 02, 2016, from <http://www.cepi.org/system/files/public/documents/publications/statistics/2015/Key%20Statistics%202014%20FINAL.pdf>
- <sup>7</sup> Barr, C. (2001). Profits on paper: the political-economy of fibre and finance in Indonesia's pulp and paper industries. Barr, C. Banking on sustainability: structural adjustment and forestry reform in post-Suharto Indonesia. Center for International Forestry Research (CIFOR) and WWF Macroeconomic Program Office, Washington, DC.
- <sup>8</sup> The World Bank (2014). Land area (sq. km). Retrieved April 03, 2016, from [http://data.worldbank.org/indicator/AG.LND.TOTL.K2?order=wbapi\\_data\\_value\\_2014+wbapi\\_data\\_value+wbapi\\_data\\_value-last&sort=asc](http://data.worldbank.org/indicator/AG.LND.TOTL.K2?order=wbapi_data_value_2014+wbapi_data_value+wbapi_data_value-last&sort=asc)
- <sup>9</sup> Thompson, G., Swain, J., Kay, M., & Forster, C. F. (2001). The treatment of pulp and paper mill effluent: a review. *Bioresource technology*, 77(3), 275-286.
- <sup>10</sup> Munkittrick, K. R., Portt, C. B., Kraak, G. V. D., Smith, I. R., & Rokosh, D. A. (1991). Impact of bleached kraft mill effluent on population characteristics, liver MFO activity, and serum steroid levels of a Lake Superior white sucker (*Catostomus commersoni*) population. *Canadian Journal of Fisheries and Aquatic Sciences*, 48(8), 1371-1380.
- <sup>11</sup> Pokhrel, D., & Viraraghavan, T. (2004). Treatment of pulp and paper mill wastewater—a review. *Science of the total environment*, 333(1), 37-58.
- <sup>12</sup> Smith, R. (2011). The Environmental Sustainability of Paper. *Graduate Studies Journal of Organizational Dynamics*, 1(1), Article 4
- <sup>13</sup> Ince, B. K., Cetecioglu, Z., & Ince, O. (2011). Pollution Prevention in the Pulp and Paper Industries. *Environmental Management in Practice*. doi:10.5772/23709

- 
- <sup>14</sup> US EPA. (2012). Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012. Retrieved from [https://www3.epa.gov/epawaste/nonhaz/municipal/pubs/2012\\_msw\\_fs.pdf](https://www3.epa.gov/epawaste/nonhaz/municipal/pubs/2012_msw_fs.pdf)
- <sup>15</sup> Grand View Research. (2016, March). Petrochemical Market Size To Grow At A CAGR Of 8.8% From 2015 to 2022. Retrieved April 03, 2016, from <http://www.grandviewresearch.com/press-release/global-petrochemical-market>
- <sup>16</sup> PlasticsEurope. (n.d.). Types of Plastics: Polypropylene. Retrieved April 03, 2016, from <http://www.plasticseurope.org/what-is-plastic/types-of-plastics-11148/polyolefins/polypropylene.aspx>
- <sup>17</sup> North, E. J., & Halden, R. U. (2013). Plastics and environmental health: The road ahead. *Reviews on Environmental Health*, 28(1), 1-8.
- <sup>18</sup> US EPA. (2012). Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012. Retrieved from [https://www3.epa.gov/epawaste/nonhaz/municipal/pubs/2012\\_msw\\_fs.pdf](https://www3.epa.gov/epawaste/nonhaz/municipal/pubs/2012_msw_fs.pdf)
- <sup>19</sup> Olie, K., Vermeulen, P. L., & Hutzinger, O. (1977). Chlorodibenzo-p-dioxins and chlorodibenzofurans are trace components of fly ash and flue gas of some municipal incinerators in the Netherlands. *Chemosphere*, 6(8), 455-459.
- <sup>20</sup> Gabrys, J. (2009). Sink: the dirt of systems. *Environment and Planning D: Society and Space*, 27(4), 666-681.
- <sup>21</sup> US EIA. (2015, July 10). How much oil is used to make plastic? Retrieved April 03, 2016, from <http://www.eia.gov/tools/faqs/faq.cfm?id=34>
- <sup>22</sup> Wake, H. (2005). Oil refineries: a review of their ecological impacts on the aquatic environment. *Estuarine, Coastal and Shelf Science*, 62(1), 131-140.
- <sup>23</sup> North, E. J., & Halden, R. U. (2013). Plastics and environmental health: the road ahead. *Reviews on environmental health*, 28(1), 1-8.
- <sup>24</sup> Taiwan Lung Meng Technology Co. Ltd. (n.d.). ECO-Friendly. Retrieved April 03, 2016, from [http://www.taiwanlm.com/page003\\_eng.php?ab\\_ID=22](http://www.taiwanlm.com/page003_eng.php?ab_ID=22)
- <sup>25</sup> Fişne, A., Kuzu, C., & Hüdaverdi, T. (2010). Prediction of environmental impacts of quarry blasting operation using fuzzy logic. *Environmental Monitoring and Assessment Environ Monit Assess*, 174(1-4), 461-470.
- <sup>26</sup> Teir, S., Eloneva, S., & Zevenhoven, R. (2005). Production of precipitated calcium carbonate from calcium silicates and carbon dioxide. *Energy Conversion and Management*, 46(18), 2954-2979.
- <sup>27</sup> Viastone, email communication. (2016, March)
- <sup>28</sup> Bestak Self-Adhesives Inc, personal communication (2015, May)
- <sup>29</sup> Taiwan Lung Meng Technology Co., Ltd., personal communication (2015, May)

- 
- <sup>30</sup> Kroy LLC. (n.d.). Manufacturing Process. Retrieved April 03, 2016, from <http://www.kroylabel.com/about-kroy/manufacturing-process/>
- <sup>31</sup> Leurs, L. (n.d.). Printing processes. Retrieved April 03, 2016, from <http://www.prepressure.com/printing/processes#offset>
- <sup>32</sup> Ince, B. K., Ince, O., & Cetecioglu, Z. (2011). *Pollution prevention in the pulp and paper industries*. INTECH Open Access Publisher.
- <sup>33</sup> Paperonline.com. (n.d.). Paper Production. Retrieved April 03, 2016, from <http://www.paperonline.org/paper-making/paper-production>
- <sup>34</sup> ACC. (2005). How Plastics Are Made. Retrieved April 03, 2016, from <https://plastics.americanchemistry.com/Education-Resources/Plastics-101/How-Plastics-Are-Made.html>
- <sup>35</sup> Macro Advanced Extrusion Systems. (n.d.). Fundamentals of Cast Film Extrusion Technology. Retrieved April 03, 2016, from <http://www.macroeng.com/fundamentals-of-cast-film-extrusion-technology.php>
- <sup>36</sup> American Profol Inc. (n.d.). About CPP Film FAQ. Retrieved April 03, 2016, from <http://www.profol.com/en/about-cpp-film-faq.html>
- <sup>37</sup> Reich Paper. (n.d.). Technical Printing and Use. Retrieved April 03, 2016, from <https://www.reichpaper.com/label/printing-and-use-information.html>
- <sup>38</sup> Yupo Synthetic Papers. (n.d.). Yupo Stock List. Retrieved April 03, 2016, from <http://yupousa.com/what-is-yupo/yupo-stock-list/>
- <sup>39</sup> Ink World. (2008, January 04). New Developments of Printing Ink in China. Retrieved April 03, 2016, from [http://www.inkworldmagazine.com/issues/2008-01/view\\_features/new-developments-of-printing-ink-in-china](http://www.inkworldmagazine.com/issues/2008-01/view_features/new-developments-of-printing-ink-in-china)
- <sup>40</sup> Haur Tyi Paper Bag Co. Ltd., personal communication (2015, May)
- <sup>41</sup> Recycling-guide.org.uk. (n.d.). Recycling Etiquette. Retrieved April 03, 2016, from <http://www.recycling-guide.org.uk/etiquette.html>
- <sup>42</sup> Ann Arbor Recycling, personal communication (2016, February 28)
- <sup>43</sup> McNatt, M. (2010, March 22). What not to Put in the Bin. Retrieved April 03, 2016, from <http://www.earth911.com/home-garden/what-not-to-put-in-the-bin/>
- <sup>44</sup> Waste Management Department, Setagaya City Hall. (2014, April). How to Properly Sort and Dispose of Garbage and Recyclable Resources. Retrieved from [http://www.city.setagaya.lg.jp/foreign/1703/d00127704\\_d/fil/en\\_gomibunbetu.pdf](http://www.city.setagaya.lg.jp/foreign/1703/d00127704_d/fil/en_gomibunbetu.pdf)
- <sup>45</sup> Eurostat. (2014). Municipal waste generation and treatment, by type of treatment method. Retrieved 03 April. 2016 from <http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tsdpc240>

- 
- <sup>46</sup> Weigel, M. (2011, November 17). Energy and economic value of plastics and municipal solid wastes. Retrieved April 03, 2016, from <http://journalistsresource.org/studies/environment/energy/energy-non-recycled-plastics-landfill>
- <sup>47</sup> Menoufil, K. A. I. (2011). Life Cycle Analysis, and Life Cycle Impact. 2011. "An Overview on Life Cycle Impact Assessment ( LCIA ) Methodologies : State of the Art. Retrieved April 03, 2016, <http://repositori.udl.cat/bitstream/handle/10459.1/45831/AlI.pdf?sequence=2>
- 48 US EPA. (2015, December 17). Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI). Retrieved April 03, 2016, from <https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci>
- 49 ReCiPe. (n.d.). Retrieved April 03, 2016, from <http://www.lcia-ReCiPe.net/>
- 50 SeaRates. (2016). [Kaohsiung to Long Beach] Retrieved from <https://www.searates.com/reference/portdistance/?K=ChIJWdeZQOjKwoARqo8qxPo6AKE&A=ChIJG3R6eIFDbjQRNypzVEqjJkg&D=12776&G=15873&>
- 51 U.S. Department of Transportation. (2016). [Railroad map]. Retrieved from <http://fragis.fra.dot.gov/GISFRASafety/>
- 52 U.S. Department of Transportation, U.S. Department of Commerce. (2015). 2012 Commodity Flow Survey. Retrieved April 03, 2016, from <https://www.census.gov/econ/cfs/2012/ec12tcf-us.pdf>
- 53 SeaRates. (2016). [Kaohsiung to Barcelona] Retrieved from <https://www.searates.com/reference/portdistance/?K=ChIJ5TCOcRaYpBIRCmZHTz37sEQ&A=ChIJG3R6eIFDbjQRNypzVEqjJkg&D=12776&G=3190&>
- 54 Google Maps. (2016). [Port of Barcelona to Frankfurt] Retrieved from <https://www.google.com/maps/dir/Port+of+Barcelona/Frankfurt,+Germany/@45.3799842,-3.5991823,5z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1s0x12a4a2249e23480d:0xe9f67d7ba7b87450!2m2!1d2.1612087!2d41.3324387!1m5!1m1!1s0x47bd096f477096c5:0x422435029b0c600!2m2!1d8.6821267!2d50.1109221!3e0>
- 55 Eurostat. (2015, December). Road freight transport by journey characteristics. Retrieved April 03, 2016, from [http://ec.europa.eu/eurostat/statistics-explained/index.php/Road\\_freight\\_transport\\_by\\_journey\\_characteristics#Data\\_sources\\_and\\_availability](http://ec.europa.eu/eurostat/statistics-explained/index.php/Road_freight_transport_by_journey_characteristics#Data_sources_and_availability)
- 56 SeaRates. (2016). [Kaohsiung to Shimizu] Retrieved from <https://www.searates.com/reference/portdistance/?A=ChIJG3R6eIFDbjQRNypzVEqjJkg&K=ChIJK4pnEh8zGmAR3Dv1XW9BMOY&D=12776&G=10212&>
- 57 Google Maps. (2016). [Shimizu Port to Tokyo] Retrieved from <https://www.google.com/maps/dir/Tokyo,+Japan/Shimizu+Port,+Japan/@35.3487536,138.5225796,9z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1s0x605d1b87f02e57e7:0x2e0161>

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8b22571b89!2m2!1d139.6917064!2d35.6894875!1m5!1m1!1s0x601a315dbe28629f:0xf  
d0b6cb6ff0a1162!2m2!1d138.4974611!2d35.0154741!3e0

- <sup>58</sup> Ryberg, M., Vieira, M. D., Zgola, M., Bare, J., & Rosenbaum, R. K. (2014). Updated US and Canadian normalization factors for TRACI 2.1. *Clean Technologies and Environmental Policy*, 16(2), 329-339.
- <sup>59</sup> Sleeswijk, A. W., van Oers, L. F., Guinée, J. B., Struijs, J., & Huijbregts, M. A. (2008). Normalisation in product life cycle assessment: An LCA of the global and European economic systems in the year 2000. *Science of the total environment*, 390(1), 227-240.
- <sup>60</sup> EarthShift. (n.d.). Impact 2002 Impact Assessment Method. Retrieved April 03, 2016, from <http://www.earthshift.com/software/simapro/impact2002>
- <sup>61</sup> Bare, J. (2012). Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) TRACI version 2.1 User's Guide. Retrieved April 03, 2016, from [https://www.pre-sustainability.com/download/TRACI\\_2\\_1\\_User\\_Manual.pdf](https://www.pre-sustainability.com/download/TRACI_2_1_User_Manual.pdf)
- <sup>62</sup> Bare, J. (2012). Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) TRACI version 2.1 User's Guide. Retrieved April 03, 2016, from [https://www.pre-sustainability.com/download/TRACI\\_2\\_1\\_User\\_Manual.pdf](https://www.pre-sustainability.com/download/TRACI_2_1_User_Manual.pdf)
- <sup>63</sup> Bare, J. (2012). Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) TRACI version 2.1 User's Guide. Retrieved April 03, 2016, from [https://www.pre-sustainability.com/download/TRACI\\_2\\_1\\_User\\_Manual.pdf](https://www.pre-sustainability.com/download/TRACI_2_1_User_Manual.pdf)
- <sup>64</sup> Bare, J. (2012). Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) TRACI version 2.1 User's Guide. Retrieved April 03, 2016, from [https://www.pre-sustainability.com/download/TRACI\\_2\\_1\\_User\\_Manual.pdf](https://www.pre-sustainability.com/download/TRACI_2_1_User_Manual.pdf)
- <sup>65</sup> Bare, J. (2012). Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) TRACI version 2.1 User's Guide. Retrieved April 03, 2016, from [https://www.pre-sustainability.com/download/TRACI\\_2\\_1\\_User\\_Manual.pdf](https://www.pre-sustainability.com/download/TRACI_2_1_User_Manual.pdf)
- <sup>66</sup> Bare, J. (2012). Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) TRACI version 2.1 User's Guide. Retrieved April 03, 2016, from [https://www.pre-sustainability.com/download/TRACI\\_2\\_1\\_User\\_Manual.pdf](https://www.pre-sustainability.com/download/TRACI_2_1_User_Manual.pdf)
- <sup>67</sup> Ryberg, M., Vieira, M. D., Zgola, M., Bare, J., & Rosenbaum, R. K. (2014). Updated US and Canadian normalization factors for TRACI 2.1. *Clean Technologies and Environmental Policy*, 16(2), 329-339.
- <sup>68</sup> Neelis, M. (2008). Energy Efficiency Improvement and Cost Saving Opportunities for the Petrochemical Industry-An ENERGY STAR (R) Guide for Energy and Plant Managers. *Lawrence Berkeley National Laboratory*. Retrieved from [https://www.energystar.gov/ia/business/industry/Petrochemical\\_Industry.pdf](https://www.energystar.gov/ia/business/industry/Petrochemical_Industry.pdf)
- <sup>69</sup> Tangram Technology Ltd. (n.d.). Energy efficiency in plastics processing, Practical worksheets for industry. Retrieved April 03, 2016, from [http://www.tangram.co.uk/TI-Energy%20Worksheets%20\(Plastics\)%20-%20Tangram.PDF](http://www.tangram.co.uk/TI-Energy%20Worksheets%20(Plastics)%20-%20Tangram.PDF)



- 
- <sup>70</sup> The Society of the Plastics Industry, Inc. and the U.S. Department of Energy. (2005). Improving Energy Efficiency at U.S. Plastics Manufacturing Plants Summary Report and Case Studies. Retrieved from <http://www.nrel.gov/docs/fy05osti/37791.pdf>
- <sup>71</sup> Rocky Mountain Institute. (n.d.). U.S. industry energy-saving potential, 2010–2050. Retrieved February 2016 from [http://www.rmi.org/RFGGraph-US\\_industry\\_energy\\_saving\\_potential](http://www.rmi.org/RFGGraph-US_industry_energy_saving_potential)
- <sup>72</sup> Bouton, S., Creyts, J., Kiely, T., Livingston, J., & Naclér, T. (2010). Energy efficiency: A compelling global resource. *McKinsey Sustainability & Resource Productivity*. Retrieved from [https://www.mckinsey.com/~media/mckinsey/dotcom/client\\_service/Sustainability/PDFs/A\\_Compelling\\_Global\\_Resource.ashx](https://www.mckinsey.com/~media/mckinsey/dotcom/client_service/Sustainability/PDFs/A_Compelling_Global_Resource.ashx)