Experts in Product Stewardship

Life Cycle Assessment of Down Fill Material

Understanding the environmental impacts of down fill material and how down fill material compares to polyester fill material.

Final Report

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Executive Summary

The International Down and Feather Bureau (IDFB), the global trade association of the down and feather industry, has commissioned Long Trail Sustainability to conduct an attributional, comparative life cycle assessment (LCA) on down fill material. The goal of the study is to understand the cradle-to-gate[1] environmental impacts and opportunities to reduce them, as well as compare the down fill material to polyester fill material. The intended applications include informing IDFB's marketing activities, external communication and informing product sustainability strategies. The functional unit, which enables comparison of two different systems, for this study is: *Fill material with a CLO*[2] *value of 4.06 (108 grams per square meter (GSM) of 700 Fill Power down; 230 GSM of polyester) over a lifetime of 5 years* (IDFL Laboratory and Institute, 2018).

Under the direction of LTS, select IDFB members gathered primary data on energy, water and material inputs and waste outputs of manufacturing down fill material. Secondary data were used for processes outside of their operations and where primary data was not available (e.g. raw material extraction, processing of material inputs, transportation, disposal). The down fill material utilizes a weighted average, based on geography and further based on reported 2017 annual production by factory.

Secondary data and literature values were used for the polyester fill material. Polyester fill material is based on general knowledge that polyester fill material is made of PET and a spinning process, which consumes electricity and steam (Sustainable Apparel Coalition, 2019), (van der Velden, 2014).

Based on the results and study assumptions, methods and data, the majority of the cradle-to-gate environmental impacts of the down fill material come from energy use and duck/goose (Figure 1). Detergents also have a significant impact in the ecosystem and water use categories.

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[1] Includes raw material extraction through the production of the fill material.

[2] CLO value is Thermal Insulation Index used in the apparel industry.

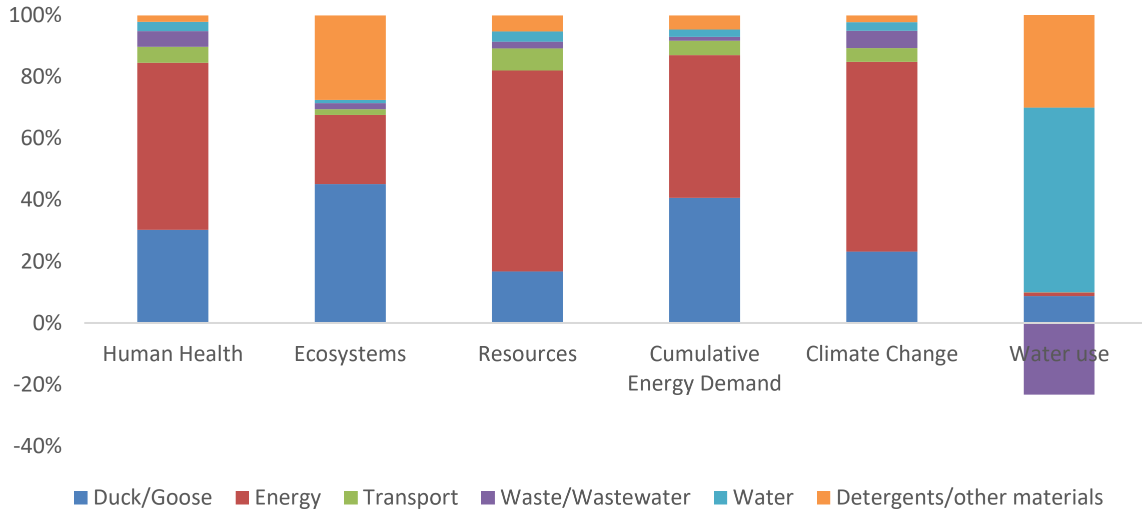

Figure 1: Contribution analysis of down fill material, per functional unit, using the LTS Method

Compared to the polyester fill material, the down fill material has fewer environmental impacts in all impact categories (**Figure 2**). Uncertainty analysis was performed to determine how data quality affects the reliability and robustness of the results. The comparative results are considered to have high certainty and to be statistically significant[3] in all impact categories, except water use, which therefore was removed from the comparative analysis as statistically significant conclusions cannot be made in that category.

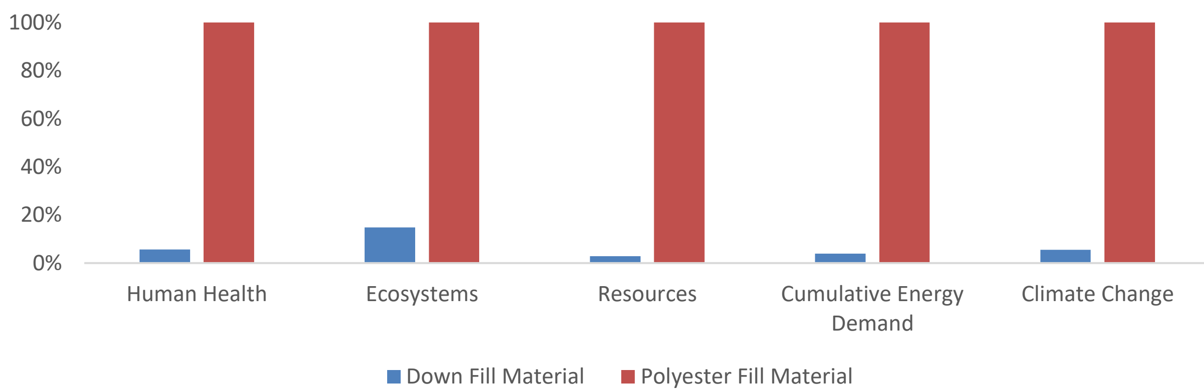

Figure 2: Comparative analysis of down vs. polyester fill material, per functional unit, using the LTS Method

Recommendations from this study include investigating ways to reduce energy usage and reduce waste during down fill manufacturing, along with the installation and/or use of renewable energy. In addition, researching and utilizing environmentally friendly detergent options will help reduce the ecosystem and water use impact categories.

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[3] When one fill material was shown to have greater impacts in 95% or more of the uncertainty analysis simulations, the comparative results are considered to be certain and statistically significant.

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1 Definitions / Terminology

For purposes of clarity, a brief definition of terminology used throughout the report is provided below.

Characterization: Assessment of environmental impacts associated with raw material inputs and emissions using science-based conversion factors (e.g., modeling the potential impact of carbon dioxide and methane on global warming (U.S. EPA, 2006).

Critical review: A process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment (ISO 14040, 2006a).

Impact category: A class representing environmental issues of concern to which life cycle inventory analysis results may be assigned (ISO 14040, 2006a).

Life Cycle Assessment (LCA): Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040, 2006a).

LCA has also been defined as a technique to assess the environmental aspects and potential impacts associated with a product, process or service, by:

- Compiling an inventory of relevant energy and raw material inputs and environmental releases.
- Evaluating the potential environmental impacts associated with identified inputs and releases.
- Interpreting the results to help you make a more informed decision.

Life Cycle Inventory (LCI): A phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle (ISO 14040, 2006a).

Life Cycle Inventory Analysis (LCIA): A phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product (ISO 14040, 2006a).

Primary data: Data collected specifically for the study at hand. These data are based on measurements and/ or estimates for a given product or a process (e.g. measured electricity data for a process being studied).

Reference flow: A measure of the outputs from processes in a given product system required to fulfill the function expressed by the functional unit (ISO 14040, 2006a).

Secondary data: Industry average data that are not specific to a given process or a product. Secondary data are typically obtained from commercial data libraries.

Sensitivity analysis: A systematic procedure for estimating the effects of the choices made regarding methods and data on the outcome of a study (ISO 14040, 2006a).

System boundary: A set of criteria specifying which unit processes are part of the product system (ISO 14040, 2006a).

Uncertainty analysis: A systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty and data variability (ISO 14040, 2006a).

2 Introduction

2.1 Introduction to the Study

Down and feathers are part of the global poultry industry, with ducks and geese producing meat, eggs, as well as down and feathers. Between 2009 and 2013, 2.7 billion ducks and 653 million geese were raised for meat, annually. As a byproduct of this meat production, an estimated 186 million kilograms of down and feathers are produced and traded each year. Roughly three quarters of ducks raised for the poultry industry were raised in China; as a result, China is also the world's largest supplier of down and feathers for both apparel and bedding (Schmitz, The Sustainable and Human Practices of the Down and Feather Industry: A Global Assessment of Industry Statistics and Practices, 2016).

The International Down and Feather Bureau (IDFB), the global trade association of the down and feather industry, has commissioned Long Trail Sustainability to conduct a full comparative life cycle assessment (LCA) on down fill material, to understand the environmental impacts and opportunities to reduce them, as well as compare the down material to polyester fill material. The results of the LCA are intended to be communicated externally. This study will also be expanded to include feather products at a future date.

This study is based on the attributional LCA approach, which describes the physical reality of an existing supply chain by quantifying the energy and material flows to and from an existing life cycle. The attributional LCA approach is appropriate because the primary focus of the study is to inform IDFB on the environmental impacts of their process and compare it to polyester fill material.

The study follows guidelines outlined by the International Organization for Standardization (ISO 14040, 2006a) (ISO 14044, 2006b) for comparative assertions intended for public disclosure.

2.2 Introduction to LCA

Life cycle assessment (LCA) is an analytical tool used to quantify and interpret the impacts as a result of flows to and from the environment (including emissions to air, water and land, as well as the consumption of energy and other material resources), over the entire life cycle of a product or service. By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the environmental trade-offs in comparing alternatives.

ISO 14040 and ISO 14044 set out a four-phase methodology framework for completing an LCA as shown in Figure 3: (1) goal and scope definition, (2) life cycle inventory, (3) life cycle impact assessment, and (4) interpretation.

Goal and scope definition: The first step of an LCA is to define the specifics of the study. To do this, one must choose and explain the goal and scope of the study, the functional unit, the system boundaries, the assumptions and limitations, the allocation methods to be used, as well as the impact categories. The goal and scope define the context of the study, which also explains to whom and how the results are to be communicated. The functional unit is the reference function, a chosen standard, to which all flows in the

LCA are related. Allocation is the method used to assign portions of the environmental load of a process when several output products or functions share the same process.

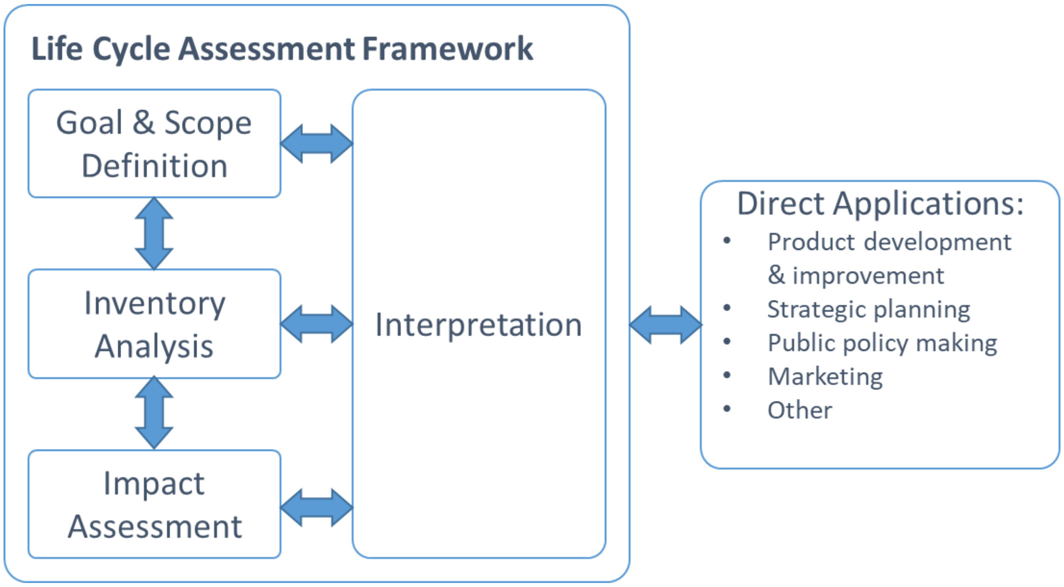

Figure 3: LCA framework (ISO 14040)

Inventory analysis: After the study is defined, the raw resources, energy requirements, emissions to air and water, and waste generation that correspond to the product/process of the study are collected for an inventory analysis. In the inventory analysis, a flow model of the technical system is built using the data on inputs and outputs mentioned above. The flow model, often illustrated with a flow chart or process flow diagram, includes the activities that are going to be assessed and gives a clear picture of the technical system boundary. The inventory analysis must be directly related to the functional unit and cumulates the raw materials and emissions throughout the life cycle of the system.

Impact assessment: Following an inventory analysis, an impact assessment is conducted in which the life cycle inventory (LCI) data are interpreted in terms of their environmental impact (for example acidification, eutrophication and global warming). The assessment begins with the classification stage; cumulated inventories are sorted and assigned to specific impact categories. The next step is characterization. In this stage, the cumulated inventories are multiplied by characterization factors specific to the inventory. Lastly all characterized data included in each impact category are added to obtain the result for the impact category.

The completion of this characterization stage usually concludes the analysis in many LCAs; it is also the last compulsory stage according to ISO 14044 (2006b). However, some studies involve the further step of normalization, in which the results of the impact categories are compared with the total impact in the world. In many LCAs, weighting also takes place, where the different environmental impacts are weighted against each other to get a total environmental impact single score. This study does not use normalization or weighting.

Interpretation: Finally, the results from the inventory analysis and impact assessment are summarized and interpreted. The outcome of these interpretations is made in the form of conclusions and recommendations of the study. According to ISO 14044 (2006b), the interpretation should include:

- key findings based on the results of the life cycle inventory and life cycle impact assessment (LCIA) phases of LCA;
- evaluation of the study to consider completeness, sensitivity and consistency; and
- conclusions, limitations, and recommendations.

Although an LCA is described above in stages, the working procedure of an LCA is iterative. This means that information gathered in a later stage can affect a former stage. When this occurs, all stages have to be reworked taking into account the new information. Therefore, it is common for an LCA practitioner to work on several stages at the same time.

3 Goal and Scope Definition

The first phase of an LCA defines the goal and scope of the study. According to ISO 14044, the goal of the study should clearly specify the intended application, reasons for carrying out the study, the intended audience, and whether the results are intended to be disclosed to the public.

The scope of the study describes the most important aspects of the study, including the functional unit, system boundaries, cut-off criterion, allocation, impact assessment method, assumptions and limitations.

3.1 Objectives

The goal of this study is to understand the cradle-to-gate[4] environmental impacts of the down fill material, and to compare to a polyester fill material.

The intended applications include informing IDFB's marketing activities, external communication and informing product sustainability strategies.

IDFB wishes to communicate the results of the full comparative LCA publicly, therefore, the LCA model and report follow ISO 14040 (ISO, 2006a) and 14044 (ISO, 2006b) requirements for comparative LCA studies intended to be disclosed publicly. The study was critically reviewed by a panel of experts. The critical review statement is provided in Appendix E: Critical Review Statement.

2.1 Function

The function of the down fill material is to provide insulation in apparel (e.g. jackets), home products (e.g. duvets) and outdoor gear (e.g. sleeping bag).

[4] Includes raw material extraction through the production of the fill material.

3.2 Functional Unit

A functional unit identifies the primary function(s) of a system based on which alternative systems are considered functionally equivalent (ISO 14040, 2006). This facilitates the determination of reference flows for each system, which in turn facilitates the comparison of two or more systems.

A functional unit is a measure of the function of the studies system (fill material) and which the inputs and outputs can be related. It enables comparison of two different system (down vs. polyester fill material) and should include performance characteristics and duration. Based on the identified function, the following functional unit will be used to determine the reference flows:
Fill material with a CLO[5] value of 4.06 (108 grams per square meter (GSM) of 700 Fill Power down; 230 GSM of polyester) over a lifetime of 5 years (IDFL Laboratory and Institute, 2018).

3.3 System Boundaries

System boundaries are established in LCA in order to include the significant life cycle stages and unit processes, as well as the associated environmental flows in the analysis. This lays the groundwork for a meaningful assessment where all important life cycle stages, and the flows associated with each alternative, are considered. Figure 4 details the system boundaries for the down fill material. More details are provided in Section 4: Life Cycle Inventory.

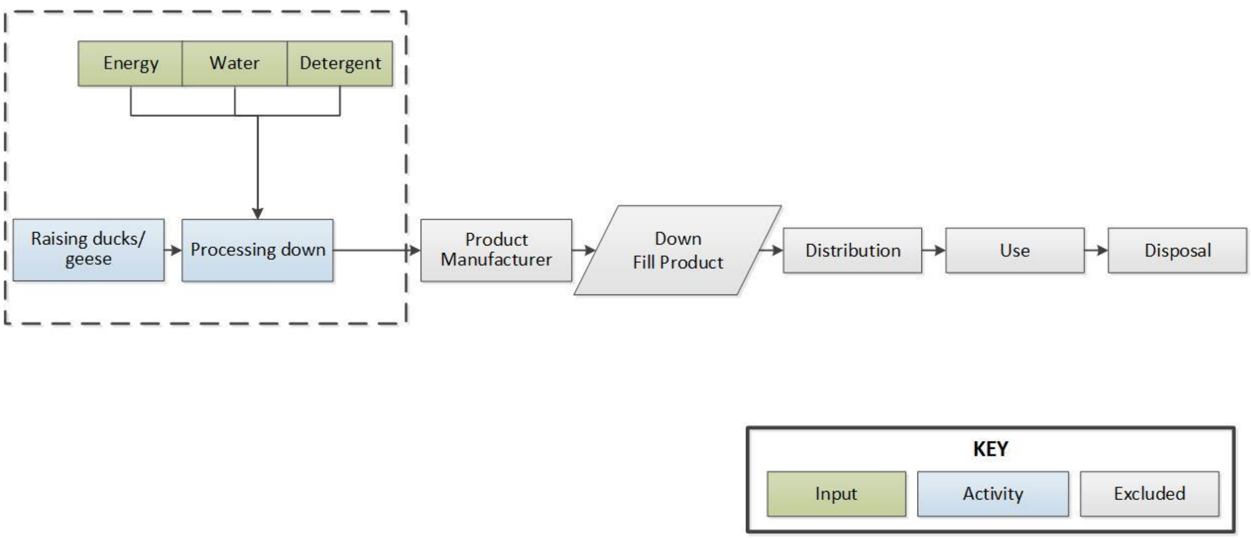

Figure 4: System Boundary diagram for Down Fill Material

The polyester fill material is made from polyethylene terephthalate and a spinning process. Figure 5 below shows the system boundaries for the polyester fill material.

[5] CLO value is Thermal Insulation Index used in the apparel industry.

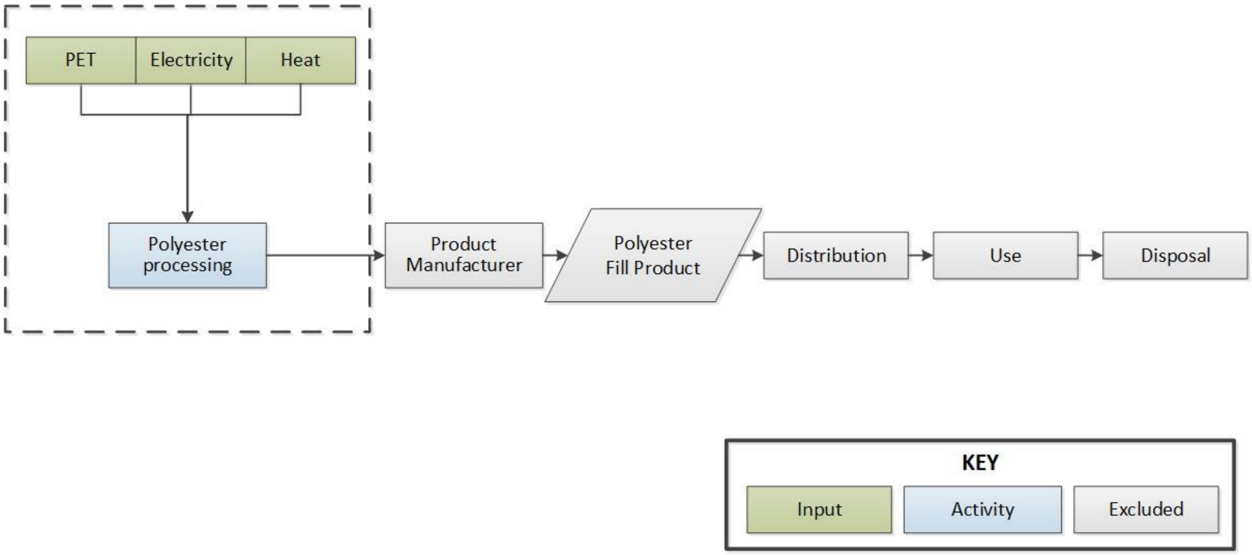

Figure 5: System Boundary diagram for Polyester Fill Material

Table 1 details the IDFB members participating in the LCA.

Table 1: IDFB Members Participating in the LCA

Company Name	Country
Hop Lion	China
Molina	Italy
Eurasia	USA
SN Interplume	France
Samsung	China
Rhodex	Germany
Kwong Lung	China
Kawada	Japan

3.4 Excluded Processes

Typically in an LCA, some aspects within the set boundaries are excluded due to statistical insignificance or irrelevancy to the goal and scope. The following impacts were also excluded from the scope and boundaries for this study:

- Human activities (e.g., employee travel to and from work);
- R&D (i.e., the laboratory and inputs related to the development of the technologies); and
- Services (e.g., the use of purchased marketing, consultancy services and business travel).

3.5 Cut-Off Criteria

Cut-off criteria are often used in LCA practice for the selection of processes or flows to be included in the system boundary. The processes or flows below these cut-offs or thresholds are excluded from the study. Several criteria are used in LCA practice to decide which inputs are to be considered, including mass, energy and environmental relevance. In the current study, every effort will be made to include all the flows associated with the processes studied. During the interpretation phase, we will use a 1% of environmental relevance criterion to test the sensitivity of the results to assumptions and data substitutions made.

3.6 Assumptions

Based on data availability several assumptions were made and tested; none exceeded the 1% cut-off criterion described above. Study assumptions included the following:

- Raw material transportation distances of 500 km by truck and 5,000 by ocean are used when actual distances are unknown;
- Waste transportation of 15 km by truck is used when actual distances are unknown;
- Duck is used for both for duck and goose for down due to lack of goose data; and
- 10% of animal is allocated to down fill material (Responsible Down Standard, 2018).

3.7 Allocation & Recycling

While conducting an LCA, if the life cycles of more than one product are connected, allocation of the process inputs should be avoided by using the system boundary expansion approach. If allocation cannot be avoided, an allocation method – based on physical causality (mass or energy content, for example) or any other relationship, such as economic value – should be used (ISO 14044 2006).

This study uses the cut-off approach method for recycling. According to this approach, the first life of a material bears the environmental burdens of its production (e.g., raw material extraction and processing) and the second life bears the burdens of refurbishment (e.g., collection and refining of scrap). The burdens from waste treatment are taken by the life after which they occur (Frischknecht 2010). This method is applied in the secondary data utilized in the study (ecoinvent, cut-off and DATASMART).

According to the Responsible Down Standard less than 10% of the value of the bird is from down and feathers (Responsible Down Standard, 2018). This value was confirmed with industry experts, with some industrial providers indicating that the economic value of the down fill material is as low as 2%. The default scenario uses 10% to be conservative, which is tested in section 6.3: Sensitivity Analysis.

3.8 Impact Assessment Method

Impact assessment methods are used to convert LCI data (environmental emissions and raw material extractions) into a set of environmental impacts. ISO 14044 does not dictate which impact assessment method to use for a comparative assertion; however, the chosen method needs to be an internationally-accepted method if the results are intended to be used to support a comparative assertion disclosed to the public.

The primary impact assessment method used for this study is the ReCiPe Endpoint (H) v1.13 method (Goedkoop *et al*. 2009). ReCiPe is one of the most robust and updated methods available to LCA practitioners. Using the endpoint method, we are able to assess the environmental impacts to the three endpoint impact categories: Human Health, Ecosystems and Resources.

In addition to the ReCiPe Endpoint method, three midpoint impact categories are used: Cumulative Energy Demand (Frischknecht *et al*. 2007), Climate Change (IPCC 2013) and Water Use (Huijbregts MAJ, 2017) . These six categories are found to be of interest and readily understandable to readers of LCA reports. For purposes of simplicity, the combination of the ReCiPe Endpoint method and the selected midpoint categories is called the LTS Method, summarized in Table 2. More information is in Appendix A: LTS Method: Description of Impact Assessment Method. Midpoint results are provided in Appendix C: Midpoint Results.

Table 2: LTS Impact Assessment Method

Impact Category	Unit	Description
Human Health	Disability Adjusted Life Years (DALY)	Includes human health impacts from Climate Change, Human Toxicity, Photochemical Oxidant Formation, Particulate Matter Formation, Ionizing Radiation, and Ozone Depletion
Ecosystems	Species * yr	Includes ecosystem impacts from Climate Change, Terrestrial Acidification, Freshwater Eutrophication, Ecotoxicity, Agricultural Land Occupation, Urban Land Occupation and Natural Land Transformation
Resources	$/kg	Includes resource impacts from Fossil Depletion and Metal Depletion
Climate Change	kg CO_2 eq.	Combines the effect of the periods of time that the various greenhouse gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation
Cumulative Energy Demand	MJ	Includes non-renewable and renewable energy sources
Water Use	m3	Measures the amount of fresh water consumed

Each impact category above is characterized by a unit of measure to which the resource and emission flows are normalized. To aggregate the substances into the impact categories, substances are multiplied by their characterization factor to convert into an equivalent substance (e.g., CO_2) and then added together to create a total for each impact category (e.g., climate change).

3.9 Calculation Tool

Once all the required data were obtained and the associated flows were normalized to the reference flows (based on the chosen functional unit), system modeling was carried out by using the commercial LCA software SimaPro (Version 9.0.0.35), developed by PRé Consultants, the Netherlands. This software allows the calculation of life cycle inventories and impact assessment, contribution analysis, parameterization and related sensitivity analysis and uncertainty analysis.

3.10 Critical Review

A critical review is required by ISO 14044 for comparative assertions intended for public dissemination. Critical review is a process that ensures consistency between a life cycle assessment and ISO requirements for carrying out an LCA. The main purpose of a critical review is to ensure ISO compliance. The critical review is carried out by a panel of experts in order to decrease the likelihood of miscommunication and negative effect on the public knowledge. As outlined by ISO 14044, the role of the critical review is to determine if:

- the methods used to carry out the LCA are consistent with this International Standard;
- the methods used to carry out the LCA are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretations reflect the limitations identified and the goal of the study; and
- the study report is transparent and consistent.

The critical review panel members for the study are specified in Table 3.

Table 3: Critical Review Panel Members

Member	Affiliation
Cashion East, chair	Pivot Analytics
Tom Gloria	Industrial Ecology Consultants
James Rogers	The North Face

The critical review does not imply that the panel members endorse the results of the LCA study, or that they endorse the assessed products. The critical review statement is provided in Appendix E: Critical Review Statement.

3.11 Limitations of the Study

The results of the study are only applicable to the defined scenarios. Any adjustment of the study boundaries or processes may change the results. This study only included primary data from eight IDFB members who produce down.

No primary data on raising ducks or geese were available, therefore secondary data were used. Geese take longer to raise than ducks, and only secondary data for raising duck were available, which was used to model both the duck and the geese down fill material. A sensitivity analysis to the bird data is provided in section 6.3 Sensitivity Analysis.

No primary data for the polyester fill material was available, and the specific fill power is unknown. More details about the polyester fill material data sources are provided in section 4.1.2 Polyester Fill Material.

3.12 Limitations of LCA Methodology

LCA's ability to consider the entire life cycle of a product makes it an attractive tool for the assessment of potential environmental impacts. Nevertheless, like other environmental management analysis tools, LCA has several limitations.

With current availability of data, it is nearly impossible to follow the entire supply chain associated with the product life in a company-specific way. Instead, almost all processes within the supply chains are modeled using average industry data with varying amounts of specificity (e.g., data on a more-or-less specific technology or region). This makes it difficult to accurately determine how well the unit process data actually represents the actual factors in the products' life cycle. It also makes it difficult to know in which region the processes are found.

Furthermore, LCA is based on a linear extrapolation of emissions with the assumption that all the emissions contribute to an environmental effect. This is contrary to threshold-driven environmental and toxicological mechanisms. Thus, while the linear extrapolation is a reasonable approach for more global and regional impact categories such as Global Warming Potential (GWP) and Acidification, it may not accurately represent the actual on-the-ground human- and ecotoxicity-related impacts.

Additionally, even if the study was critically reviewed, it should be noted that, as for any LCA, the impact assessment results generated for this study are relative expressions and do not predict impacts on category midpoints, exceeding thresholds, or risks. It should also be noted that, even though LCA covers a wide range of environmental impact categories, some types of environmental impacts (e.g., noise, social, and economic impacts) are typically not included in LCA.

4 Life Cycle Inventory

The second phase of an LCA is to collect life cycle inventory (LCI) data. LCI data contains the details of the resources flowing into a process and the emissions flowing from a process to air, soil and water.

4.1 LCI Data Collection

The study uses a combination of primary and secondary data. Where primary data were not available, ecoinvent v3.4, Cut-off at Classification (Weidma, 2013) database and DATASMART v2018.1 (Long Trail Sustainability, 2018), which both contain detailed peer reviewed LCI data, are used. Primary data are used for the following:

- energy, water and material inputs for the down material; and
- transportation distances and modes for all raw material transportation links.

Literature data are used for the energy and material inputs for the polyester fill material. The following sections describe each of the key process steps. More information is provided in Appendix B: Life Cycle Inventory Data.

4.1.1 Down Fill Material

Under the direction of LTS, select IDFB members gathered primary data on energy, water and material inputs and waste outputs of manufacturing down fill material. Secondary data were used for processes outside of their operations and where primary data was not available (e.g. raw material extraction, processing of material inputs, transportation, disposal).

Data from the AGRIBALYSE v1.3 database[6] was used for raising ducks/geese, as ecoinvent and DATASMART do not have data on raising ducks. The boundary of this data is farm-gate and does not contain processing/slaughtering, therefore slaughtering data was sourced from literature (Michael, 2011).

Data providers for down completed data collection templates on production from the 2017 calendar year. Factories use down from ducks and geese, with the majority of the IDFB participating member down coming from ducks (see Appendix B: Life Cycle Inventory Data (Confidential – Supplied separately for critical review panel) for details by factory). All factories report similar steps to processing the down material. These steps include sorting, pre-washing/washing, drying, dedusting, and mixing. Each factory supplied data to the greatest detail possible, but it is not always possible to gather data for each individual manufacturing step listed. For instance, not all factories separately report a pre-washing, dedusting, or mixing step when reporting, but the functions of these steps likely occur within the other steps that were reported, resulting in an end material of comparable quality. Additionally, factories reported these manufacturing steps occurring in different orders. For example, in some cases sorting is the first step and in other cases sorting occurred after washing. During the washing process of the down, a portion of the water used is often recycled and discharged. This is especially prominent in the factories located in China, as Chinese processors are required to have efficient water recapture systems by law.

Approximately 75% of global down production occurs in China, therefore the down fill material utilizes a weighted average, based both on geography and further based on reported 2017 annual production by factory (IDFB Laboratory and Institute , 2010)[7]. To elaborate, three participating members are based in China, therefore 75% of the IDFB weighted average down fill material is comprised of data from these companies, which is also weighted by annual production. The remaining 25% of the down fill material is comprised of the other participating members, located outside of China. More details are provided in Appendix B: Life Cycle Inventory Data (Confidential – Supplied separately for critical review panel).

To fulfill the functional unit of fill material with a CLO value of 4.06 over a lifetime of 5 years, 108 grams per square meter of 700 fill power down fill material are required. No replacement is needed during the 5 year duration, as down is estimated to last between 5 – 10 years (IDFL Laboratory and Institute, 2018).

[6] AGRIBALYSE uses background data from Ecoinvent 3, cut-off, consistent with what is used in the study. More information is available here >> https://simapro.com/products/agribalyse-agricultural-database/

[7] More up-to-date statistics on global down production are not available; however, LTS confirmed that this statistic is still valid with industry experts.

It should be noted that participating IDFB members were not able to report specifically on 700 fill power down, as they produce a range of fill powers in their factories, which include 700 fill power and typically range between 500 and 850 fill power. Further, it was reported that the fill power itself does not influence the processing steps of the down.

4.1.2 Polyester Fill Material

Secondary data and literature values were used for the polyester fill material. Polyester fill material is based on general knowledge that polyester fill material is made of PET and a spinning process. (Sustainable Apparel Coalition, 2019). A 10% loss of raw material was used for the raw material PET. This is consistent with both a comparative ecoinvent 3.4 plastic production[8] processes and the assumptions used in SAC polyester fill process. Data for electricity and steam for the spinning process was sourced from literature (van der Velden, 2014).

To fulfill the functional unit CLO value of 4.06, 230 GSM of polyester fill material are needed**.** Additionally, the polyester fill material has a lifetime of 2 years, therefore 3 replacements are needed over 5 years, the functional unit duration (IDFL Laboratory and Institute, 2018).

4.2 Electricity Mixes

For the down fill material, country specific electricity grid mixes were used for each participating member. For the polyester fill material, a Rest of World electricity mix was used. The specific processes used are detailed in Appendix B: Life Cycle Inventory Data (Confidential – Supplied separately for critical review panel).

4.3 Data Quality

In practice, all data used in an LCA study is a mixture of measured, estimated, and calculated data. The quality of data is rarely homogenous. Therefore, all specific data points were evaluated according to the pedigree matrix (for more details on the pedigree matrix see Appendix D: Uncertainty Analysis). The sections below describe the data quality in this study.

4.3.1 Geographic Boundaries

This study used data from eight IDFB members to represent the down fill material, based in China, Italy, U.S., France, Japan and Germany. Global and Rest of World secondary data were used to represent the polyester fill material.

[8] The ecoinvent process *Fleece, polyethylene {RoW}* utilizes a 10% yield for the raw material input of *polyethylene, high density, granulate {GLO}*

4.3.2 Treatment of missing data

Proxy data were used for missing data, as discussed in Section 3.6 LCI Data Collection. In the case that missing data exceeded the 1% cut-off employed, sensitivity tests are conducted. More detailed information is provided in Section 6.3: Sensitivity Analysis and Appendix B: Life Cycle Inventory Data.

4.3.3 Uncertainty Analysis

Uncertainty analysis is performed to determine how data quality affects the reliability and robustness of the results of the LCIA (ISO 14044, 2006). To evaluate the robustness of results in this study, we performed uncertainty analyses using the following procedure.

- Flows and parameters within the model were changed from deterministic to probabilistic values, i.e. from point estimates to probability distribution functions (PDFs). As is common practice in LCA, lognormal distributions were used.
- Monte Carlo simulations were carried out in SimaPro (1,000 runs). These evaluated the frequency at which one system was preferable to another.

The method to change the point estimates to PDFs is based on the pedigree matrix developed by Weidema and Wesnaes (1996). Each flow type is attributed to a basic uncertainty factor, taken from Goedkoop et al. (2013), which is then combined with "additional uncertainty factors" using the following equation to calculate a squared geometric standard deviation:

$$SD_{g95} = \sqrt{exp[\ln(U_1)^2 + \ln(U_2)^2 + \ln(U_3)^2 + \ln(U_4)^2 + \ln(U_5)^2 + \ln(U_6)^2 + \ln(U_b)^2]}$$

With:

U_1: uncertainty factor of reliability
U_2: uncertainty factor of completeness
U_3: uncertainty factor of temporal correlation
U_4: uncertainty factor of geographic correlation
U_5: uncertainty of other technological correlation
U_6: uncertainty of sample size (obsolete indicator, followed recommendation and did not use)

When one material was shown to have greater impacts in 95% or more of the Monte Carlo simulations, we considered the comparative results to be certain and statistically significant. When the percentage was less than 95%, we considered the comparative results to be uncertain and therefore statistically significant conclusions could not be drawn. More information about the assessment of data quality is provided in Appendix D: Uncertainty Analysis and the uncertainty scores are provided in Appendix B Life Cycle Inventory Data (Confidential – supplied separately for critical review panel).

5 Results of Life Cycle Impact Assessment

The following sections summarize the key characterized results of the LCA including contribution analyses of the down fill material and polyester fill material, uncertainty analyses showing the robustness of the results, and comparative analyses of the down compared to polyester fill material. Explanations of each type of analysis is provided below. The life cycle inventory was analyzed using the LTS Method. A description of the LTS Method is provided in Appendix A: LTS Method: Description of Impact Assessment Method. Midpoint results are provided in Appendix C: Midpoint Results.

Contribution: Contribution analyses identify the environmental hot-spots in the life cycle of each system, which are the life cycle processes that contribute disproportionately to the overall life cycle impacts of the system. The identification of hot-spots provides a deeper understanding of what is driving the environmental performance of the system and allows for the identification of opportunities for process improvement.

Uncertainty: Uncertainty analyses determine how data quality affects the reliability and robustness of the results. When one option was shown to have greater impacts in 95% or more of the Monte Carlo simulations, we considered the comparative results to have a high level of certainty and statistically significant. When the percentage was less than 95%, we considered the comparative results to have a low level of certainty and therefore statistically significant conclusions could not be drawn.

Comparative: Comparative analyses show which option has more or less environmental impacts in a given impact category.

5.1 Down Fill Material Results

As shown in Figure 6 and Table 4, 22% - 54% of the down fill material impacts are from energy use, except in water use. More specifically, between 60% and 80% of the energy impacts are from electricity, and 20% to 40% are from gas, and less than 1% is from steam and propane, across all impact categories except water. Duck/goose contributes 17% - 45% of overall impacts across all impact categories (except water use). A wastewater credit is given for water recycled and discharged, which is reflected in the graph in negative value for the water use category for waste/wastewater. Detergents have a large portion of ecosystems impact (27%) and water use impacts (43%). Freshwater eutrophication is particularly relevant for agricultural supply chains, included in the Ecosystems damage category. The majority of the eutrophication impacts are from emissions of phosphorus from the duck production process. Most of these impacts are related to the upstream production of the grains for animal feed for the duck production. Midpoint results are provided in Appendix C: Midpoint Results.

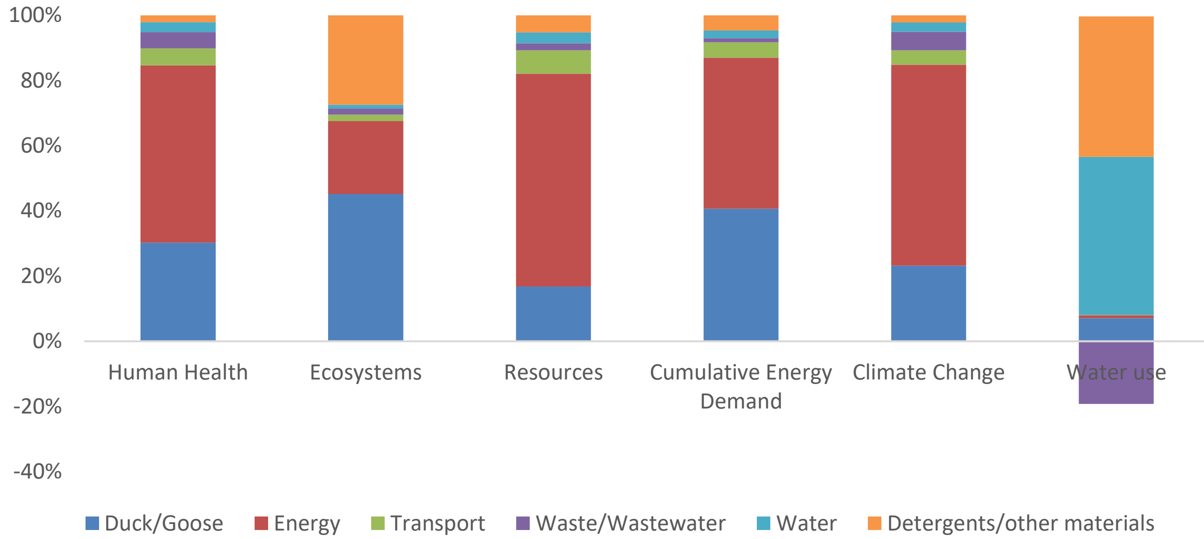

Figure 6: Contribution analysis of down fill material, per functional unit, using the LTS Method

Table 4: Contribution analysis of down fill material, per functional unit, using the LTS Method

Step	Human Health (DALY)	Ecosystems (Species * yr)	Resources ($/kg)	Cumulative Energy Demand (MJ)	Climate Change (kg CO_2 eq.)	Water Use (m3)
Duck/Goose	1.28E-09	2.00E-11	1.24E-05	1.23E-02	4.56E-04	1.50E-05
Energy	2.29E-09	9.96E-12	4.82E-05	1.40E-02	1.21E-03	1.86E-06
Transport	2.19E-10	8.60E-13	5.27E-06	1.43E-03	8.77E-05	2.85E-07
Waste/Wastewater	2.15E-10	8.60E-13	1.62E-06	3.73E-04	1.12E-04	-3.98E-05
Water	1.25E-10	4.84E-13	2.47E-06	7.23E-04	5.43E-05	1.02E-04
Detergents / other materials	8.96E-11	1.22E-11	3.84E-06	1.41E-03	4.38E-05	9.10E-05

The uncertainty analysis shown in Figure 7 indicate that the environmental impacts of down fill material could be around 22% lower and 44% higher in human health, ecosystems, resources, cumulative energy demand and climate change, due to variations in the data. Water use results are more uncertain, ranging from 517% lower to 416% higher, and show separately in Figure 8. All secondary datasets contain uncertainty information per datapoint, and in this study the uncertainty related to water is largely due to the uncertainty associated with these secondary (background) datasets and not the primary data reported by the individual facilities. Specifically, the farm level data for raising the duck has large uncertainty related to water use impacts. For comparison, the ecoinvent chicken process (tested in the sensitivity analysis) also has comparably large uncertainty around water use.

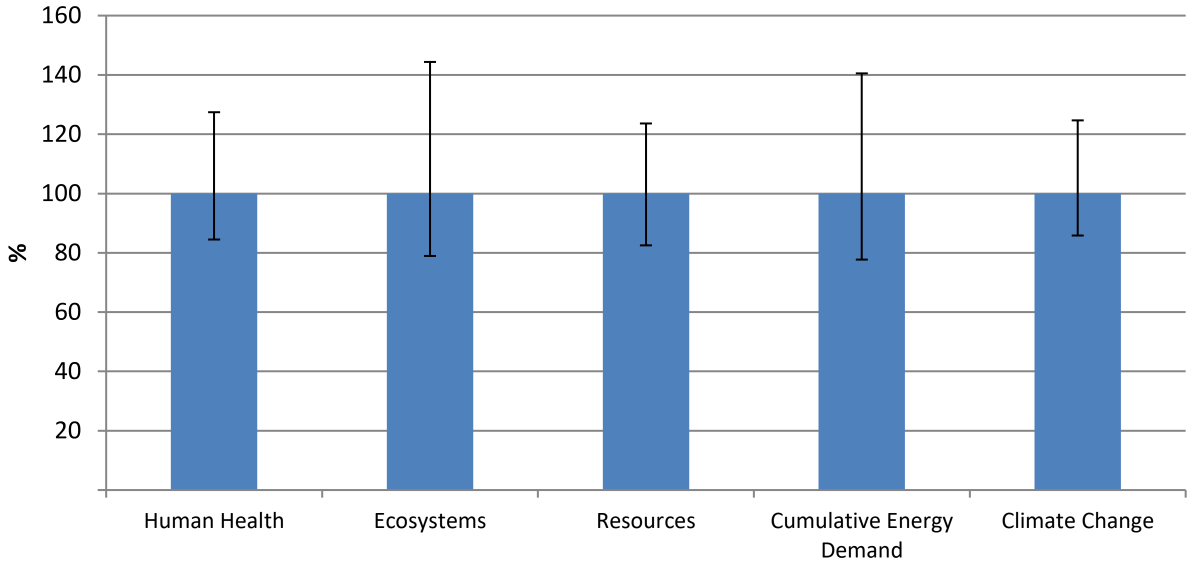

Figure 7: Uncertainty analysis of down fill material, using the LTS Method, excluding water use

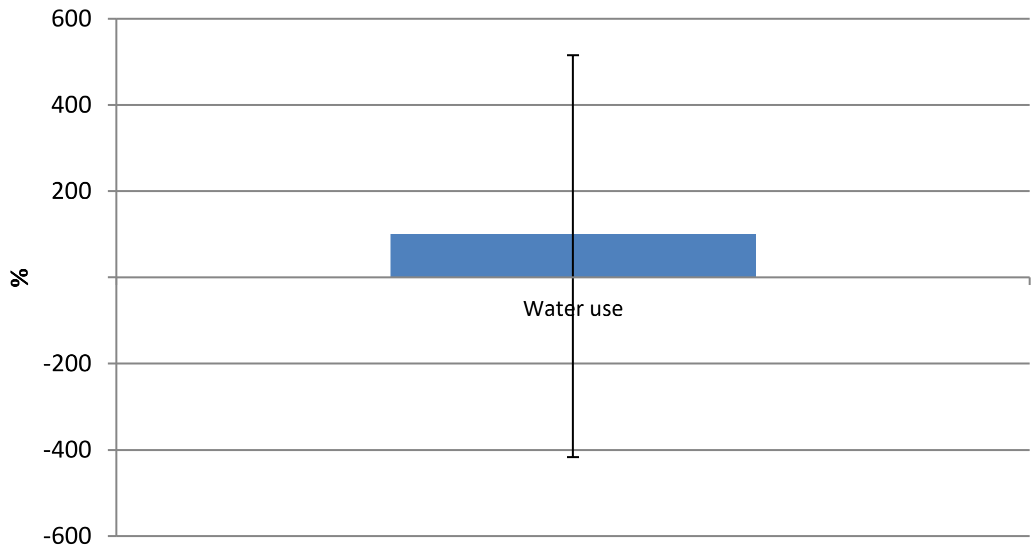

Figure 8: Uncertainty analysis of down fill material in water use, using the LTS Method

5.2 Polyester Fill Material Results

Figure 9 and Table 5 show that the polyester fill material impacts are driven by the PET raw materials (65% - 81% across all and impact categories). More specifically, the purified terephthalic acid contributes between 53% and 63% of the impacts for the PET impacts and ethylene glycol contributes between 21% and 24% across all impact categories. Electricity contributes 13% - 27% across all impact categories.

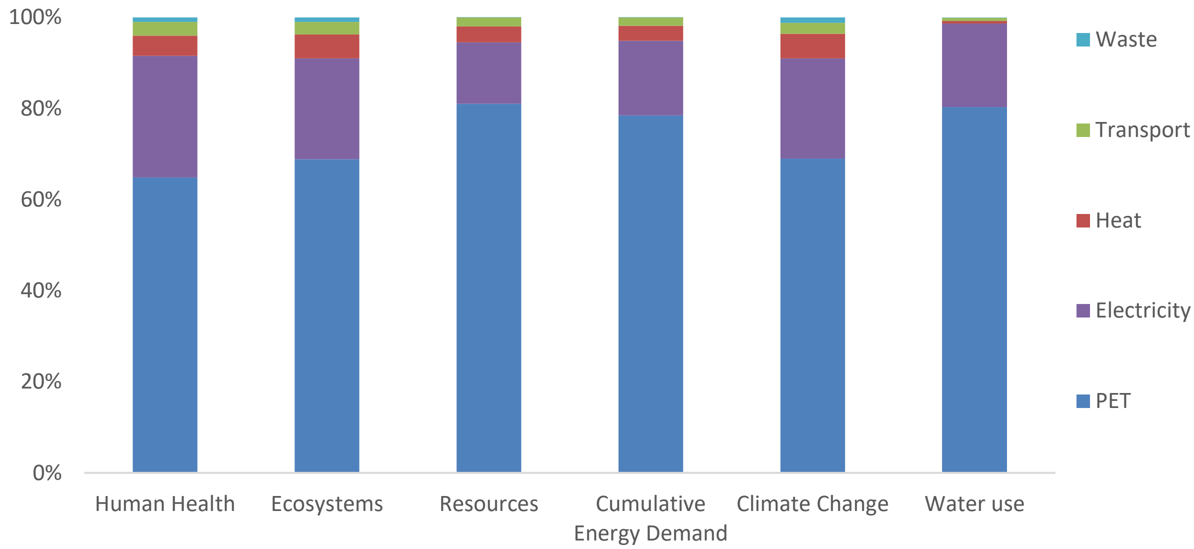

Figure 9: Contribution analysis of polyester fill material, per functional unit, using the LTS Method

Table 5: Contribution analysis of polyester fill material, per functional unit, using the LTS Method

Step	Human Health (DALY)	Ecosystems (Species * yr)	Resources ($/kg)	Cumulative Energy Demand (MJ)	Climate Change (kg CO_2 eq.)	Water Use (m3)
PET	4.79E-06	2.06E-08	2.12E-01	6.01E+01	2.43E+00	2.75E-02
Electricity	1.97E-06	6.59E-09	3.52E-02	1.25E+01	7.73E-01	6.28E-03
Heat	3.30E-07	1.58E-09	9.27E-03	2.57E+00	1.91E-01	1.88E-04
Transport	1.01E-07	4.67E-10	2.86E-03	7.55E-01	4.55E-02	1.34E-04
Waste	1.22E-07	3.48E-10	2.20E-03	6.09E-01	3.95E-02	1.12E-04

Due to variations in the data, the uncertainty analysis shown in Figure 10 indicate that the environmental impacts could be around 30% lower and 47% higher in human health, ecosystems, resources, cumulative energy demand and climate change. Results for water use (Figure 11) are highly uncertain, ranging from 5,475% lower to 4,025% higher. The uncertainty is mainly driven by the data uncertainty in the underlying secondary data.

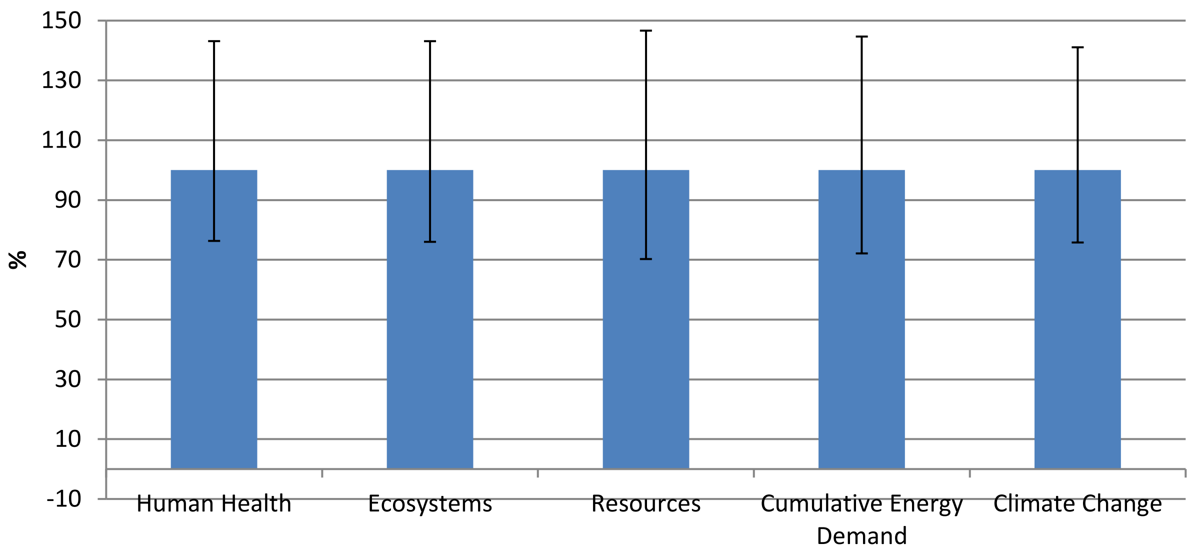

Figure 10: Uncertainty analysis of polyester fill material, using the LTS Method, excluding water use

Figure 11: Uncertainty analysis of polyester fill material in water use, using the LTS Method

5.3 Down vs. Polyester Fill Material Results

Uncertainty analysis shown in Figure 12 indicates with a high level of certainty, within the 95% confidence interval, that down fill material has fewer impacts than polyester fill material in human health, ecosystems, resources, cumulative energy demand and climate change. Results for water use fell below the 95% confidence interval, therefore the comparative results for that category are not shown.

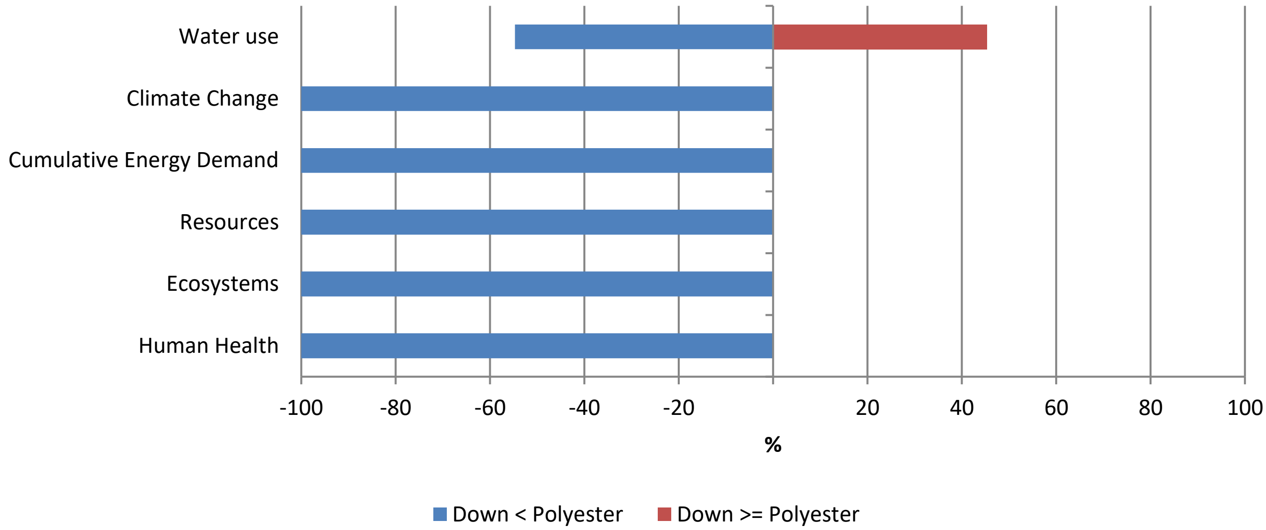

Figure 12: Uncertainty analysis of down vs. polyester fill material, per functional unit, using the LTS Method

As shown in Figure 13, polyester has more environmental impacts than down fill material in all categories. The down fill material has 6% of the polyester impacts in human health, 15% in ecosystems, 3% in resources, 4% in cumulative energy demand and 6% in climate change. Results for water use fell below the 95% confidence interval, therefore the comparative results for that category are not shown because statistically significant conclusions cannot be drawn in that category.

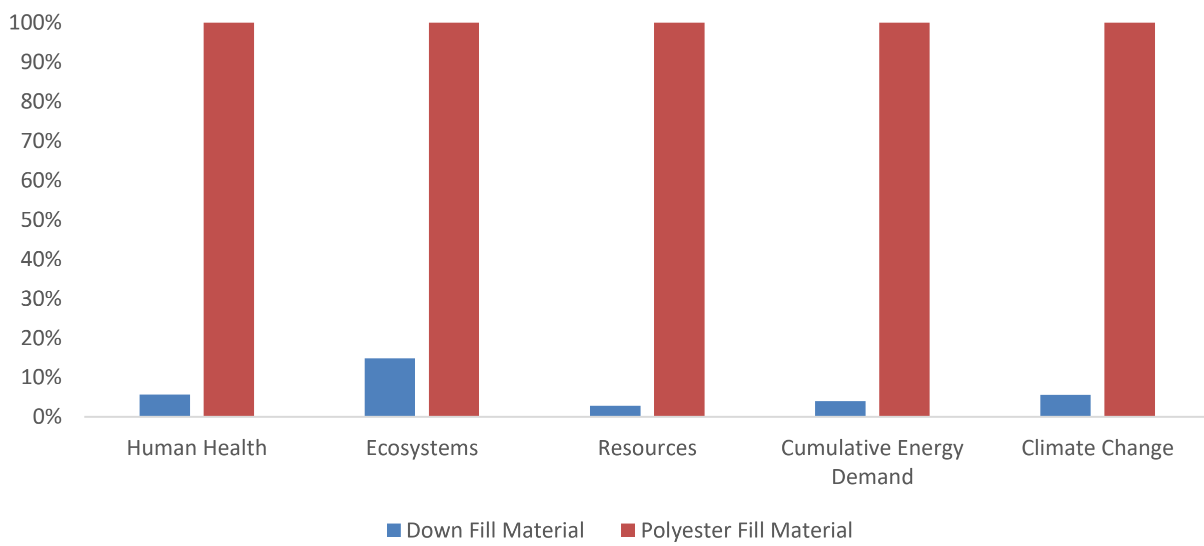

Figure 13: Comparative analysis of down vs. polyester fill material, per functional unit, using the LTS Method

6 Interpretation

Interpretation is the last phase of an LCA, although it is typically done iteratively to inform and refine the goal and scope. In this section, the results are examined based on the data quality and consistency. Key assumptions are tested to ensure that conclusions and recommendations are consistent with the goal and scope. It should be noted that the LCA results are based on a relative approach and indicate potential environmental effects and do not predict actual impacts on category impacts.

6.1 Key Observations

By analyzing the down fill material, the study provides useful insight regarding the environmental impacts of down fill material production, as well as how down fill material compares to polyester fill material. The LCA results also identify where the largest impacts are occurring so that IDFB members can make further improvements.

6.2 Completeness Check

Detailed information on the inputs and outputs of the down and polyester fill material were gathered and every effort was made to perform a comprehensive analysis. An attempt was made to include as much detail as possible, even for processes that were found to be largely negligible in the environmental impact assessment. Processes were mass balanced before allocation to ensure all waste and emissions were captured. This was done to ensure completeness. Furthermore, all energy consumption that was understood as relevant for the comparison was included. Additional information is provided in Appendix B: Life Cycle Inventory Data (Confidential – Supplied separately for critical review panel).

6.3 Sensitivity Analysis

Sensitivity analysis is performed to understand the influence of variations in the assumptions, methods and data on the results. In other words, sensitivity analysis is used to understand the robustness of the conclusions and identify limitations to the results.

6.3.1 Allocation of bird for down fill material

The default scenario allocates 10% of bird to down fill material, based on an independent source (Responsible Down Standard, 2018). Some industrial providers have indicated that the economic value of the down fill material is as low as 2%. As shown in Figure 14, when the allocation percentage is varied between 2% - 50%, the down fill material has lower environmental impacts compared to polyester in all scenarios and impact categories.

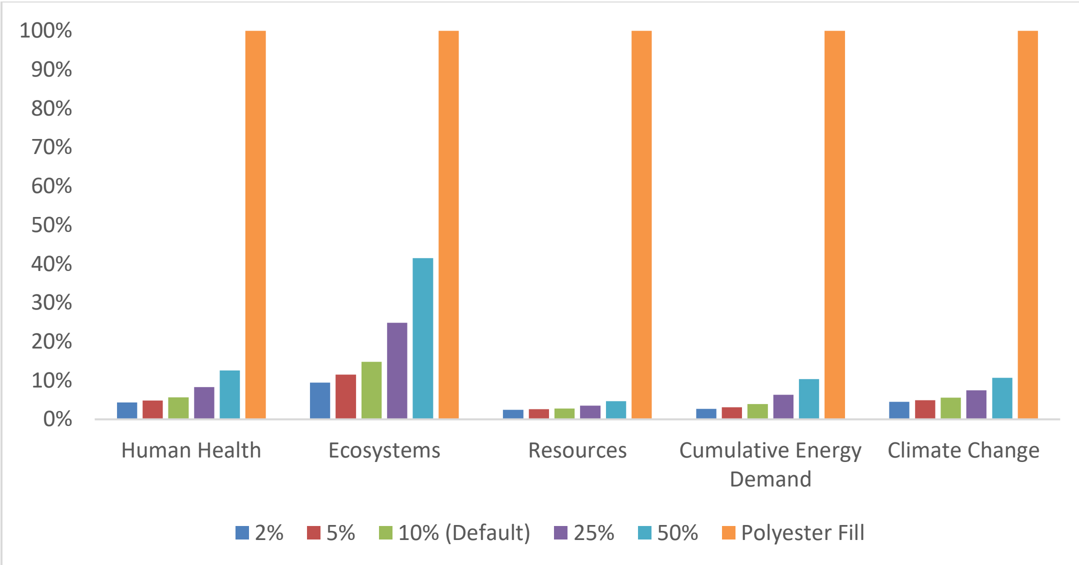

Figure 14: Sensitivity analysis of allocation of bird for down fill material, per function unit, using the LTS Method

6.3.2 Lifetime of polyester fill material

The polyester fill material has a lifetime of 2 years. As shown in Figure 15, with equal lifespans, the down fill material still has lower impacts across all categories, if polyester did not need to be replaced. If polyester is replaced 6 times compared to the single down fill material, the polyester fill material has roughly 35 times the impact of down. Considering only performance and not lifetime, if polyester is not replaced during the same time period, polyester has between 0.67 and 11.8 times the impact of down.

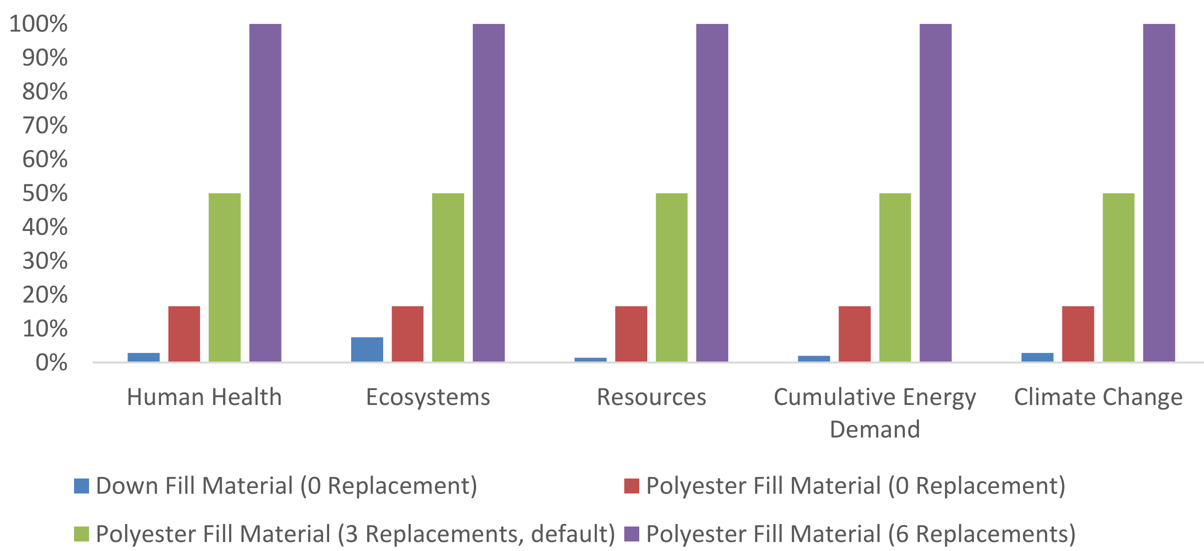

Figure 15: Sensitivity analysis of lifetime of polyester fill material, per function unit, using the LTS Method

6.3.3 Equal weight for down and polyester

To fulfill the functional unit, 108 grams down fill material are required versus 230 grams polyester fill material to meet the CLO value of 4.06. As seen in Figure 16, comparing the down and polyester of equal weights, the down still has fewer overall impacts in all categories. This does not take into account the different lifetimes. To meet the 5-year duration, the polyester is replaced 3 times.

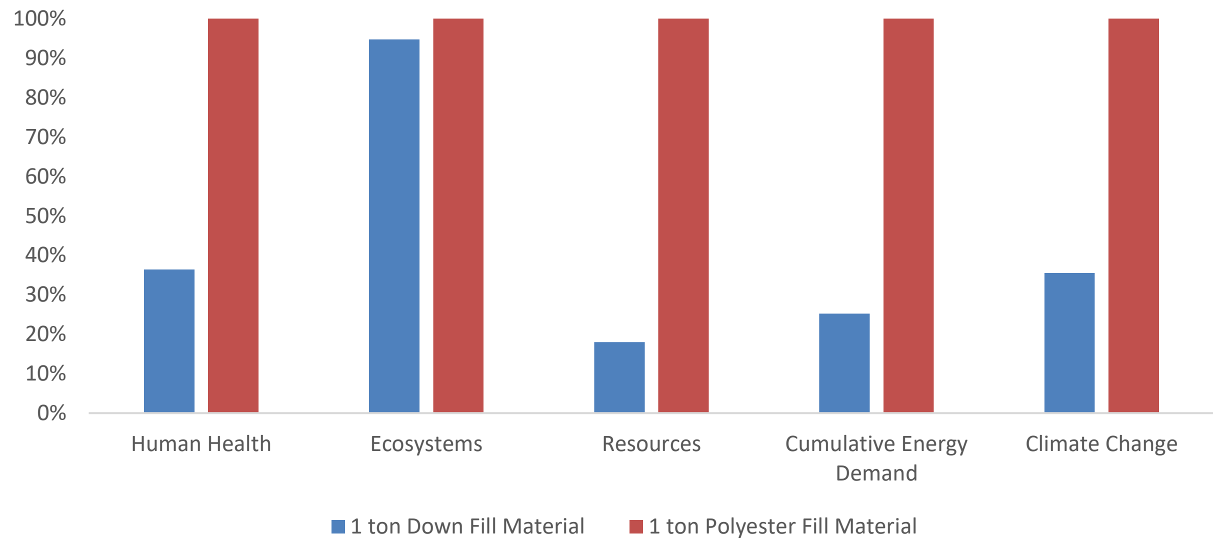

Figure 16: Sensitivity analysis of equal weight, 1 ton of each down and polyester fill material, not accounting for lifetime, using the LTS Method

6.3.4 Equal Weighting of Participating IDFB Member's Data

The down fill material utilizes a weighted average, based on both geography and further based on reported 2017 annual production by factory. Equal weight assigns each factory equal portion of impacts. As seen in Figure 17, impacts for equal weight vary between 4% and 11% difference across impact categories.

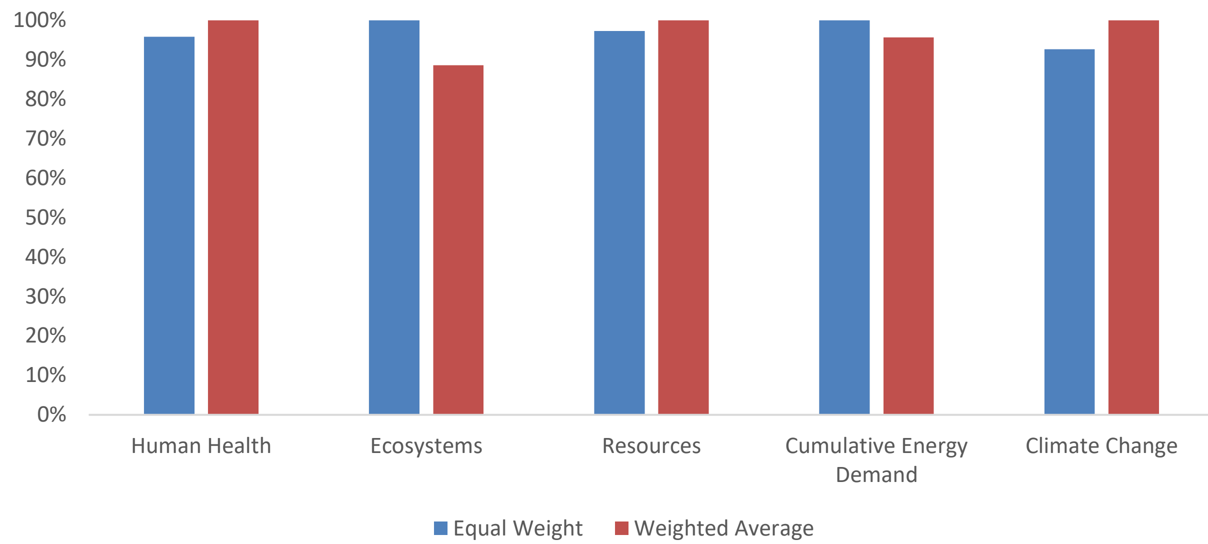

Figure 17: Sensitivity analysis of equal weighting of participating IDFB member's data, per functional unit, using the LTS Method

6.3.5 Bird data

The data used for the duck and geese is a combination of AGRIBALYSE (birth to farm gate) and a literature source (slaughtering). If ecoinvent data for chicken (birth through slaughter)[9] were used instead, the down fill material would have slightly lower impacts in all impact categories than the default down fill material.

[9] Ecoinvent process name, *Chicken for slaughtering, live weight {GLO}| market for*

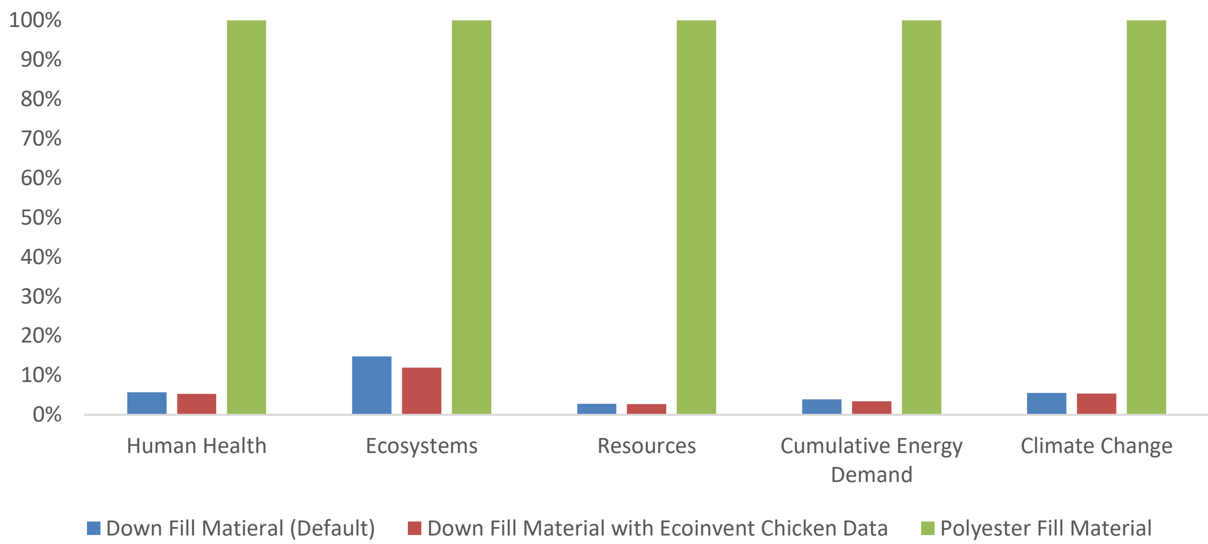

Figure 18: Sensitivity analysis of bird data, per function unit, using the LTS Method

6.3.6 Fill Power

The fill power used in this study is 700 fill power, which has a CLO value of 4.06. The conclusions are similar if a fill power of 650 is utilized, which has a CLO value of 3.86, and requires 108 GSM of down (the same as 700 fill power) and 216 GSM of polyester (slightly less than 700 fill power). The polyester is still replaced 3 times during the functional unit duration of 5 years (IDFL Laboratory and Institute, 2018).

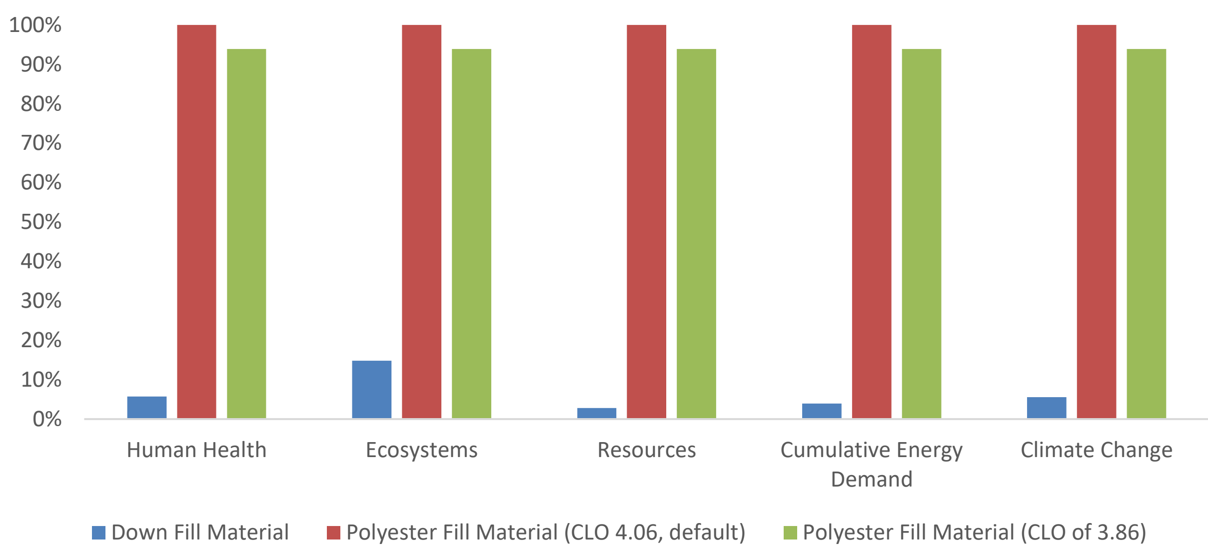

Figure 19: Sensitivity analysis of fill power, per function unit, using the LTS Method

6.3.7 Recycled Content of PET

The polyester fill material is assumed to be 100% virgin. If this is changed to 85% virgin, 15% recycled content, the polyester fill material impacts are reduced by 5% - 10%, but the polyester fill material still has around 85% - 90% more impacts than the down fill material.

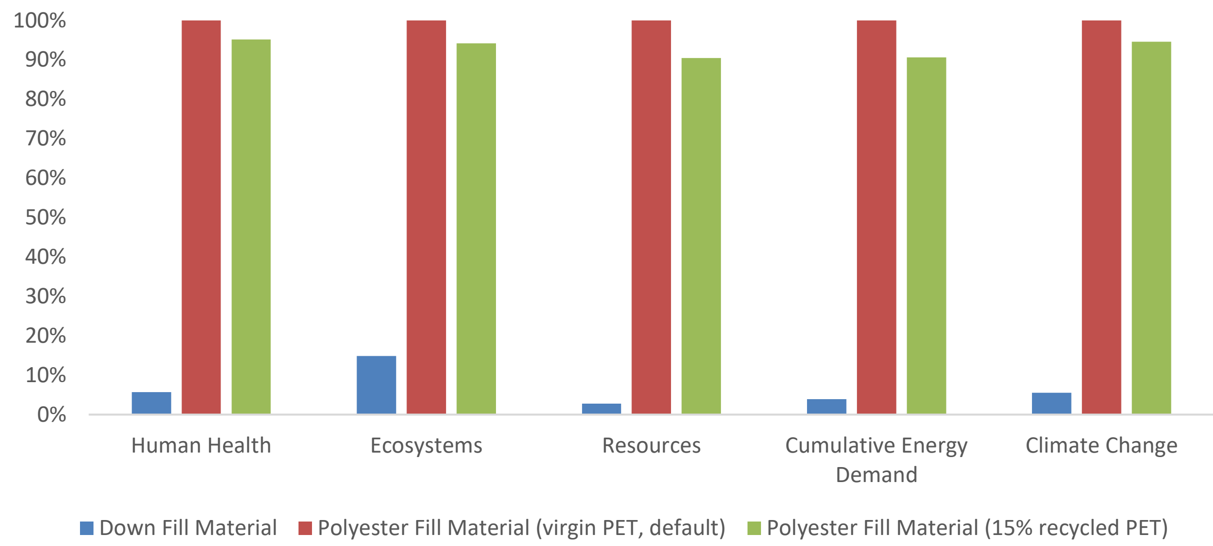

Figure 20: Sensitivity analysis of recycled content in polyester fill material, per function unit, using the LTS Method

6.3.8 Transportation Distances

Assumptions for raw material transportation distances were used when actual distances were unknown (500 km by truck and 5,000 km by ocean). If these distances were halved to 250 km by truck and 2,500 km by ocean or doubled to 1,000 km by truck and 10,000 km by ocean, this does not have a significant impact on the overall results.

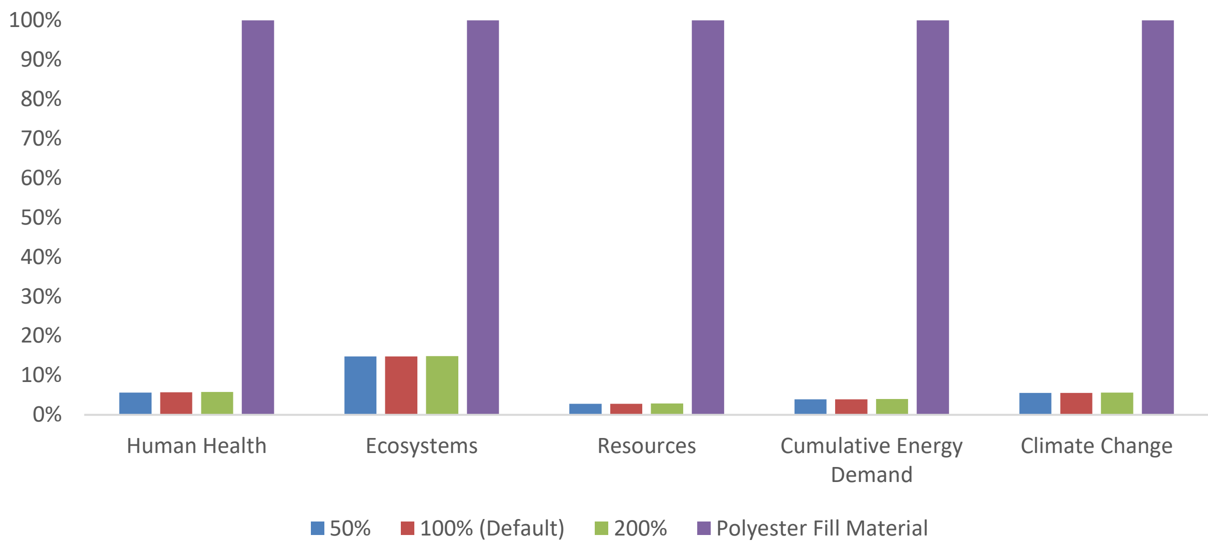

Figure 21: Sensitivity analysis of raw material transportation distances, per function unit, using the LTS Method

6.3.9 Impact Assessment Method

ISO 14044 requires testing the sensitivity of the results to the selected method. This approach allows for the confirmation of general patterns in the results. IMPACT 2002+ 2.14[10] method was used, along with ILCD 2011 Midpoint+ V1.10[11] for water resource and AWARE V1.02[12] for water use. As shown in Figure 22, similar conclusions are reached in human health, ecosystems, climate change and resources, where down has fewer environmental impacts in all categories than polyester fill material.

The water category continues to be uncertain with the ILCD method showing that the down has more water impacts than polyester fill material, and the AWARE method showing that the down has fewer impacts than polyester fill material. As explained in section 5.3: Down vs. Polyester Fill Material Results, the results for water use using the LTS Method fell below the 95% confidence interval, therefore the comparative results for that category are not shown above.

[10] Supporting documents for IMPACT 2002+ can be found at www.impactmodeling.org.

[11] Additional information about ILCD can be found at http://eplca.jrc.ec.europa.eu/?page_id=140.

[12] More information about AWARE can be found at http://www.wulca-waterlca.org.

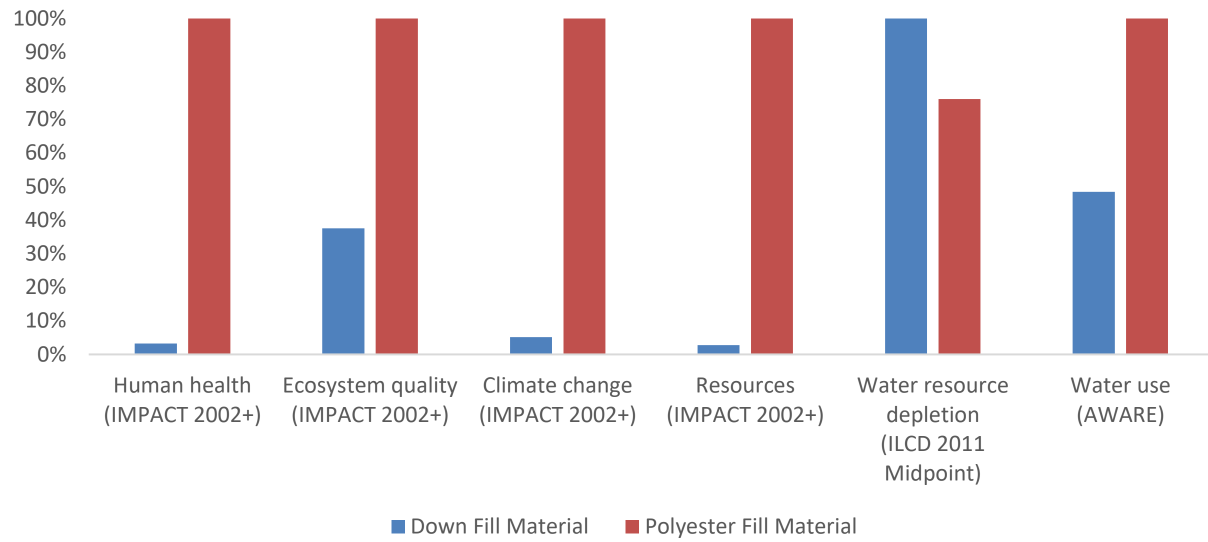

Figure 22: Sensitivity analysis of Impact Assessment Method comparing down versus polyester fill material, per functional unit, using IMPACT 2002+ V2.14, ILCD 2011 Midpoint for Water Resource and AWARE for Water Use

6.4 Consistency Check

The compared systems were modeled in a consistent manner. System boundaries for both systems were defined in a similar manner. Therefore, any differences in overall potential environmental impacts should not be due to inconsistent modeling or data. Additional information is provided in Appendix B: Life Cycle Inventory Data (Confidential – Supplied separately for critical review panel).

6.5 Animal Welfare

Life cycle assessment is a powerful methodology to evaluate the environmental impacts over the life of a product or service. An LCA can help answer many questions about where the hot spots are, how one material or product compares to another, where there are tradeoffs, but there are also aspects to consider that are beyond an LCA, including animal welfare.

IDFB and its members support animal welfare[13]. All members of IDFB adhere to the legal standards for animal welfare. Many animal welfare programs exist, including the voluntary Responsible Down Standard (RDS). RDS is not a legal standard but an audit of supply chain to check that animal welfare concerns are met[14]. Other examples of programs include TDS, DIST, Down Pass and other private label brand programs. The specific program (if required) an IDFB member follows is directed by the finished product customer, not by the supplier of the down. One goal of the IDFB is to expose the reality of live

[13] http://www.idfb.net/

[14] https://responsibledown.org/

plucking. Accordingly, IDFB commissioned a White Paper that clearly demonstrates that down and feathers are a by-product of the poultry industry (Schmitz, The Sustainable and Human Practices of the Down and Feather Industry: A Global Assessment of Industry Statistics and Practices, 2016).

7 Conclusions & Recommendations

The primary objectives of this LCA are to understand the environmental impacts of the down fill material, and to compare to a polyester fill material. Based on the results and study assumptions, methods and data, the majority of the cradle-to-gate environmental impacts of the down fill material come from energy use and duck/goose. Detergents have a large impact in the ecosystem and water use categories.

Compared to the polyester fill material, the down fill material has fewer environmental impacts in all impact categories. Varying the allocation percentage of the bird between 2% and 50% (default at 10%), down still has lower impacts in all categories. Even on a per ton basis (not taking into account performance or duration), down has lower impacts than polyester in all categories.

Recommendations from this study include investigating ways to reduce energy usage during down fill manufacturing, along with the installation and/or use of renewable energy. In addition, researching and utilizing environmentally friendly detergent options will help reduce the ecosystem and water use impact categories in particular. Due to the large uncertainty around the water use in the upstream background datasets, we recommend IDFB members investigate water use and water conservation efforts from their duck and geese suppliers in their individual supply chains. In the long term, water data can be collected from IDFB suppliers to improve the certainty in this category. Another recommendation is improved water usage during down fill material production. This is already happening in significant ways in the largest producing country, China, as well as at other participating IDFB members' facilities.

It is recommended that this study be expanded upon for specific products to understand the full cradle-to-grave impacts of down vs. polyester fill products. Further use of LCA will enable IDFB to evaluate the impacts of the recommendations above and other process changes that may have environmental benefits.

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Appendix A: LTS Method: Description of Impact Assessment Method

The LTS Method, created by Long Trail Sustainability, covers a range of midpoint and endpoint impacts. The method combines ReCiPe endpoint (H) with Cumulative Energy Demand (CED), Climate change and Water.

ReCiPe, developed by Goedkoop *et al*. (2009), is one of the most recent and updated impact assessment methods available to LCA practitioners. The method addresses a number of environmental concerns at the midpoint level and then aggregates the midpoints into a set of three endpoint categories. Endpoint characterization models the impact on Areas of Protection (i.e., on human health, ecosystems, and resources). In other words, endpoint is a measure of the damage – at the end of the cause-effect chain – caused by a stressor in terms of human life-years lost and the years lived disabled, species disappeared, and resources lost.

The Cumulative Energy Demand (CED) of a product is the direct and indirect energy use throughout the life cycle, including the energy consumed during the extraction, manufacturing and disposal. The CED method considers both renewable and non-renewable energy and the direct and indirect energy consumption. For its implementation in SimaPro, the method published by Ecoinvent (Frischknecht *et al*. 2007) is used. The method is expanded further by PRé Consultants to include the energy resources available in SimaPro.

The IPCC 2013 method for assessing the Global Warming Potential (aka, Climate Change) was developed by International Panel on Climate Change. It is one of the most widely used methods to estimate climate change potential of global warming gases in LCA studies. The global warming factors have been developed for 20, 100 and 500-year time horizons to address the global warming potential of emissions in the short as well as long term. This study uses the climate change factors for the 100-year time horizon.

8.1.1 Endpoint Categories

Human Health: In this category, the damage analysis links the six midpoint categories (Climate Change, Human Toxicity, Photochemical Oxidant Formation, Particulate Matter Formation, Ionizing Radiation, and Ozone Depletion) to the Disability Adjusted Life Years (DALYs). The DALY tool is primarily a disability weighting scale of 0 – 1, where 0 represents perfect health and 1 represents death.

Ecosystems: The damage to ecosystems is measured by calculating the species that disappear in a given time period and area. The unit of damage assessment is species.yr. The midpoint impact potentials that apply to ecosystem quality are: Climate Change, Terrestrial Acidification, Freshwater Eutrophication, Ecotoxicity, Agricultural Land Occupation, Urban Land Occupation and Natural Land Transformation.

Resources: The two midpoint categories contributing to the resources category are Fossil Depletion and Metal Depletion. The quantification of the damage is based on the marginal increase of cost due to the extraction of resources, measured as dollars per kilogram ($/kg).

8.1.2 Midpoint Categories

Cumulative Energy Demand: This category includes non-renewable (fossil and nuclear) and renewable (biomass, water, solar, wind, and geothermal) energy sources. Characterization factors are based on the upper (or higher) heating value. Characterization factors are expressed as equivalent megajoules (MJ).

Climate Change: There are several gaseous emissions that cause global warming, including carbon dioxide, methane, nitrous oxides and fluorinated gases. This category combines the effect of the periods of time that the various greenhouse gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation. The global warming potential is measured as kg equivalents of CO_2 (i.e., the relative global warming potential of a gas as compared to CO_2). The IPCC model with a 100-year time horizon is used for characterization. The uptake of CO_2 from the air (i.e., sequestration of CO_2 by plants) and the subsequent emission of biogenic CO_2 (from the burning of biomass) is not included.

Water Use: This category measures the amount of fresh water consumed. This does not include regionalized characterization factors, nor does it take into account the impact that water draw is having on humans or the environment. The unit is m3 water consumed.

Appendix B: Life Cycle Inventory Data (Confidential – Supplied separately for critical review panel)

Appendix C: Midpoint Results

The LTS Method is comprised of a range of midpoint and endpoint impact categories. The three ReCiPe endpoints (human health, ecosystems and resources) are reported in 18 midpoint categories. Cumulative Energy Demand is further detailed into six midpoint categories, separating non-renewable and renewable energy types. The midpoint results for the endpoints included are provided below.

Figure 23 shows the midpoint results for the down fill material. Consistent with the results presented earlier, the majority of the cradle-to-gate environmental impacts of the down fill material come from energy use and duck/goose. Detergents have a large impact in the ecosystem categories, like natural land transformation and in water use.

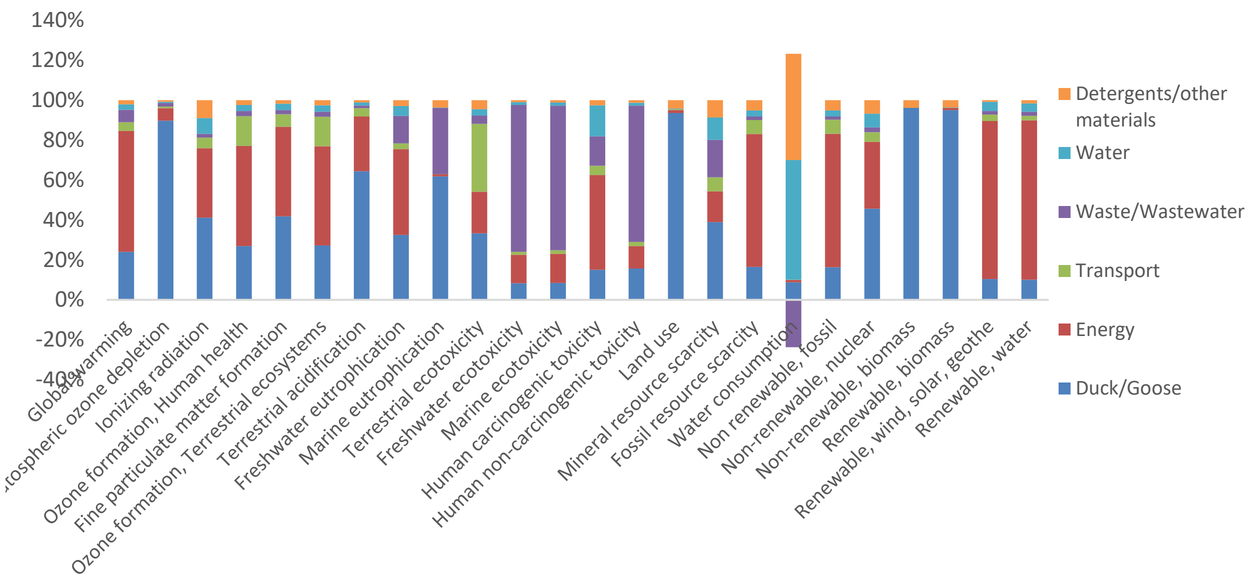

Figure 23: Contribution Analysis of Down Fill Material Showing Midpoint Results, using the LTS Method

Figure 24 shows the midpoint results for the polyester fill material. Also similar to earlier results, the majority of the polyester fill material impacts come from the PET raw material and from electricity.

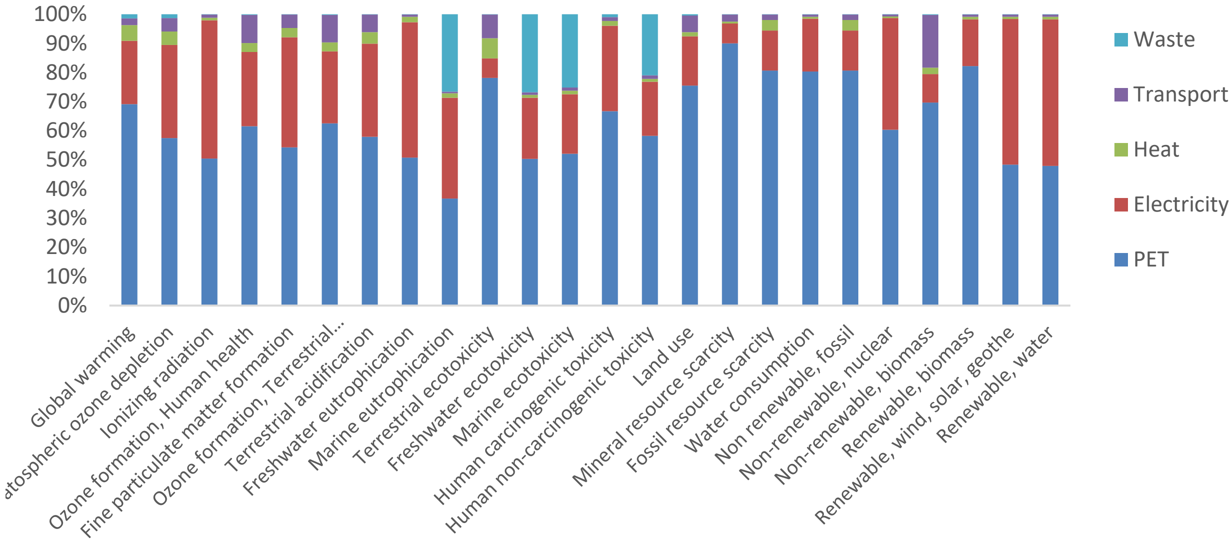

Figure 24: Contribution Analysis of Polyester Fill Material Showing Midpoint Results, using the LTS Method

Figure 25 shows the midpoint comparative results for down vs. polyester fill material. Similar to the endpoint results, down has fewer impacts than polyester fill material in all categories, with the exception of the land use, non-renewable biomass and renewable biomass midpoint categories. When these are aggregated at the endpoint level, down has few impacts than polyester fill material.

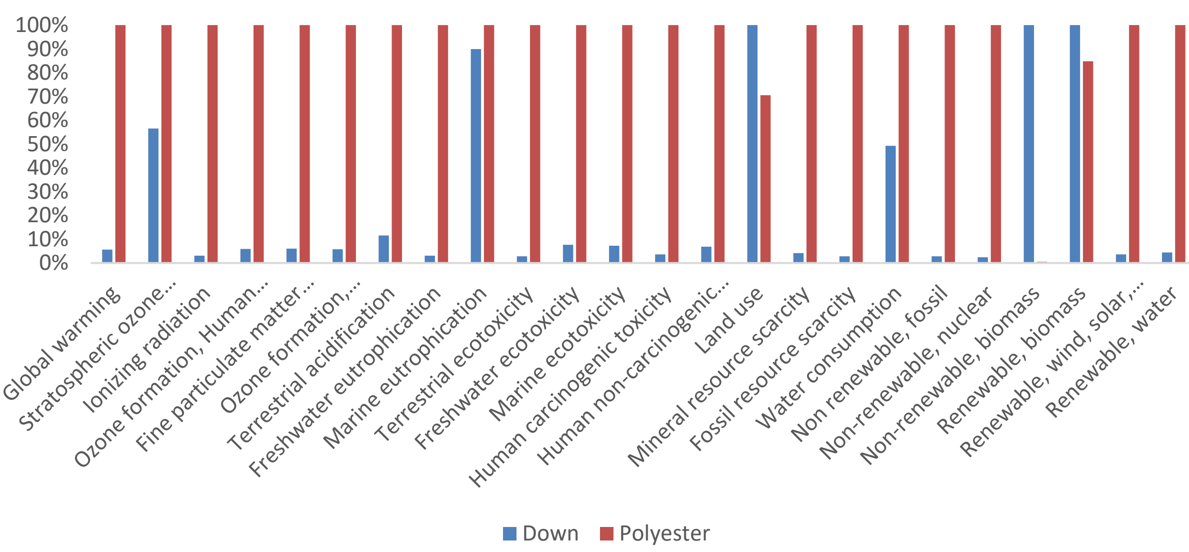

Figure 25: Comparative analysis of down vs. polyester fill material, per functional unit, using ReCiPe Midpoint (H) and CED Midpoint

Appendix D: Uncertainty Analysis

Pedigree Matrix

In practice, all data used in an LCA study is a mixture of measured, estimated, and calculated data. The quality of data is rarely homogenous. In the study, some data is very reliable while some has been estimated. To evaluate the quality of data used for modeling the two manufacturing systems, Data Quality Indicators (DQI) have been assigned to each flow using the data quality matrix approach. These scores have also been used to assess uncertainties on the data and subsequently assess the uncertainty of the model and the results.

Six types of DQI are evaluated by the Pedigree matrix (Weidema & Wesnaes, 1996) by using scores from 1 to 5:

1. Reliability (related to the reliability of the collected *primary* data);
2. Completeness (related to the completeness of the *primary* data);
3. Temporal correlation (related to the temporal correlation of the *primary* data);
4. Geographical correlation (related to the geographical correlation of the *secondary* data used);
5. Further technological correlation (related to the technological correlation of the *secondary* data used)
6. Sample size (Considered obsolete, therefore N/A was used).

In addition, a score is given to the basic uncertainty of the measured input or output. Inputs to a manufacturing process are given a low uncertainty, for example, since these quantities are well known and often metered. Higher uncertainties are given to transportation, for example, since routes may change based on weather, construction, accidents, etc., and to emissions such as carbon monoxide which may vary engine to engine and even from week to week using the same engine. Scores are assigned to the data based on the criteria presented in the Pedigree matrix and a Monte Carlo uncertainty analysis is conducted to determine the influence of data quality on the significance of the study results.

Scores have been assigned to the data in the SimaPro model based on the criteria presented in the Pedigree matrix. Table 6 presents the Pedigree matrix which was used to assign uncertainty to data modeled.

Table 6: Pedigree Matrix

DQI	1	2	3	4	5
Reliability	Verified data based on measurements	Verified data partly based on measurements OR non-verified data based on measurements	non-verified data partly based on qualified estimates	Qualified estimates (e.g. by industrial expert) data derived from theoretical information	Non-qualified estimate
Completeness	Representative data from all sites relevant for the market considered over an adequate period to even out normal fluctuations	Representative data from >50% of the sites market considered over an adequate period to even out normal fluctuations	Representative data from only some sites (<50%) relevant for the market considered OR >50% of the sites but from shorter periods	Representative data from only one site for the market considered OR some but from shorter periods	Representativeness unknown or data from a small number of sites AND from short periods
Temporal correlation	Less than 3 yrs of difference to reference year	Less than 6 yrs of difference to reference year	Less than 10 yrs of difference to reference year	Less than 15 yrs of difference to reference year	Age of data unknown OR more than 15 yrs difference from reference year
Geographical correlation	Data from area under study	Average data from smaller area than area under study or from similar area	Data from smaller area than area under study, or from similar area	Data from area with slightly similar production conditions.	Data from unknown or distinctly different area
Further technological correlation	Data from enterprises, processes and materials under study (i.e., identical technology)	Data from processes or materials under study (i.e. identical technology) but from different enterprises	Data from related processes or materials but same technology, OR data from processes and materials under study but from different technology OR process partially represented	Data from related processes or materials but different technology, OR data on laboratory scale processes and same technology	Data on related processes or materials but on laboratory scale of different technology

Appendix E: Critical Review Statement

Date:	**1 July 2019**
Study Reviewed:	**IDFB "Life Cycle Assessment of Down Fill Material"**
Panel Chair:	**Cashion East, Pivot Analytics**
Panel Members:	**Tom Gloria, Industrial Ecology Consultants; James Rogers, The North Face**
Panel Decision:	**Study is in accordance with ISO 14040 and 14044.**
Applicability of Study Results:	**Study provides results ready for public dissemination.**

Critical Review Summary

Long Trail Sustainability was commissioned by the International Down and Feather Bureau (IFDB) to convene a panel of experts to conduct a third-party critical review of this comparative LCA report.

The review panel critically reviewed this LCA study report and supporting documents to determine if:

- The methods used to carry out the LCA are consistent with the international standards (ISO 14040, 14044);
- The methods used to carry out the LCA are scientifically and technically valid;
- The data used are appropriate and reasonable in relation to the goal of the study;
- The interpretations reflect the limitations identified and the goal and scope of the study; and
- The study report is transparent and consistent.

Since the study is intended to be used to make public claims about the environmental impacts associated with competing product systems, the review panel also considered whether the LCA study report is compliant with the specific reporting requirements of ISO 14044 Section 5.3 for studies intended to be used to support comparative assertions disclosed to the public.

The critical review panel's comments and the study team's responses have been appended to this statement.

Final Review Statement

The review panel has concluded that the study is in compliance with the ISO 14040 and 14044 standards for LCA studies used to support comparative assertions to be disclosed to the public. There are no outstanding methodological or technical issues upon completion of this review, and the general findings of the review panel are summarized below. More detailed comments on the study methodology and technical assumptions, including the study team's responses, can be found in the attached review summary.

Are the methods used to carry out the LCA consistent with the international standards (ISO 14040, 14044)?

The review panel finds that the study is consistent with the ISO LCA standards, and in particular, the reporting requirements under Section 5.3 for studies used to support comparative assertions. The methodology is clearly described, and all modeling assumptions are documented and explained. Sensitivity analyses were conducted to verify key assumptions and the results of sensitivity analyses did not vary significantly from the primary results, generally supporting the study conclusions. A detailed data quality assessment was also conducted, and the study conclusions were supported by uncertainty analysis using Monte Carlo simulations in the SimaPro software program.

Are the methods used to carry out the LCA scientifically and technically valid?

The review panel finds that the methods used are scientifically and technically valid.

Are the data used appropriate and reasonable in relation to the goal of the study?

The reviewer panel finds that the data used are appropriate with respect to the study objectives.

Do the interpretations reflect the limitations identified and the goal and scope of the study?

The review panel finds that the interpretation of the results reflects the limitations identified and the sensitivity analyses provided support the conclusions.

Is the study report transparent and consistent?

The review panel finds that the study report is transparent and consistent. A high-level of detail is provided in the description of the product systems, key assumptions, and data used.