The Development of a Standard Tool to Predict the Environmental Impact of Footwear

A Group Project in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management from the Donald Bren School of Environmental Science and Management at the University of California, Santa Barbara

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Prepared March, 2010

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deckers
OUTDOOR CORPORATION

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March 2010

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The mission of the Bren School of Environmental Science & Management is to produce professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principal of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a four-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

____ Sarah Anderson, Ph.D.

ABSTRACT

To calculate the total lifecycle environmental impact of shoes during the design phase, *prior* to manufacture, a model called EcoSTEP (Simple Tool for Environmental Prediction) was developed using life cycle assessment (LCA) methodology. The goal of the model is to give shoe designers at Deckers Outdoor Corporation the ability to incorporate environmental performance into their shoe design process.

Once Deckers shoe designers enter designs into the model, the inputs are translated into five specific impact potentials: global warming, human toxicity, acidification, freshwater aquatic ecotoxicity, and eutrophication. Designers can choose to view the impacts of one pair of shoes or to compare impacts of multiple pairs to aid their decision-making processes during shoe design.

The creation and testing of the model led to several insights regarding materials and assembly. First, materials derived from livestock should be avoided in favor of other materials such as cotton and hemp. Second, cold-cement assembly uses less energy than vulcanization. Third, some natural materials, such as natural rubber, that are thought to cause less environmental damage through cultivation can actually be more harmful then synthetic materials. Additional conclusions are expected through extended use of EcoSTEP when Deckers designers incorporate it into footwear production.

EXECUTIVE SUMMARY

Although shoes are not typically thought of as consumer products that are harmful to the environment, typical footwear manufacturing uses environmentally harmful materials that contribute to greenhouse gas emissions and toxic pollution during their production and disposal. These emissions cause damage to human and ecosystem health, especially when shoes are produced in large quantities. Assuming that each pair of shoes generates approximately 15 kg of CO_2 through its life cycle,[1] and assuming that the average American owns 15 pairs of shoes,[2] the total CO_2 emissions resulting solely from the production of shoes in American closets is roughly 67 million metric tons[3] -- an amount slightly higher than the annual CO_2 emissions of Finland (United Nations Statistical Division, 2009).

While all shoe production has environmental ramifications, Deckers Outdoors Corporation aims to be an industry leader in reducing environmental impacts through their Simple Shoes brand. Simple Shoes is a line of footwear focused on "100 percent sustainability" of their products (Simple Shoes, 2009). As part of their commitment to environmental stewardship, the company uses natural materials, such as organic cotton and hemp, believed to generate less significant environmental impacts than conventional materials. In addition, Simple aims to use less energy and material intensive manufacturing processes. Despite these efforts, the impact of alternative materials can often be anecdotal and rigorous analyses may show that the changes have minimal benefits. Therefore, designers cannot be certain that their product sustainability efforts are successful. If the impacts of a pair of shoes could be quantified before the design is final, designers would have the capability to compare similar shoe designs, selecting the design with the lowest impact while avoiding the production of a high-impact shoe.

To make this capability a reality, Deckers approached the Bren School for assistance in creating a model to predict the environmental impact of a pair of shoes during the design phase using life cycle assessment (LCA) methodologies. However, LCAs have typically been conducted to assess environmental impacts of a product retrospectively. In contrast, this new model was intended for use during the design phase, *prior* to manufacture. In order to have predictive capability, the model was required to include two major features. First, the model must include all current and *potential* materials currently used in the Simple Shoes line. Second, the model must be able to incorporate any possible shoe design.

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[1] The GaBi model was used to calculate the environmental impact of a leather low-top vulcanized sneaker.
[2] An email request was sent out to all Bren Graduate students asking, "how many pairs of shoes do you have?" There were 94 responses and the average was 15.97 shoes.
[3] 15 shoes x 15 kg x 300 million people = 67.5 million metric tons

Using expertise and resources from the Bren School and Deckers, this project created a predictive model, EcoSTEP (Simple Tool for Environmental Prediction), using GaBi4 and I-Report software by PE International, the industry standard software for conducting LCAs. EcoSTEP calculates quantitative impacts for several comparable designs giving Deckers employees accurate knowledge about the potential harm caused by their products and allowing them to target problem areas in their designs and supply chain.

In order to properly assess Deckers' shoes environmental impact, data was collected directly from the client and its supply chain. Several shoes were also disassembled in order to learn all of the shoe parts and generate a list of possible materials and material weights for each part. The GaBi software was the foundation upon which EcoSTEP was developed. Preliminary and master models were built, and I-Report, an extension of the GaBi software, served as the interface between the user and the model. This interface allows designers to enter design specifications for up to seven different shoes, including materials and their respective amounts for shoe uppers, reinforcements, linings, accessories, and soles. The interface also allows designers to select the assembly process under consideration.

Once Deckers' employees enter designs into the model, the elementary flows, or the waste and pollution generated, are calculated for the life cycles of each pair of shoes. These flows are translated into five specific impact potentials, which the designer can understand through an easy-to-read output display. Designers can choose to view the impacts of one pair of shoes or to compare impacts of multiple pairs to aid their decision-making processes during shoe design.

To maximize the options for designers in this predictive model, assumptions regarding material weights, logistics, and manufacturing processes were necessary. To test these assumptions, sensitivity analyses were conducted, ensuring the relative accuracy of EcoSTEP and justifying the assumptions. EcoSTEP results were logical and comparable to past LCAs of Simple Shoes' products (Albers et al., 2008).

The output of the model includes five potential environmental impacts: Global Warming (GWP), Human Toxicity (HTP), Acidification (AP), Freshwater Ecotoxicity (FEP), and Eutrophication (EP). These five characterization factors were selected because they cover a wide variety of impacts on multiple spatial scales. For example, these impacts include climate change through greenhouse gas emissions, human health degradation through the release of toxins into the atmosphere, damage to land through the deposition of acid rain, and death of aquatic organisms caused by harmful substances entering freshwater systems. These impacts were found to be most relevant to shoes, making them important to Deckers.

Using EcoSTEP, Deckers' designers can incorporate quantified environmental burdens into their designs. As designers continue to use this model over time, they will learn specifically how shoes can be altered to reduce Simple Shoes's environmental footprint. A few guiding principles have already been noticed during the creation and testing of the model. First, materials derived from livestock should be avoided. A sneaker composed of leather or wool may have several times the potential impacts of a sneaker composed of hemp. Second, contradicting conventional knowledge, a cold cement assembly process is less energy intensive than vulcanization. Data shows that cold-cementing a pair of shoes uses 35 MJ of energy, where vulcanization uses 18 MJ. Third, some natural materials, such as natural rubber, that are thought to cause less environmental damage through cultivation can actually be more harmful then synthetic materials. For example, natural rubber production creates a larger eutrophication potential than synthetic rubber because of the fertilizers used for its production.

Many more conclusions are expected to be found through extended use of the model and will hopefully be incorporated into footwear production by Simple Shoes designers. Demand for shoes, especially by American consumers, is expected to continue to increase, causing a surprising amount of harm to the earth. However, if quantitative results from EcoSTEP help designers learn the specific impacts of various designs, harm from Simple Shoe production will decrease. EcoSTEP has potential for industry-wide mitigation of environmental damage due to shoe production.

ACKNOWLEDGMENTS

We would like to thank the following people for their guidance, expertise, time, and energy throughout this project. From our client, Deckers Outdoor Corporation: Mark Fegley, Abigail Nugent, Ron Hillas, and Darrien Peoples for their technical expertise and gracious availability, and Jun Hadap, our contact at the China office.

We would also like to thank the following people from the Donald Bren School of Environmental Science and Management at the University of California, Santa Barbara for their assistance: Roland Geyer, Brandon Kuczenski, Jeff Dozier, Lee Hannah, Trish Holden, and the entire Bren Administrative Staff.

From PE Americas, we would like to thank Peter Canepa and Liila Woods, who assisted with our model creation, results, explanation, and software purchasing and logistics.

We would like to extend a special thanks to our faculty advisor Sarah Anderson for her guiding support during this project. Finally, we are extremely grateful for the help, time, and patience of Chris and Benjamin Utley.

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ACRONYM GUIDE

AP – Acidification Potential (in SO_2 equivalents)

CFC – Chlorofluorocarbons

CML – Institute of Environmental Sciences

DCB - Dichlorobenze

EcoSTEP – Simple Tool for Environmental Prediction

EP – Eutrophication Potential (in PO_4 equivalents)

EVA - Ethylene vinyl acetate

FAETP – Freshwater Aquatic Ecotoxicity Potential (in DCB equivalents)

Flippee – basic flip-flop sandal designed and manufactured by Simple Shoes

GWP – Global Warming Potential (in CO_2 equivalents)

HTP – Human Toxicity Potential (in DCB equivalents)

IPCC – Intergovernmental Panel on Climate Change

IA – Impact Assessment

ISO – International Organization for Standardization

LCA – Life Cycle Assessment

LCIA – Life Cycle Impact Assessment

PET - Polyethylene terephthalate

PLM – Product Life Cycle Management

PU - Polyurethane

Satire – low-top sneaker designed and manufactured by Simple Shoes

TMS – Toyota Motor Sales

DEFINITIONS

Acidification: The ability of certain substances to build and release H+ ions resulting in acid rain.

Cold Cement: A process to attach the shoe upper onto the shoe last using water-based glue. Considered to be more energy intensive per pair than vulcanization.

Die-Cut: A footwear manufacturing process involving cutting out of the material for a sole, similar to a cookie-cutter. The upper is then attached to the sole and attached to the upper in the same way as for the vulcanized and cold cement shoes.

Disassemble: Break or take apart into its separate material components and can be performed either by hand or by machinery.

Elementary Flows: Natural resource extracted or released directly to the environment with little or no human transformation.

End-of-Life (EoL): Footwear that has reached the end of its use phase as determined by the end user. EoL shoes can still be in functional condition.

Environmental Impact: The effect on the environment from the production of footwear at any stage along its supply chain. Environmental impacts can occur to the land, water and air and be a result of byproducts, waste and or intense resource consumption.

Environmental Impact Category: A class of environmental issues for which life cycle inventory analysis results may be assigned.

Eutrophication: An increase in the concentration of chemical nutrients in an ecosystem an extent that increases the primary productivity of the ecosystem. Depending on the degree of eutrophication, subsequent negative environmental effects such as anoxia and severe reductions in water quality, fish, and other animal populations may occur.

Freshwater Aquatic Ecotoxicity: Pollutants in aquatic ecosystems impacting that system's organisms, populations, and communities.

Functional Unit: Quantified performance of a product system for uses as a reference unit in a Life Cycle Assessment study.

Global Warming: The progressive gradual rise of the earth's surface temperature thought to be caused by the greenhouse effect and responsible for changes in global climate patterns.

Human Toxicity: a unit of chemical released into the environment, is based on both the inherent toxicity of a compound that could harm human health.

Intermediate Flows: Material or product that is considered valuable in the product system, and thus transformed and transported along the supply chain.

Landfilling: A method of solid waste disposal where the waste is buried in a low level site with other refuse.

Life Cycle: Consecutive and interlinked stages of a product system, from either raw material acquisition or generation from natural resource to final disposal.

Life Cycle Assessment (LCA): A technique that compiles an inventory of relevant inputs and outputs of a product system; evaluates the potential environmental impacts associated with those inputs and outputs; and interprets the results of the inventory and impact phases in relation to the objectives of the study.

Life Cycle Inventory Analysis: Phases of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Organic: The term organic is based on ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that minimizes or eliminates the use of manufactured chemicals.

Recycling: To treat or process, used or waste materials, so as to make suitable for reuse.

Reference flow: Measure of the outputs from processes in a product system required to fulfill the function expressed by the functional unit in Life Cycle Assessment.

Supply Chain: A system of organizations, people, activities, information and resources involved in moving shoes from suppliers to end users. The supply chain activities transform raw materials and components into a finished product that is transported and delivered to the end user for use and then disposal.

Sustainable: relating to a method of extracting or using a resource so that it is not depleted or permanently damaged.

Vulcanization: An initial process to attach the shoe upper onto the shoe last that, involve large ovens, is not as energy intensive as the cold-cement manufacturing process.

1. BACKGROUND INFORMATION

In February 2010, the average Bren student surveyed had 15 pairs of shoes.[4] Assuming that each pair of shoes generates approximately 15 kg of CO_2 through its life cycle,[5] the total CO_2 emissions resulting from the production of shoes in American closets is roughly 67 million metric tons.[6] This amount is slightly higher than the annual CO_2 emissions of the entire country of Finland (United Nations Statistical Division, 2009).

Besides the impact of greenhouse gas emissions, typical footwear manufacturing uses environmentally harmful materials such as synthetic rubbers, chromium tanned leather, and chemical-based adhesives (Albers et al., 2008). The production and disposal of these materials contributes to greenhouse gas emissions in the atmosphere, as well as toxic pollutant production and dispersal that can be harmful to human and ecosystem health (Albers et al., 2008). Moreover, the number of shoes purchased by consumers in the United States has increased by more than 200 percent since 1980 (AAFA, 2006), signaling that consumer demand will continue to increase. Within the same time frame, the percentage of outsourced footwear production for U.S. consumption has increased from 50 percent to nearly 99 percent. China alone manufactures 85 percent of this outsourced footwear (AAFA, 2006). This dramatic increase in outsourcing of manufacturing produces a significant environmental footprint. This outsourcing has resulted in the shift of the environmental burden to developing countries that tend to exhibit lax environmental regulations or a lack of compliance (Cote-Schiff et al., 2009).

Concurrently, American consumers have become more aware of the environmental impacts of their consumption habits, which have driven companies to become more environmentally responsible (Hoffman, 2000). As a consumer-driven industry, apparel companies have been receptive to the idea of the sustainability of products and business practices. This stewardship helps companies by attracting environmentally conscious consumers and minimizing risks and liability from environmental regulations. For example, one major benefit is customers' increased willingness to pay for the differentiation of the product due to a company's visible environmental policies (Reinhardt, 1998). Improved employee retention rates, higher employee productivity, and recruitment of better quality employees are other benefits of an environmentally proactive business style (Hoffman, 2000). Risks for companies are minimized by preempting regulations, increasing barriers to competition through strategic differentiation, preventing liability, and helping government entities design new regulatory structures (Reinhardt, 1998).

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[4] An email request was sent out to all Bren Graduate students asking, "how many pairs of shoes do you have?" There were 94 responses and the average was 15.97 shoes.
[5] The GaBi model was used to calculate the environmental impact of a leather low-top vulcanized sneaker and its impact is used in these calculations.
[6] 15 pairs x 15 kg x 300 million people = 67 million metric tons

By using life cycle assessment (LCA) methodology, companies selling consumer products can incorporate the environmental impacts into their decision-making process and provide reliable environmental information to their customers. In particular, models such as the one designed for Deckers Outdoor Corporation enable environmentally concerned companies to reduce their environmental impact while still remaining competitive in the marketplace.

2. DECKERS OUTDOOR CORPORATION

Deckers Outdoor Corporation, based in Goleta, California, is a shoe company that owns six brands: Ahnu, Teva, Tsubo, Simple Shoes, Ugg Australia, and Deckers's own line of shoes. Deckers' management strives to make the company an industry leader in environmental responsibility among shoe companies as exhibited by their Simple Shoes brand. Simple is a line of fashion shoes that has the goal of making products "100 percent sustainable" (Simple Shoes, 2009). The shoes in this line are composed of materials thought to have lower environmental impacts than conventional materials, such as organic cotton and hemp. In addition, Simple Shoe managers have considered a variety of recycling and take-back programs while remaining cost competitive in the market (Derby 2008). Finally, Simple management has aimed to quantify the environmental impacts caused by their manufacturing by conducting LCAs on three shoe designs (Albers et al., 2008).

To reduce their environmental harm, Deckers' needed a reliable way to incorporate environmental impacts into their shoe designs. However, impacts of products have traditionally been assessed after manufacture when some impacts have already occurred. If designers knew the impacts of alternative styles and materials while designing shoes, they could use that knowledge to make informed decisions that could subsequently reduce the impacts of shoe production. To accomplish this goal, Deckers' management approached the Bren School for assistance in creating a model that could predict the environmental impact of a pair of shoes during the design phase.

3. PROJECT OBJECTIVES

The goal of this project was to create a model that would allow designers to quantify the environmental impacts of shoes prior to production using the best available methodology. This model enables Deckers to incorporate environmental impacts into their decision-making processes while designing shoes. If Deckers' designers consider predicted outputs, the environmental impacts of Simple Shoes' production can significantly decrease.

4. Project Approach and Software

In order to quantify the environmental impact of shoes, this project uses a life cycle assessment (LCA) approach. LCA is the "compilation and evaluation of the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle" (ISO 14040). This tool is used to analyze the environmental burden caused by each life stage of a product – from extraction of resources (cradle), through the production of materials, product parts and the product itself, through the use of the product, and to the product's end of life (grave) (Guinee, 2001). An LCA can determine numerous environmental impacts in a quantitative manner while identifying problematic parts of a product's life cycle. It can also compare different modifications to an existing product. However, it is rarely used to predict the environmental impacts of products because it was originally designed for retrospective use only (Guinee, 2001). For more detail on LCA, see Appendix B.

Two previous Bren School group projects helped to define the approach for creating a model that can predict environmental impacts. In 2008, a Bren School project conducted an LCA to evaluate the impacts of three Simple Shoe designs in comparison to a conventional leather shoe. This project verified that Simple's alternative materials were indeed more environmentally benign than conventional materials (Albers et al., 2008). The same year, another group project designed an LCA model for Toyota Motor Sales (TMS). In contrast to the 2008 Simple Shoes project, the Toyota group created a user-friendly LCA model to predict the environmental impacts of alternative packaging options. Drawing upon these two projects, a predictive LCA model for shoes was determined to be the best way to achieve the project goals.

Predictive LCAs inform designers of accurate and quantitative LCA results for any change to a product design prior to manufacture and before any environmental impacts have occurred. The 2008 Bren TMS project designed a tool called the *Environmental Packaging Impact Calculator (EPIC)* which gave three different result outputs: a life cycle cost comparison, an environmental indicator comparison, and a table listing substances of concern. The complex results are simplified for TMS into the company's five "Areas of Concern:" Climate Change, Resource Depletion, Human Health and Toxicity, Air Pollution, and Substances of Concern. The user-friendly EPIC calculator allows packaging engineers to enter readily available information and receive LCA results, as well as the life cycle cost.

Following the two previous Bren projects, the LCA for this project was completed using PE International's GaBi4 software, the prominent tool for conducting LCAs. To make the model simple to use, I-Report, an extension software of GaBi, served as the interface between the model and the designer. GaBi is essentially a library of data files that contain the input and output flows of thousands of processes which track environmental impacts. This database allows many different products and services to be modeled. Processes can range from material production, power generation, transportation, and end-of-life activities. The model was built by connecting the appropriate processes to allow for the intermediate flow (product components) to move along the product life cycle accurately.

Description of Deliverables: The final deliverables given to Deckers management and designers are as follows:

- EcoSTEP: Using expertise and resources from the Bren School and Deckers, this project created a predictive LCA model called EcoSTEP (Simple Tool for Environmental Prediction). This model was intended for use during the design phase, *prior* to manufacture, to inform designers of the predicted, quantitative environmental impact of any shoe design. With this information, they can alter the design to reduce the environmental impact.

- User's Guide: A User's Guide (See Appendix A) was presented to Simple Shoes designers to ensure that they understood how to use the model, why certain inputs were chosen, and how to interpret the outputs of alternative designs.

- Final Report: Deckers management also received this final report. This report allowed Deckers' employees to understand how the goal and scope were determined, how the project was conducted, what assumptions were made, and the value of EcoSTEP to the company and to the shoe industry.

5. Life Cycle Assessment in Practice

5.1 Background

With growing concern over resource scarcity, greenhouse gas emissions, waste accumulation, and pollution, many companies worldwide are seeking to decrease the environmental impacts of their supply chains and business practices. These activities are an important component of the international movement to protect the environment. The environmentally friendly practices demonstrate to customers and investors that companies are concerned about business and product sustainability and that they have taken steps to reduce their impacts (Cote-Schiff et al., 2009). Life cycle assessment (LCA) has become an important tool to assist companies in these environmental efforts.

5.2 Strengths and Weaknesses of LCAs in the Apparel Industry

Companies of all sizes that have sought to quantify the environmental impacts from their products and to improve their environmental responsibility have used LCA tools. Apparel companies such as Levi Strauss & Company, Patagonia, and Nike have demonstrated that LCA can be used as an approach to calculate environmental impacts in their industry. However, while LCA proved helpful with providing information necessary to evaluate the impacts, these studies conducted by Levi Strauss & Company, Patagonia, and Nike had many shortcomings including: a lack of quantitative data, analyses conducted after the product was already in production, limited environmental impact categories, or a focus on activities outside the company's control. Deckers shares these companies' desire to display environmental stewardship using LCA and hopes to capitalize on the strength of previous approaches, while improving on their weaknesses.

Nike has become an environmental leader within the footwear industry. Nike aims to use more environmentally benign materials, to reduce CO_2 emissions, to use innovative chemistry to eliminate toxins, and to create closed-loop products and business models (Nike, 2009). In addition, the company is committed to reducing waste across its entire supply chain. Nike created the "Reuse-A-Shoe" program, which administered the collection of retired footwear and the production of new products from the remains. Such products have included running tracks, sports fields and courts, and playgrounds. Although Nike is using a life cycle approach to reduce the various impacts of their footwear, there is no evidence that they have conducted an actual LCA. Therefore, Nike management cannot know the specific, rigorous impacts of individual products. Without this knowledge, there is no way to quantitatively assess the success of their environmental efforts. Despite Nike's current commitment, the benefits from its efforts can often be anecdotal and inaccurate, and rigorous analyses may show that the changes have little to no benefits. A model similar to the one designed for Deckers would help Nike to evaluate the environmental impacts in a more quantitative manner.

In the apparel industry, Levi Strauss & Company has conducted retrospective but quantitative LCAs to measure the cradle-to-grave (from resource extraction to disposal) global warming potential caused by energy and water consumption for two products: Levi’s 501 Jeans and Dockers Original Khakis. From the study, Levis concluded that the most harmful phase of both products’ life cycle is consumer use due to washing and drying the pants (PE Americas, 2008). The information gained from these LCAs was informative but the Levi model only assessed the potential for climate change caused by these pants; many other kinds of impacts may have been caused by their manufacture. In contrast, the model for Deckers will include five different environmental impact categories to evaluate broader impacts.

As another environmental leader within the apparel industry, Patagonia’s “Footprint Chronicles” use LCA to compare the impacts of several products and communicate each product’s environmental strengths and weaknesses to the public. This analysis is valuable because it communicates transparent details about their products to consumers. Patagonia has also aimed to incorporate the LCA results in the mitigation the product impacts. However, the LCAs conducted were retrospective, meaning that the environmental impacts of making the products already occurred prior to the assessment. Patagonia and Levi have both been motivated to increase environmental responsibility of their products and supply chain using knowledge gained from LCA. However, the assessments were retrospective. In contrast to the Patagonia and Levis LCAs, the model developed for Deckers will predict the environmental impact of shoes and can be used to reduce the impacts before they occur.

The boundaries for the Patagonia and Levi LCAs focused on parameters that were beyond the control of a designer. In order to minimize the replacement of their shoes, Patagonia’s *Sugar & Spice Shoes* are made of detachable components held together using minimal glue. If one component wears out, an owner can replace it without buying a whole new shoe. However, because this practice is new to the industry, Patagonia has not been able to develop an infrastructure with their suppliers to accomplish recycling of the individual parts (Patagonia, 2009). Similarly, the results from the Levi LCA identified the use phase as the largest contributing factor to environmental impact. This discovery may have prevented some motivation to increase environmental responsibility of their products and business practices. Although Levis learned about the life cycle of their pants, the LCA did not result in any major change in their supply chain practices. The model built for Deckers includes the infrastructure required throughout the supply chain but does not focus on these processes since they are not within the control of a designer. The boundaries for the Deckers model were defined to exclude the use phase completely since the designers do not have control over the consumption of their products. This set of boundaries and model assumptions allows designers to focus on reducing the impact of phases that they can control.

As mentioned above, the current Bren School project for Deckers addressed the shortcomings of previous studies assessing environmental impacts. Most importantly and in contrast to Nike, the model designed in this project is based on quantitative process data from the Simple Shoes supply chain. In addition, the model includes various materials that have been used or might someday be used through the Simple Shoes supply chain. Also, this project assesses five separate impacts and is able to justify why those five were chosen. The boundaries for the LCA were defined based on what parameters the designers could influence such as material choice or production process, rather than parameters beyond their control such as the use phase. The most innovative aspect of this model is that it is predictive. Rather than conducting an LCA on products that are already being manufactured, the model will allow designers to modify the shoes in a way that will reduce the environmental impact. With a predictive model, initial environmental impacts of samples or existing shoe lines with a high burden can be avoided and future designs with high impact potentials can be replaced by those with lower impact potentials.

6. ECOSTEP – SIMPLE TOOL FOR ENVIRONMENTAL PREDICTION

6.1 Goal and Scope Definition

Rather than conduct a retrospective LCA that examines an already manufactured product, the goal of this project was to create a predictive model to determine environmental impacts of products not yet in existence. This model, EcoSTEP, was made for Simple Shoes designers to predict the environmental impacts of different designs.

This analysis was limited to the two shoe sizes in which Deckers typically designs their shoe samples: women's' size 7 and men's' size 9. Deckers sells shoes for children and toddlers but these shoes were not included in the analysis. Most toddler shoes do not have rubber soles and therefore undergo completely different assembly processes. Toddler shoes with soles and children's shoes undergo the same processes as adult shoes. The only difference is in the size and therefore the amount of material used so the overall environmental impact will be lower for the smaller shoes.

Therefore, the **functional unit** of this LCA is: *to protect women's' size 7 or men's' size 9 feet for two years.*

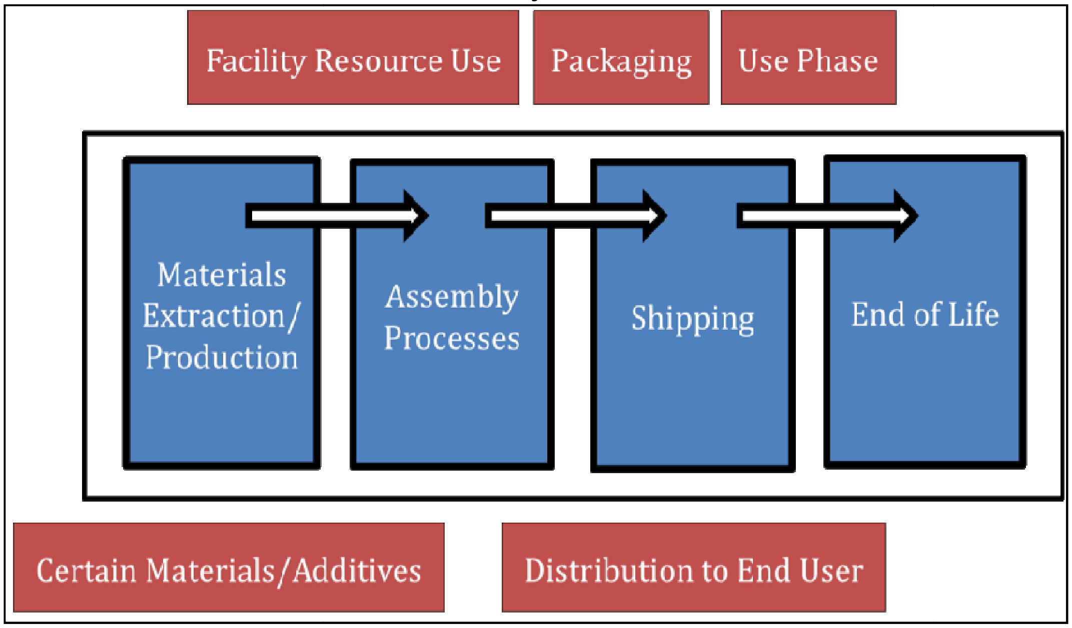
The **scope** of the LCA includes manufacturing processes, logistics, and disposal; however, the project focuses on materials for three reasons: (1) materials are the most variable aspect of designs, (2) materials were proven to be the biggest contributors to environmental impacts of shoes in the 2008 Bren Master's project for Deckers, and (3) designers have most control over this aspect of their designs.

The **reference flow**, or the quantified amount of product necessary to fulfill the function, is variable because the inputs change based on the designer's inputs.

6.2 System Boundaries

Determining the system boundaries of a project is one of the first steps in an LCA since the system boundaries determine which unit processes will be included in the LCA study. The boundaries for this project are depicted in Figure 6.1. Inside the boundaries (the blue boxes) are the material extraction/production, assembly, transportation, and disposal. Specific information on the data used in the model is discussed in detail in the "Methods" section.

Figure 6.1: The system boundary of the LCA drawn as a box around the phases under consideration. Boxes outside the boundary were not considered in the assessment.



The red boxes in Figure 6.1depict the factors that were defined to be outside of the boundaries. Certain materials and additives, facility resource use, packaging, transportation past the distribution center, and the use phase were excluded from the study. Excluded upstream elements such as dyes, innovative materials like beeswax, and biodegradable additives were not included in the boundaries due to a lack of information from suppliers or a lack of processes in the GaBi database. Energy and resource use for the manufacturing facilities themselves was assumed to be constant across all shoe designs and outside of the control of the designer. Furthermore, some of the manufacturing facilities produced shoes for multiple companies and facility resource use could not be partitioned to isolate the effect for a pair of Simple Shoes.

Excluded downstream elements included packaging, distribution to the end user, and the use phase. Packaging was excluded because of a lack of time and reliable data. Transportation past the distribution center in Camarillo, CA could not be determined due to a lack of information. Also, designers do not have influence over distribution networks.

The use phase was not included in the system boundaries because use was not considered to add to a shoe's impact. Since it was assumed that Simple Shoe consumers rarely wash or repair their shoes, this life stage generally has a negligible environmental impact.

6.3 Durability

While some materials, such as leather, have a higher impact than others, they also can increase the life expectancy of the shoe. Depending on the type of shoe, customers may buy replacements for the worn out shoes and create an additional impact. Therefore, shoes with shorter lifetimes may have larger cumulative impacts. The resulting trade-off of either creating a durable shoe or creating a shoe with a lower impact would appear necessary for this model. However, due to the nature of the Simple Shoes Brand and customer behavior, durability was not factored into EcoSTEP when assessing the environmental impact.

The principle reason durability was not included in EcoSTEP was that Simple Shoes are fashion shoes and therefore have life spans limited by style, not durability. Fashion trends in the apparel industry change rapidly. While Simple Shoe designers create their shoes to last for at least two years, it is expected that customers will buy new shoes not because the old ones wear out but rather due to changing fashions (M. Fegley, personal communication, 2010).

The second reason that it was not necessary to include durability as a parameter in EcoSTEP is that designers will be comparing similar shoes with similar design structure. When using the model, designers indicated that they would likely be considering shoe designs with only one or two component changes (M. Fegley, personal communication, 2010). Reinforcements, shoe binding, and other key structural elements will remain unchanged thereby preserving a similar expected shoe lifespan. For example, when comparing a low top sneaker with a cotton upper to a low top sneaker with a hemp upper, the only parameter changing is the upper material; the rest of the shoe will be the same.

Third, there are many possible points of failure in a shoe, which can shorten its lifespan even if it is made of otherwise durable material. The stitching and adhesives of a shoe could fail before the material is worn through, even if the rest is made of strong leather. If the adhesives fail, then the shoe will likely be replaced, even though the leather material is still usable. Consequently, making a shoe with more durable material does not guarantee the shoe will have a longer lifetime.

Finally, the way in which a customer uses a shoe is a major variable for durability. The same shoe can degrade slowly if its owner only wears it occasionally or it can degrade rapidly if used for rigorous hikes. While any shoe can eventually wear out, Deckers cannot control when and how that will happen. Deckers attempted to obtain information about their shoes' durability through a customer survey but there was too much variability in shoe use to draw any clear conclusions (M. Fegley, personal communication, 2010).

With little quantitative data about durability of materials available, the unpredictability of how customers use the shoe and ever-changing fashion trends, quantifying the durability was beyond the scope of this project. Moreover, given the intended use of the model by designers in comparing relatively similar shoes, its effect is expected to be minimal.

6.4 Allocation

One difficult and controversial issue in LCA is called allocation, which addresses the problem of assigning environmental impacts to different products. For example, the Simple Shoes brand uses recycled car tires for shoe soles. This raises the question of whether to allocate the entire environmental impact of rubber, none of the impact, or some of the impact to the shoe sole. Allocation is important to take into consideration because allocation dictates what environmental burdens are associated with manufacturing a product.

In technical terms, allocation is the partitioning of the total environmental burden to the system boundary under assessment (ACLCA, 2009). When an industrial activity results in multiple product outflows, the total impact must be divided among the different flows. For EcoSTEP, allocation was addressed for two different types of processes: recycling and co-production.

Simple Shoes utilizes various reused and recycled materials in their designs, such as car tires, tire tubes, and recycled rubber. Reused or repurposed shoe components require little to no energy or material inputs to transform them into a usable state. For these components, the model does not attribute the environmental impact of their production to the shoes. In contrast, recycled materials require considerable reprocessing inputs, thus the model accounted for their recycling activities whenever the data was available in GaBi. Plastic recycling requires multiple steps such as grinding, washing, and re-pelletizing. Therefore, the environmental burden of plastic recycling was attributed to EcoSTEP. Unfortunately, information for other recycled materials that Deckers utilizes, such as recycled rubber was not available so it was not included in the model. Only the environmental burden of transporting the rubber is included in the model.

If the use of the recycled material offsets the production of virgin materials, it is common to credit the system for this elimination (Fernandez, 1997). However, in the EcoSTEP model, the use of recycled materials was not considered to displace any virgin production of tire rubber since it was assumed that the tires would be produced regardless of the presence of Simple Shoes products (Albers et al, 2008). Consequently, only the environmental burden of transportation was allocated to car tire soles and no environmental credits were given in the system for the displacement of rubber. The virgin manufacturing and the recycling burdens were not included in the model. The environmental burden of the virgin tire rubber production was allocated to a product chain outside the system boundary of EcoSTEP.

Another allocation problem arises in the use of such products as allocation of the environmental burden of raising livestock animals. Cattle, when slaughtered, produce many economic goods: meat, tallow, leather, and biomass for fuel conversion. The proportion of the environmental impact of raising cattle allocated to produce shoe leather must be determined. The GaBi process on leather allocates the environmental burden by considering the economic allocation, largely between food and leather (P. Canepa, e-mail correspondence, 2009). Similarly, the process for wool is allocated in proportion to the economic value between of wool and lamb meat (ecoinvent, 2007).

6.5 Characterization Factors

EcoSTEP results are displayed in five distinct characterization factors. These factors include Global Warming Potential over 100 years (GWP100), Human Toxicity Potential (HTP), Acidification Potential (AP), Freshwater Aquatic Ecotoxicity Potential (FAETP), and Eutrophication Potential (EP). These factors were developed by the Institute of Environmental Sciences (CML). CML characterization factors were chosen because CML is a well-respected institution and the model results could be compared to those of the 2008 Simple Shoes project.

Characterization factors convert and combine the study results into representative indicators of impacts to human and ecological health. These factors, also called equivalency factors, translate different inventory inputs into directly comparable impact indicators. For example, characterization would provide an estimate of the relative terrestrial toxicity between lead, chromium, and zinc. However, the entire decision cannot be made based completely on scientific analyses. For example, natural rubber production has a lower GWP than synthetic rubber production, but a higher EP and AP. The designer must choose which impact is more important from Deckers's perspective.

The five specific characterization factors were selected for four reasons. First, they cover impacts on three spatial scales: local, regional, and global. For example, the release of toxins into the atmosphere affects human health on a local scale, damage to land through the deposition of acid rain is regional, and climate change through greenhouse gas emissions is global.

The second reason why these characterization factors were chosen is that they cover a wide range of impacts. These impacts include negative effects on humans through HTP, on water through EP and FAETP, on land through AP, and on air through GWP. By including these impacts, the designer can evaluate potential effects on a broad range of ecosystems.

Third, Deckers management preferred these factors to others because they are easy concepts for consumers to understand: effects on people, air, water, and land. Ten different characterization factors were originally assessed but the impacts from the five were negligible, and those were therefore excluded. For example, toxicity potentials usually had the most significant impact for each shoe design, but radiation potential never had a large impact.

Finally, these characterization factors were included because they had the most substantial impacts. Simple Shoes' designers can use these factors to determine which features of the product cause the most harm in hopes of mitigating that impact. Deckers's marketing strategy involves covering concepts in a simple manner. Human health, water, land, and air are categorical impacts that fit into this strategy, yet retain adequate scientific meaning and allow designers to choose which impacts matter to them. For details on the characterization factors, see Box 6.1.

BOX 6.1: Characterization Factors	
Acidification Potential (AP)	The primary contributors to the impact category of acidification (AP) are NO_x and SO_2 which bond with water molecules to form their respective acids: H_2SO_4 and HNO_3. This interaction leads to a decrease in the pH of precipitation entering ecosystems (acid rain). The midpoint of this impact is acidification of ecosystems, which had potential for direct and indirect damaging affects. However, the potency of acidification of the emissions, the fate and transport of the emissions, and the sensitivities of the ecosystems on which acidic deposition falls can alter the resulting effect. Category endpoints of acidification are loss of biotic and abiotic natural environments, and loss of biotic and abiotic manmade resources. Acidification potential is measured in SO_2 equivalents (Guinee et al., 2001).
Eutrophication Potential (EP)	Eutrophication is defined as excess nutrients in a particular system and is expressed in PO_4 equivalents. Nitrogen and phosphorus are essential elements in aquatic ecosystems and are used by plants and algae for growth. However, excess nutrients can lead to increased algal production, which die and deplete oxygen in the water body needed by fish and other animals. This creation of an anoxic environment is the category midpoint. Eutrophication can result in an endpoint of fish mortality and completely altered biological assemblages (NOAA, 2008).
Freshwater Ecotoxicity Potential (FETP)	Freshwater Ecotoxicity is toxicology concerned with the study of toxic effects measured in dichlorobenzene (DCB) equivalents, caused by natural or synthetic pollutants, to biological, chemical, or physical stressors that effect aquatic (not marine) ecosystems. Such stressors might occur in the natural environment at densities, concentrations or levels high enough to disrupt the natural biochemistry, physiology, behavior, and interactions of the living organisms that comprise the ecosystem. These harms are the midpoint of freshwater ecotoxicity potential. The category endpoint is a loss of biodiversity (USEPA, 2009).
Global Warming Potential -100 years (GWP100)	Global Warming Potential is a measure of how much of a given greenhouse gas is estimated to contribute to the impact category of climate change, measured in kg CO_2 equivalents with a 100-year time horizon. Global warming is expedited by the emissions of greenhouses such as CO_2, CFCs and CH_4 that are trapped in the earth's atmosphere. Short wave solar radiation that reaches the earth is reflected as long wave radiation and may be trapped by the existing greenhouse gases in the atmosphere. This leads to a midpoint of increased average global temperatures and sea level rise. An endpoint of global warming that affects humans is loss of community and biodiversity (Guinee et al, 2001).
Human Toxicity Potential (HTP)	The human toxicity potential is a calculated index that reflects the potential harm of a unit of chemical released into the environment. It is based on the inherent toxicity of a compound and its potential dose. Total emissions are evaluated in dichlorobenzene (DCB) equivalents. The potential dose is calculated using a generic fate and exposure model, CalTOX, which determines the distribution of a chemical in a model environment. This model accounts for a multiple exposure routes, including inhalation, ingestion of produce, fish, meat, and dermal contact with water and soil. Toxicity is represented by the cancer potency $q1*$ for carcinogens and the safe dose for noncarcinogens. (Hertwich et al, 2001).

7. METHODS/INVENTORY ANALYSIS

7.1 Data Collection

Inventory analysis is the phase of LCA and involves the compilation and quantification of inputs and outputs for a given product system throughout its life cycle. Data collected is an important part of this phase because the accuracy of the results of any LCA is dependent on the quantity and quality of the data collected. This project involved the collection of data on footwear transportation, manufacturing, materials, and disposal. Data was gathered from experts in manufacturing, from experts in materials, and by examining shoe samples.

7.2 Transportation

Transportation information was gathered from Deckers Management for the Simple Shoes supply chain. The model included specific data on the Simple Shoes product lifecycle once the shoes are made in the factory. Simple Shoes are shipped from the Chinese assembly facility to the Long Beach Harbor in California via a container ship. The shoes are then transported to a distribution warehouse in Camarillo, California via truck. The shoes remain in Camarillo until they are shipped to the customers. Deckers supplied information on the suppliers, ports, and modes of transportation used to ship shoes. From there, Google Maps was used to find the distance from town center to town center along each segment of the supply chain. Transportation by land was assumed to be by truck and all sea shipping was assumed to be by container ships.

While GaBi assumes European emissions standards, the Simple Shoes trucking occurs in California. According to DieselNet, the federal emissions standards for model year 1994 are comparable to European emissions standards Euro II (DieselNet 2007). Therefore, it is reasonable for the model to use the European standards. Upstream transportation before the assembly point was not included because the GaBi process for fabric weaving is a *cradle-to-gate* process, which means that it already includes all transportation required to transform fibers into fabric (Dupont 2007). See Appendix F for transportation assumptions.

7.3 Manufacturing

The model incorporates three assembly processes: die-cut, vulcanization, and cold cement. Although in reality the assembly processes vary depending on the design or material composition, all Simple Shoes shoe models fall broadly within these three assembly process categories. For detailed information on the assembly processes see Box 7.1.

Data on manufacturing inputs for the processes was requested from Deckers's shoe factories. Specifically, information regarding energy use required for shoe assembly was requested and later inserted into the model. This data included the energy inputs for the following phases in all three manufacturing processes: bottoms preparation, bottom stock-fitting, cutting, stitching, lasting, bottoming and assembly, and finishing.

The additional inputs (such as needles, filters, and bulbs) were not included in the model because the impact per pair of shoes did not impact the results. For example, 18 needles per year are used in one stitching process. When this is spread over the approximately 4900 shoes produced over the year, the impact of the needles is negligible. For detailed information on assembly inputs included in the model, see Appendix F.

BOX 7.1: Description of Shoe Manufacturing and Assembly Process

Three basic manufacturing processes are used for Deckers's shoes: **vulcanization**, **cold-cement,** and **die-cut**.

Cold cement and vulcanization share the initial processes of cutting, stitching and lasting. However, the rest of the processes are different for vulcanization and cold cement.

For both cold cement and vulcanization, the material for the upper is cut and sewn to form the upper, which is then sewn onto the insole lasting board. At this point in the manufacturing process the shoe has the correct shape but lacks form and rigidity. The shoe requires mechanical force to stretch the shoe and give it structural strength. A machine is used to stretch the shoe over a foot-form mold, which is made out of heavy plastic for cold cement shoes and out of aluminum for vulcanized shoes.

The outsole preparation is more complicated and energy intensive for a cold cement shoe than for a vulcanized shoe. The outsole on a vulcanized shoe needs only be cut and buffed. In contrast, the outsole of a cold cement shoe must undergo multiple upper and sole preparations. The bonded surface must be roughed and the rubber sole must be primed before the outsole is attached. Once the adhesive is applied, the entire outsole is dried in an oven and then cooled. In addition, all ethylene vinyl acetate copolymer resin (EVA) must undergo ultraviolet treatment.

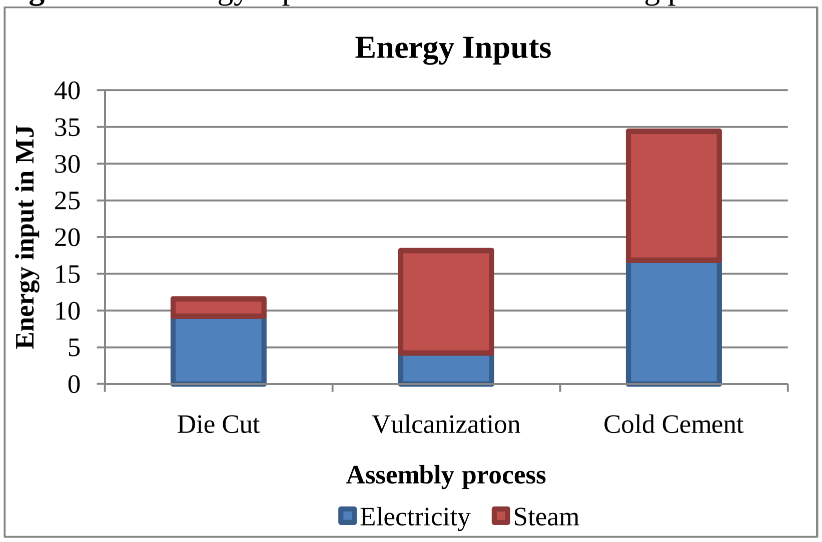
The outsole is glued on while the shoe is still on the last for both vulcanization and cold cement. However, the mechanisms of bottoming and assembly and finishing are different for the two processes. In vulcanization, once the lasted upper has been attached to the outsole, raw rubber foxing tape is attached to the vulcanized shoe. The unit is then put through an "autoclave machine" and is heated at 115˚C to 120˚C for one hour to cure the raw rubber foxing tape. The shoe is allowed to cool in fresh air. The cold cement curing process is completely different. Once the lasted upper has been attached to the outsole, a cold cement shoe is passed through a series of machines. The shoe goes through the heating channel for five to eight minutes and then into the cooling channel for fifteen to twenty minutes.

Die cut shoes undergo the simplest manufacturing and assembly process. The sole is simply cut out of the material, similar to using a cookie-cutter. The upper is then attached to the sole in the same way as for the vulcanized and cold cement shoes.

Source: Abigail Nugent, personal communication

The model includes two forms of energy into each of the three assembly and manufacturing processes: energy from the electrical grid and energy from the conversion of coal to steam (Figure 7.1). The energy inputs for both sources were based on the average energy mix profile in China. The manufacturing and assembly data is specific to the Deckers factories which increases the accuracy of the model. If the manufacturing processes change or Deckers moves to a different factory, the model would lose accuracy.

Figure 7.1: Energy inputs into three manufacturing processes.



7.3.1 Cold Cement and Vulcanization Energy Inputs

The finding that the cold cement process requires significantly higher energy inputs was unexpected. At the beginning of the project, it was assumed that cold cement was more environmentally friendly than vulcanization. This belief resulted from the expectation that the energy requirement to heat the vulcanized shoes in ovens for an extended period of time would be higher than the eight minute heating process and twenty minute cooling process used for cold cement shoes. Once the data was collected, the complete cold cement process clearly required significantly more energy than the vulcanization process. The high energy input required to prepare the sole layers for adhesion was the main driver of electricity use for cold cement shoes. This results in a higher environmental impact of cold cement shoes when compared to vulcanized shoes, which was counter to conventional wisdom.

By quantifying energy inputs, the environmental merit of vulcanization was discovered. This finding highlights the importance of using specific and detailed data to make decisions. Rather than assuming that one process will have a more significant environmental impact than another, based on qualitative observations, a survey of quantitative input data can lead to counterintuitive ways to reduce environmental impacts.

7.4 Materials

In order to design EcoSTEP, detailed quantitative and qualitative information about the materials and the shoe design was needed to ensure that the calculations were accurate. The quality of the results is limited by the quality of the input data, therefore a significant amount of time was spent collecting and verifying the information. Deckers supplied shoe specification sheets (spec sheets) about the variety of materials used for Simple Shoes, cutting losses in the manufacturing processes, and the different methods of manufacturing (for the complete list of textiles and rubber products incorporated, see Box 7.2). However, these spec sheets did not supply all of the information necessary to build the model. As a result, various shoe designs and material samples were obtained by Deckers, taken apart, and measured to assess different weights of material in relation to their area.

If there was still no available information regarding a material type, Internet research was performed for the various area weights. These were selected from industrial material sellers' websites intended to be used in industries similar to those of shoes (i.e. apparel). From there, the area and weight for an individual unit of material was obtained and the mass-area ratio was calculated and recorded for each material. In many cases, the densities of fabrics varied depending on the type of fabric or the supplier. In these cases, an average ratio for surface area to weight was calculated for each material. For example, although cotton canvas is denser than the cotton used in the linings, the same ratio was used for both materials. This assumption makes most calculations more accurate but the designer should use caution when he or she knows that a particularly heavy form of the material is being used.

The inventory analysis did not include detailed data for the primary processing of material inputs. The model uses GaBi process data for all of the materials until they reached the assembly facility. This was deemed to be acceptable because Deckers changes its suppliers frequently and therefore the information would likely become obsolete within a year. A single process was used for fabric production of all fibers, natural or synthetic. This single fabric process was considered to be an appropriate proxy for all fibers in the model (P. Canepa, personal communication, 2009).

EcoSTEP was limited to current and past materials that Simple Shoes has used in their product lines. However, unexpected materials will inevitably be included in the Simple Shoes products that have not been included within the model. In order to increase the lifespan of the model, additional materials that might be used in future shoe designs were also included in the model if feasible. Basic accessories including eyelets, zippers, and buttons were included within the model but future accessories have the potential to vary dramatically and cannot be included within the model. However, the current database was able to incorporate the vast majority of the common materials used in shoes. (For a complete list of processes used, see Appendix F)

BOX 7.2: Materials
Conventional cotton materials are derived from the fibers surrounding cottonseeds. Processing cotton requires separating the fibers from the seeds, cleaning the cotton, carding to align the fibers, spinning into threads, and weaving into fabric. Cotton is often used in shoes and can be found in the shoe upper and sole, as a lining or reinforcement, or as an accessory. Cotton is currently used by Simple Shoes in many of their products.
Organic cotton is processed in the same way as conventional cotton. However, organic cotton avoids use of pesticides, uses natural fertilizers (animal manure), avoids mono-cropping, and maintains soil fertility. Organic cotton is currently used by Simple Shoes in many of their products
Wool used in the Simple Shoes is derived from sheep's wool. The wool is shorn from the animal, then cleaned, carded and spun into wool yarn, which can then be woven. Once off of the sheep, the wool is cleaned, carded, and spun into threads. Wool is mostly used for the shoe upper and is currently used in several Simple Shoes products.
Leather and suede are made from animal hides, the most common of which is from cows. Tanning is required to remove the hair and fat from the animal hide. Conventional tanning processes use many chemicals including chromium. Smooth leather is made from the top of the animal skin, while suede is made from the underside of the hide. Leather and suede are primarily used for shoe uppers in many of the current Simple Shoes models.
Polyethylene terephthalate (PET) is a synthetic material used to make fabrics such as polyester. PET is derived from petroleum and coal and is manufactured through a polymerization and spinning process. PET can be used in shoes as a foam or as a fabric. It can be blended with other fibers to create blended materials. PET can be found in the upper, as reinforcement, a filling, an accessory, or in the soles of existing Simple Shoes designs.
Linen is a derivative of the flax plant, located behind the bark. The linen must be separated from the woody part of the plant, which is a labor-intensive process that is mostly done by hand. Once separated, the fabric is washed and then spun into thread. Linen is used primarily in the shoe uppers in current Simple Shoes models.
Hemp cloth is derived from the stems of the hemp plant. The stems are processed to separate the fibers from the rest of the plant material. The fibers are then processed again to clean them and are then woven into fabrics. The current Simple Shoes designs primarily use hemp in the shoe uppers.
Jute cloth, also known as burlap or hessian, is derived from the outside of the jute plant. Jute is processed by retting, a technique of bundling the plants together and immersing the bundles under running water. After the retting, the fibers are separated from the rest of the plant material and spun into thread. Jute is used primarily in the uppers for Simple Shoe designs.
Rubbahyde is made by pouring latex onto a textile backing material. It is used by Simple Shoes in the shoe uppers.
Bamboo & Lyocell undergo similar processes to create fabric from plants. Lyocell is derived from wood products as opposed to bamboo. For both materials, the fabrics are made by submerging the plants in water until individual fibers separate in the pulp. These fibers are then spun into thread and made into fabric. Lyocell is currently used in Simples Shoes. Bamboo fabrics are not currently used in Simple Shoes but could possibly be used in the future.

Cork is harvested from the outer bark of a cork oak tree. The bark is cut and peeled off the tree. If done properly, the tree is not harmed in the process and can be harvested for as long as 150 years. Once off the tree, cork planks are cured outside then treated with heat and water. The outer layer of cork is scrapped off and the remaining planks are allowed to dry. The cork used in Simple Shoes is generally agglomerated within latex to be used in shoe soles.
Natural latex is derived from the sap of the rubber tree. Technically, latex is the sap from the tree, which is then processed to become **natural rubber**; however, colloquially rubber and latex are synonymous. The growing and processing of natural rubber is a complicated process that takes years, and a great deal of acid. It is collected by cutting slits into the bark and allowing the rubber to flow out. If done properly, the tree is not harmed in the process. Excess water is then taken out of the sap by centrifuging or chemical separation. The rubber is then coagulated using acid and dried. Another acid is added to the rubber to concentrate the rubber further. This rubber solution is then dried and pressed into rubber sheets. In contrast, **synthetic rubber** is made in a chemical process. Latex is used primarily for the shoe uppers and soles of Simple Shoes. There are many different types of rubber. **Polyurethane** is a type of synthetic foam rubber. The **recycled carpet padding** used in Simple Shoes is also made of polyurethane. **Crepe rubber** is made by passing latex through heavy rolls and then air drying the output. The crepe rubber is used primarily in the shoe soles.
Brass & nickel & aluminum are used in the accessories as buttons, snaps, buckles or zippers. Brass is a metal alloy comprised of zinc and copper.
Coconut is used to make buttons in several Simple Shoes designs. Pieces are taken from the husk of the coconut and sanded in order to get the smooth surface.
Nylon is made from synthetic polymers that are manufactured through a chemical process. In the current Simple Shoes designs, it is used for thread and tape; however, it is also included as an upper material possibility in the model.
Ethylene vinyl acetate copolymer resin (EVA) is made through the polymerization of ethylene and vinyl acetate under high temperature and high pressure. It is used primarily for the shoe insoles.
Sources: How Products are Made, Made How, Organic Trade Association, American Baler, JJtradelinks.com, made-in-china.com, WiseGeek, Simple Shoes

7.4.1 Quantitative Data for Innovative Materials

As an innovative design brand, Simple Shoes uses many unique materials and additives that are believed to have a lower environmental impact. These materials include silk, beeswax, and the additive Bio-D used to help soles biodegrade. However, there is no available information that can be used to quantify the environmental impact for many of these materials. Without detailed data, it is impossible to incorporate the life-cycle environmental impact of these materials.

An example of this problem can be seen in trying to include silk into the model. Silk is considered an environmentally friendly product but there is little quantitative data on the environmental impact. In fact, the majority of the existing information on the environmental impact of silk was found in the blogosphere. Silk fabric is made by silk worms which secrete the fibers to form a cocoon. Silk worms only eat leaves of mulberry trees and to produce one kilogram of silk requires approximately 104 kg of mulberry leaves (Fritz and Cant, 1986). Silk worms are sensitive to toxic pesticides and insecticides, which would suggest that this aspect of the silk manufacturing process would be environmentally friendly (Kight, 2009). However, the process of growing and harvesting mulberry trees inevitably has an impact due to fertilizers which could cause large negative environmental consequences, particularly in the eutrophication impact category. Once the cocoons are made, the fibers are either collected humanely once the worms have developed into a moth, or the fibers are collected by killing the worm by either by fumigating or boiling. Although the process has been criticized by numerous animal rights groups, this would not necessarily increase the environmental impact as measured by an LCA analysis. Finally, once the fibers are taken from the worm, they must be processed into a fabric, which requires energy with an associated environmental impact.

This example highlights the complications of evaluating the environmental impacts. Without quantitative data, it is impossible to determine the level of environmental impacts from fertilizers, pesticides, insecticides, the fumigation process, or the fabric manufacturing process. Although silk may have a lower environmental impact than other fabrics in human and freshwater aquatic ecotoxicity, the eutrophication potential of silk could in fact be greater. However, this situation presents an opportunity for Deckers to go beyond material innovation and work with their supply chain to improve the quality of the data. Wal-mart is helping to lead the way in green supply chain management with their Textiles Scorecard Pilot Program (Wal-mart, 2008). By working with their suppliers to increase quantitative data on their supply chain, Deckers could verify the perceived environmental impacts of these products.

7.5 Disposal

The 2008 project examined the end of life phase of Simple Shoes in detail. Rather than repeat their study especially given the lack of shoe recycling programs in the United States, this project simplified the disposal phase. For this model the pair of shoes is modeled to be discarded into a landfill as an “inert” object, with little to no decomposition.

8. BUILDING THE MODEL

There were three significant challenges that were overcome when designing the EcoSTEP model.

1. The GaBi software requires all inputs in units of weight, but the designer is unlikely to have this information. Instead, shoe designers have information on the general shoe design, the types of materials used, and the approximate area needed to cover the shoe. In order to convert the designer's information into weight, the model had to include built-in conversion factors. This required data that could be used to convert surface areas into weights.

2. The underlying GaBi model is complex and difficult to manipulate. Designers have limited time and lack the GaBi expertise needed to use the program. A simplified user interface was developed for the designers to improve the usability of the model. The development of the interface will be explained in Section 10.

3. The goal of the EcoSTEP model was to be a predictive model, which requires that it be able to calculate the environmental impact of any shoe design. In order to accomplish this goal, the model grouped the many shoe components into broad shoe parts, and grouped all shoes into different shoe categories. These will be explained in greater detail in Section 10.

The following sections will describe how these challenges were addressed.

8.1 Calculating Areas

The model relies on precise area measurements in order to convert the design information into weights. Therefore, accurate calculations of upper and sole information were critical. Shoe areas were calculated as accurately as possible using several methods.

8.1.1 Calculating the Area of a Shoe Upper

Method 1: The areas of shoe uppers were calculated using a numerical approximation. The shoe vamp was divided into multiple pieces. The length and height were plotted onto an x-y scatter plot and the area of each piece was estimated using a fourth order polynomial. This equation was then integrated to find the area under the curve. Geometric approximation was used to find the area of the shoe tongue and the shoe toecap. The areas were added together to find the total area of the shoe.

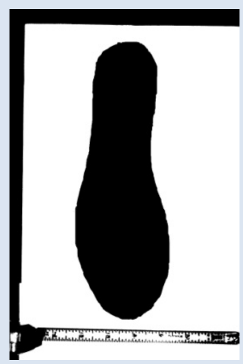
Method 2: In order to verify the accuracy of the vamp calculation, measurements were compared to a digital image calculated using the program ImageJ (http://rsbweb.nih.gov). The program ImageJ is part of the National Institutes of Health (NIH) commons. The calculation was within 5 percent. This method was also used to calculate the area of a women's slipper.

Method 3: There were no samples of women's flats that could be disassembled to get the upper area using either numerical approximation or ImageJ. Flats of non-Simple shoe brands were used instead. A fabric material was wrapped around the shoe upper and was cut out to copy the area of the shoe and the cutouts were weighed. A known area of the fabric was weighed to get the density. This density was then used to calculate the shoe area. An average of two shoes was then taken.

8.1.2 Calculating the Area of a Shoe Sole

The program ImageJ was also used to calculate the area of women's size 7 or men's size 9 soles. Digital images of shoe soles were altered in Photoshop to highlight the difference between the sole and the background. The altered images were entered into ImageJ and translated into binary (black and white) images. The program then calculated the area of the shoe using a measurement on the picture. (Figure 8.1)

Figure 8.1: Example of using ImageJ to calculate the area of a shoe sole.

Digital image	Photoshop image	ImageJ image
		

Areas for seven shoe soles were calculated.

Table 8.1: Areas for the seven soles calculated using ImageJ

Shoe Name	M9/W7	Category	Area of Sole (in^2)
Flippee	W7	Sandal	30.67
Tiptoe	W7	Sandal	32.74
Gladiator-type sandal	W7	Sandal	27.75
Underlay	W7	Slipper	33.71
Satire	W7	Low-top sneaker	26.42
Gum Shoe	M9	House Shoe / Sneaker	43.21
Tuba	M9	Low-top sneaker	33.62

Error check: In order to calculate the consistency of the methods, two pictures were taken of the Flippee sole and the area was calculated twice. The margin of error between these two pictures and calculations was seven percent. In addition, the size of sandal soles will vary slightly among different shoe designs. In order to calculate the variance among different soles, the areas of three different women's sandal soles were calculated with a range of 3 in^2.

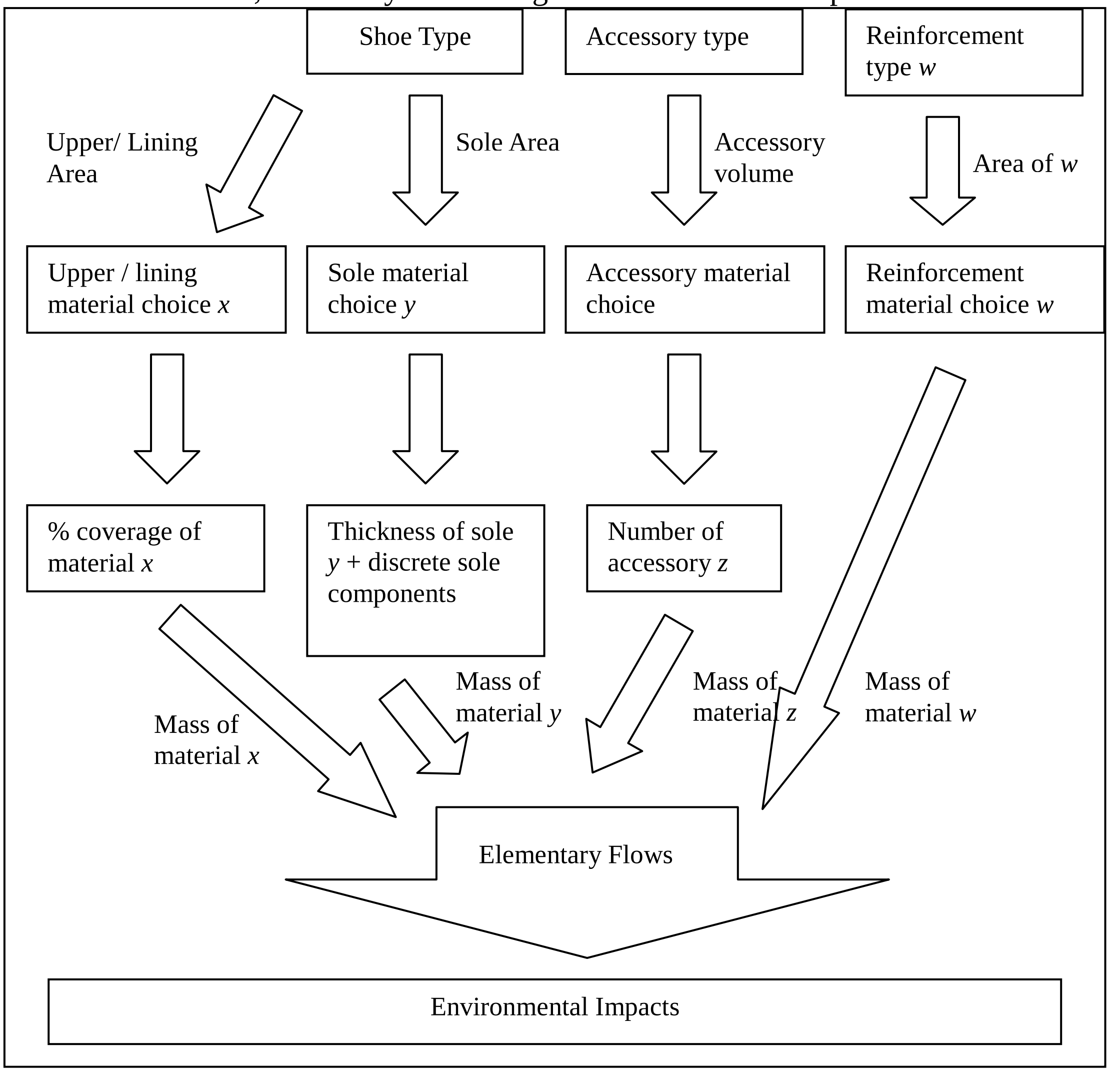
M9/W7 Shoes: There is a significant difference between men's and women's shoes. The sole of a women's Satire is approximately 77 percent that of a men's Tuba. This conversion factor was used in the model to define the area of the women's shoe sole.

Sneakers/Non-sneakers: In general soles were similar; however a relatively significant difference between sneakers and non-sneakers was noticed. Sandals and slippers often had larder soles than sneakers. The ratio of sneaker to non-sneaker was calculated to be 1 to 1.28 based on both the ratio of men's Tuba to men's Gumshoe and the ratio of a women's Satire to a women's Underlay.

8.2 Converting Basic Shoe Information into Mass

As mentioned earlier, one of the main challenges of creating a predictive model was that the information that the shoe designer knows about the material type and area coverage is different from the mass inputs that GaBi requires. Therefore, a series of conversion calculations from area to mass was incorporated into the model. For example, the basic shoe type input affects the upper area calculations, which subsequently affected the conversion to weight. This can be conceptualized as a decision tree of material choice as depicted in Figure 8.2.

Figure 8.2: Flowchart of the user choice (in box) and the consequential values calculated in model, ultimately calculating the environmental impacts of the choices



The boxes indicate the choices that are available to the user and the intermediate arrows indicate the value that the specific choice triggers. Selection of the shoe type has the greatest consequence on the resulting shoe components. Shoe type indicates the style of shoe, such as low-top sneaker, high-top sneaker, sandals, and whether it is a men's or women's shoe. The shoe type choices dictate the area of the shoe upper (and shoe lining) as well as sole area (slippers are larger than sneakers), and men/women affect both the shoe upper area and sole area, each with its respective sizing factors.

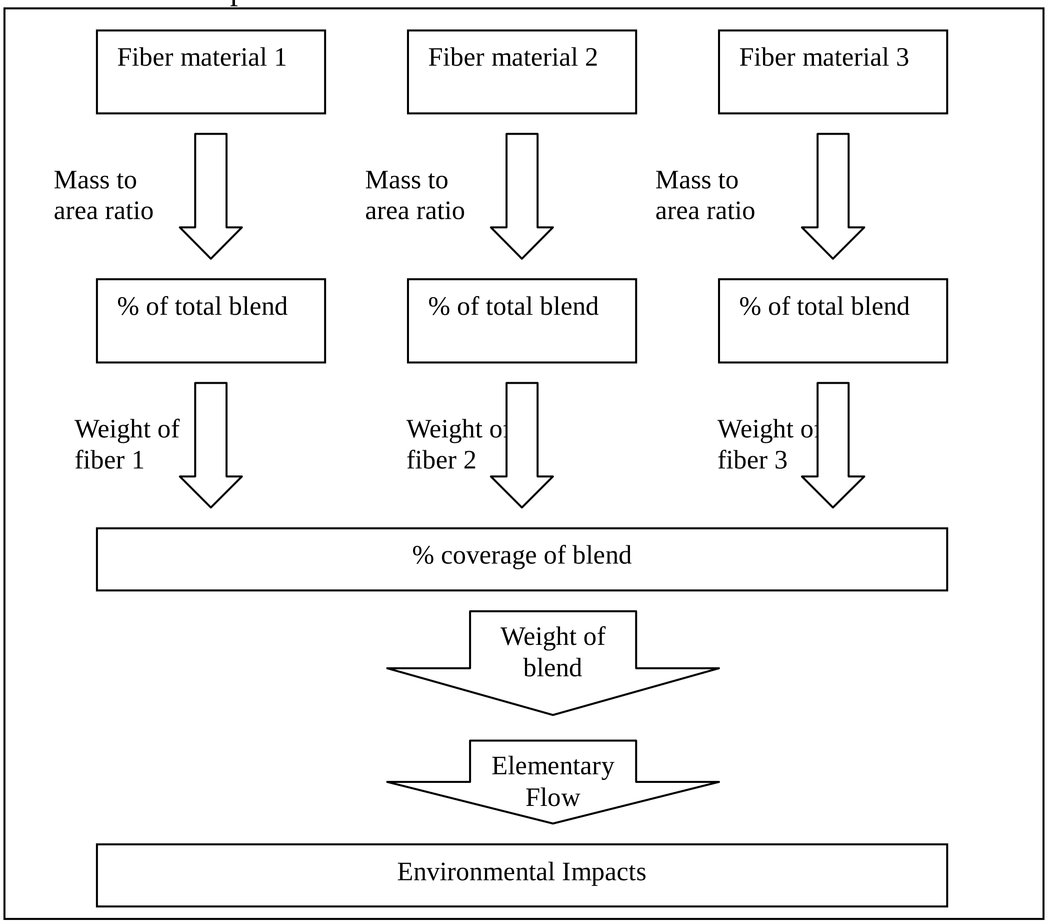
This explanation of the decision process underlying EcoSTEP will use the example of the shoe upper/lining, but the same logic is used for the soles, reinforcements, and accessories. The first prompt in the upper or lining section is a choice of material type for the component. To find the mass of material x covering the area of the upper, or the mass per area ratio, of material x must be used. This value for each material was estimated through measurement of samples and research. Multiplying the upper area with the known mass to area ratio of the material results in the mass of material x. Then, the model prompts the user with the percent coverage. This input is offered because the designer may not want the material to cover the entire component; therefore, the entry allows material x to cover any amount of the upper. For example, the calculation needed for a weight of a cotton upper of a hypothetical shoe, Shoe1, can be simplified to the following equation:

$$Mass_{Cotton} = Area_{Shoe1} \times \%Coverage_{Cotton} \times M / A\_ratio_{Cotton}$$

These calculations are hidden from the designer. The designer needs to only input the type of shoe, whether it is a men's shoe or a women's shoe, the type of material, and the percentage of area cover. Similar logic applies to reinforcements, except shoe type does not influence the area of the reinforcement and there is no choice for percent coverage but a predetermined area for each reinforcement component.

Blended materials pose unique problems in terms calculating the correct weight of each fiber component in the fabric. The model allows for blending of up to 3 different fibers to create a blended fabric. The model uses the weighted average of the area densities of the different fiber materials chosen, depending on the user input of the relative percentages of the fibers. The weighted mean of the mass to area ratio is multiplied with the area coverage of the blend as specified by the user. This decision tree can be best illustrated by the flow chart below (Figure 8.3):

Figure 8.3: Flow chart of the user choice (in boxes) of blending multiple fibers, and the consequential values calculated in the model, ultimately resulting in the environmental impacts.



The model accounts for the production burdens from the weights of each fiber and calculates the elementary flows, or natural resources directly entering or leaving the system, that result from these processes.

Soles present an additional challenge due to the fact that some sole materials vary in thickness and therefore must include an additional conversion into volume. The sole area is determined through shoe type, so multiplying the area by the thickness will result in the volume of the sole component. Finally, the material choice must be selected for the sole. Instead of the mass to area ratio, the conversion factor must now be the *volume* density. Similar to the material choice, the material choice will determine the density value with which the volume of the sole component will be multiplied to find the mass of the chosen material. Not all sole components have variable thicknesses. Some sole components have a *discrete* thickness, which has a predetermined weight that is built into the model.

Other shoe components such as shoelaces and foxing have predetermined weights that vary only based on whether the shoe is a men's shoe or a women's shoe. Shoe accessories are independent of the shoe type and selection of an accessory of a certain material type will trigger an input into the model.

Once all inputs from materials and manufacturing are entered, the model compiles the mass of each material used to construct the shoe. The GaBi software uses these masses to calculate the amounts of natural resources extracted from and released into the environment. These masses are added to the additional inputs of transportation and disposal that are written into the model but hidden from the designer to calculate the total environmental impact. Further information about model calculations can be found in Appendix F.

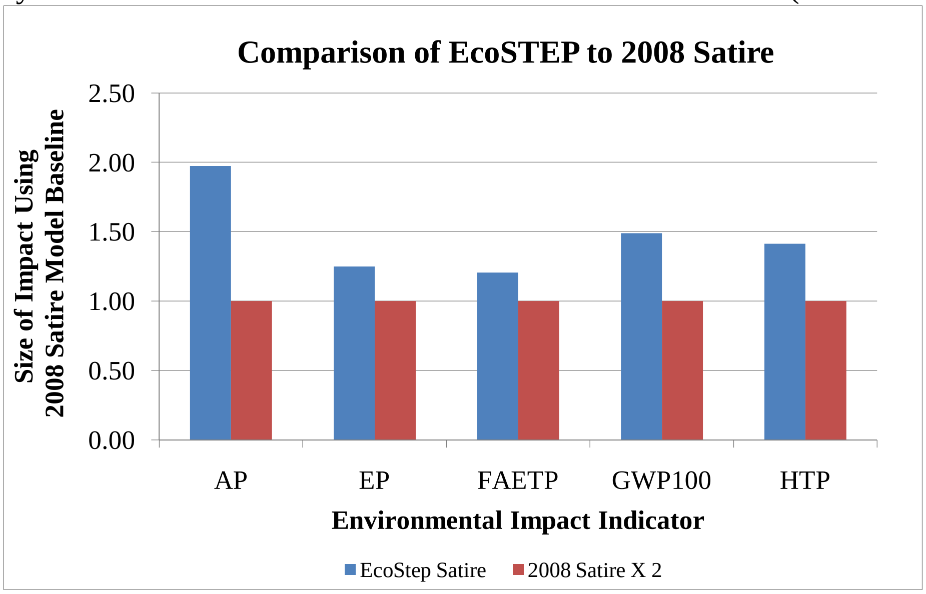
An LCA model is typically not designed to be user-friendly, but EcoSTEP is focused on creating a simplified user-input interface while still retaining the analytical rigor of a retrospective LCA model. Parameterization was used to bridge the gap between the typical user and the specific inputs needed by the GaBi model. Parameterization is essentially leaving placeholders within parts of the model calculations for future inputs by the users. Extensive discussion regarding parameterization in GaBi can be found in Appendix F.

9. TESTING THE MODEL

9.1 Comparing EcoSTEP to the 2008 Model

In order to verify the accuracy of the model, EcoSTEP was compared to the 2008 Deckers Group Project's model. The same Satire leather shoe used in the 2008 model was entered into EcoSTEP and the resulting impacts were compared. The expectation was that the model would have higher but comparable impacts since EcoSTEP included more detailed energy use data.

Figure 9.1: Comparison of the environmental impacts of a low-top sneaker evaluated by the EcoSTEP model to the same sneaker modeled in 2008 (Albers et al., 2008).

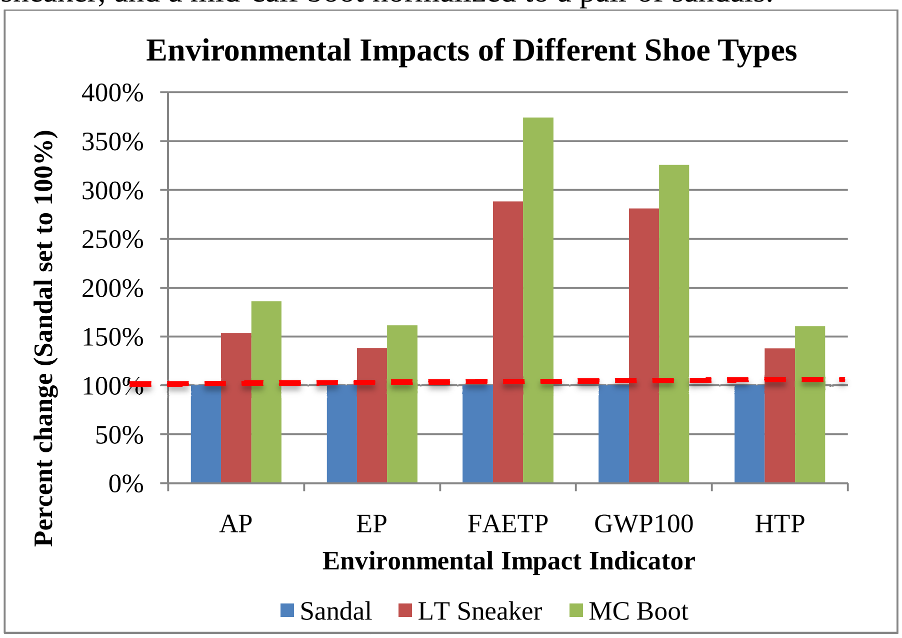


As Figure 9.1 shows, the environmental impacts were higher in EcoSTEP than in the 2008 model, especially in global warming potential and acidification potential. This difference can be explained by the increased energy use, such as the incorporation of coal inputs for steam generation. China derives most of its electrical energy from burning coal, which generates large amounts of carbon dioxide and sulfur dioxide (World Nuclear Association, 2010). Therefore, any process in EcoSTEP which had higher energy use compared to the 2008 model would have a substantially higher impact in these categories. While EcoSTEP model demonstrated a slightly different impact than the 2008 model, the difference was within the expected range and direction.

9.2 Observing EcoSTEP Inputs with Predictable Results

Another method of ensuring that the model results are reliable is to make sure that the outputs were reasonable and align with expectations. For example, a sandal should have a lower environmental impact that a sneaker because a sandal uses less material and has a simpler assembly process. In turn, a sneaker would have a lower environmental impact than a mid-calf boot for the same reasons. Keeping all other factors constant, sandals, sneakers, and mid-calf boots should have a predictable increase in overall impacts. This increase is shown in Figure 9.2 below.

Figure 9.2: Comparison of the relative environmental impact of a sandal, a low-top sneaker, and a mid-calf boot normalized to a pair of sandals.



The figure normalizes all impact categories to the baseline impacts of a sandal. Figure 9.2 shows an increase in impacts from low-top sneaker to mid-calf boot, which would be expected, as there is an incremental increase in material used. Since the sandal has a lower impact than the low top sneaker, which has a lower impact than a mid-calf boot, the model results are consistent with a reasonable qualitative prediction.

9.3 Comparison of Real Weight of Shoe to Model Outputs

To further verify EcoSTEP's accuracy, a test was performed to determine whether the model can correctly estimate the mass of a shoe. A miscalculation of shoe mass would indicate a miscalculation of environmental impact because the resulting elementary flow outputs, which ultimately are translated into environmental impacts, are based on the mass of produced materials in manufacturing. Therefore, the model's accuracy in assessing the final mass of the produced shoe is an indicator of an accurate prediction of environmental impacts. For this test, a cotton Satire was entered in the calculator solely based on visual approximations.

The resulting mass was then compared to the actual mass of the shoe, which was measured to be 294 grams. Once entered into EcoSTEP, the estimated mass from a cotton Satire was 302 grams, a difference of less than three percent. Such a high level of accuracy based on visual approximation verifies that the LCA reliably estimates the elementary flows out of and into the environment within a reasonable margin of error, which indicates a relatively accurate assessment of environmental impact.

9.4 Sensitivity Analysis

As mentioned earlier, shoes can be constructed out of multiple densities of the same fiber type. In order to simplify the input processes for the user, the surface area to weight ratio for each material was averaged into one input. However, these averages may affect the magnitude of the environmental impact by over counting or undercounting the amount of material used to make the shoe. The difference in material can greatly affect the final environmental impact, since materials are major drivers of impact.

In order to determine whether these averages could drastically change the estimated environmental impact, a sensitivity analysis was conducted using the GaBi Parameter Explorer. Since the uncertainty stemmed from the ratio of surface area to weight, the sensitivity analysis varied the surface area to weight ratio. Each input with a surface area to weight conversion was varied by +/- 50 percent. The uncertainty was acceptable if the percentage change in the output was less than the percentage change in the input. In other words, a 50 percent change should result in a less than 50 percent change in impact. This result would result in an elasticity of less than 1.

A Satire shoe was chosen for the analysis because it is a common shoe (frequently used design with commonly used materials). The shoe was entered into the calculator with all of its materials and overlays. Only one primary upper material could be calculated at a time, therefore the sensitivity analysis was run 16 times to test each of the primary upper materials.

The sensitivity analysis showed that the level of uncertainty in the surface area to weight ratio was acceptable for all inputs. The highest elasticity among all impact categories was found in leather. The elasticity of leather for eutrophication potential was 0.93. Wool also had fairly high elasticities but all were below the threshold elasticity of 1. The elasticity of all other inputs was lower, with many below 0.01.

These results supported the assumption that average parameters could be used without causing a significant difference in the results. For any materials, even if the area to mass ratio was off by 50%, the environmental impact categories should not be greatly distorted. The results also strengthen the model’s credibility as a predictive model that can incorporate new material densities that might be used in the future.

10. USER INTERFACE

As mentioned above, the designer is not required to have an understanding of the complex GaBi model but can use the software interface designed using I-Report. Deckers emphasized that the person using this model will be considering many different aspects of the shoe in the design phase, such as price, look, and feasibility, as well as environment impact. Due to these challenges in designing a shoe, interface users would only have a few minutes to enter the shoe specs into the database, often with only a picture or a basic idea of the shoe. As a result, the challenge of this project was to develop a quantitative impact assessment based on very little quantitative information generated by the user. Faced with this reality, the interface was designed for anyone to input shoe specifications using visual approximations and little available data to generate the projected environmental impact.

For detailed description of the development of the EcoSTEP user interface, refer to Appendix F.

10.1 About The Interface

The interface was separated into six sections: basics, shoe upper, linings and foams, accessories, reinforcements, and the sole.

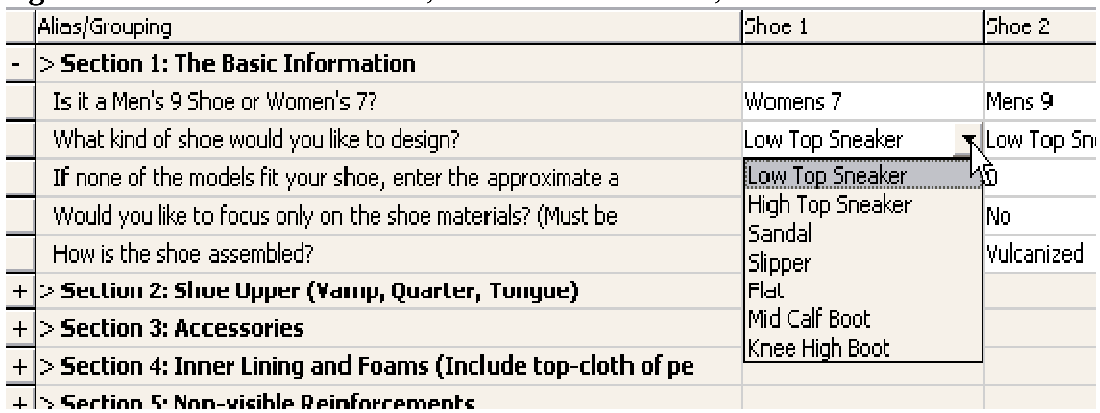
Figure 10.1: Picture of EcoSTEP collapsed.

Scenarios

	Alias/Grouping	Shoe 1	Shoe 2
+	**> Section 1: The Basic Information**		
+	**> Section 2: Shoe Upper (Vamp, Quarter, Tongue)**		
+	**> Section 3: Accessories**		
+	**> Section 4: Inner Lining and Foams (Include top-cloth of pe**		
+	**> Section 5: Non-visible Reinforcements**		
+	**> Section 6: Sole**		

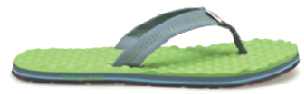
"The Basics" section allows the user to select the shoe type, construction method, and whether it is a men's or women's shoe (Figure 10.1). By entering this basic information, fixed variables are propagated into the model, such as upper surface area and sole area size. If the user has an upper design with an unusual surface area, it is possible to enter the area in replacement of the shoe category. The user can use existing shoe categories, provided in the model, as benchmarks to input the new area. For example, if a designer was creating a shoe that was between a low-top and high-top shoe, the user can reference those designs to approximate the new shoe's area.

Figure 10.2: Picture of Section 1, the basic information, of EcoSTEP.



A particularly important component in “The Basics” section is the shoe category selection. In order to convert information that a shoe designer would know (percentage of upper covered by a particular material) into information that the GaBi software required (weights), shoes were placed into the seven broad categories listed below (Figure 10.2). Each shoe category was given a defined upper surface area. In the user-interface, the designer can either choose one of the pre-defined shoe categories or can choose to input a specific area using the pre-defined shoe category areas as a benchmark (Table 10.1). For example if a designer is interested in the environmental impacts of a sandal with multiple straps, the specific area will be greater than that of a flip-flop, but less than that of a flat. Under this setup, the designer will then input the percentage of the upper covered by a specific material. This percentage is a proportion of the shoe upper, as defined by the shoe category or by the designer.

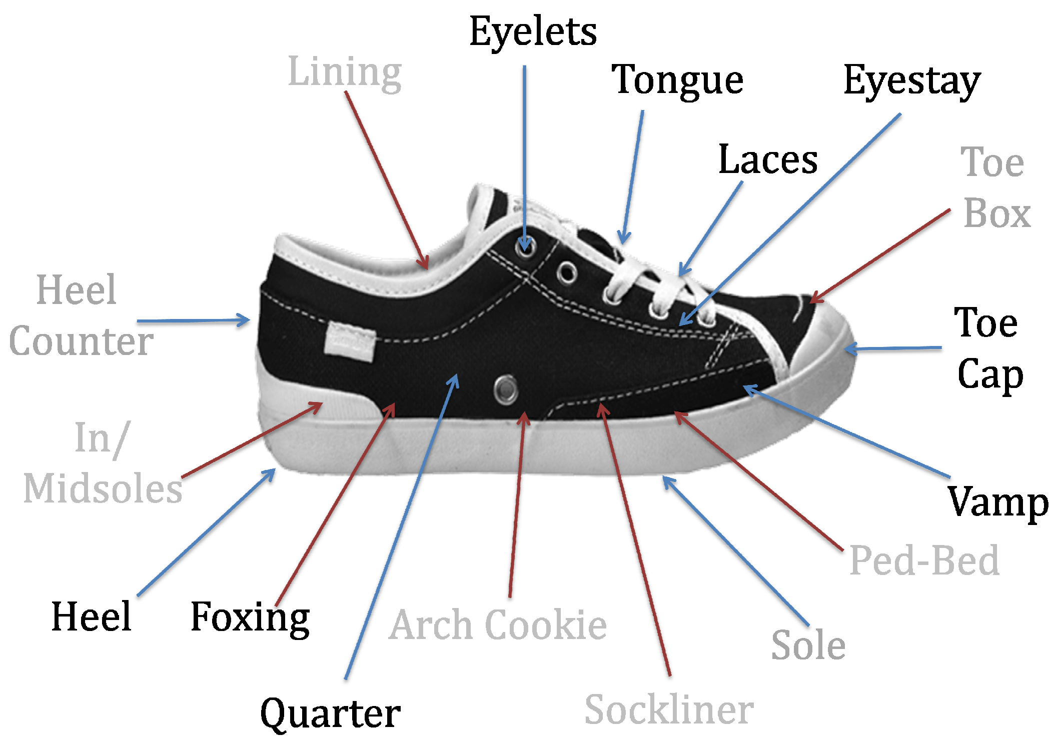
Table 10.1: Seven shoe categories

Shoe Category	Area of Women's 7 (in^2)	Area of Men's 9 (in^2)	Shoe Image
Sandal	8.94	9.62 in^2	
Flat	41.98 in^2	n/a	
Slipper	42.67 in^2	45.88 in^2	
Low-Top Sneaker	68.82 in^2	74 in^2	
High-Top	76.39 in^2	82.14 in^2	
Mid-Calf Boot	214.03 in^2	230.14 in^2	
Knee-High Boot	280.78 in^2	n/a	

10.2 Shoe Components

After “The Basics”, specific shoe components can be entered into EcoSTEP. Users of this model will need to know the names of individual shoe parts in order to properly estimate the environmental impact within the model. At first glance, shoes appear to be composed of few simple parts. However, there was a vast array of components to consider (Figure 10.3). In order to ensure that EcoSTEP outputs reflected the actual shoe, all components needed to be included within the model. Shoe component terms were used so that designers would be familiar with the wording of the interface when entering information.

Figure 10.3: Parts of the shoe. The black type represents visible components of the shoe while the gray type represents non-visible components of the shoe.



The specific components were grouped into broad categories to organize the inputs into the model. Since shoes are composed of many different parts, they were categorized into five broad components: upper, lining, sole, accessory, and reinforcement. The various parts that make up the different components are summarized below.

Table 10.2: Shoe components

Component Name	Part Name	Description
Upper	Base layer	Fiber, natural or synthetic, or leather
	Overlay	Additional layers superimposed on the base layer
Accessory	Shoe lace	-N/A-
	Eyelets	Metal or plastic, punched into upper
	Buttons	-N/A-
	Snaps	-N/A-
	Zipper	-N/A-
	Buckles	-N/A-
Lining	Lining	Inner layer of base layer
	Pedbed	Inserts for arch support
	Foam	Foam sandwiched between upper and lining
Reinforcements	Toe box	Strengthens the toe
	Heel counter	Strengthens the heel of shoe
	Arch cookie	Provides arch support in lieu of a pedbed
Sole	Insole	Layer immediately below the pedbed
	Midsole	Multiple layers sandwiched between in and out sole
	Outsole	The layer that makes contact with ground

10.3 The Upper

The second critical section in the interface is the upper (Figure 10.4). The upper is the most variable part of the shoe in terms of possible material types, foot cover, and size with the possibility of overlaying material. Therefore, there were more input categories for this part of the shoe.

Figure 10.4: Picture of the Upper section of the EcoSTEP model.

	Alias/Grouping	Shoe 1	Shoe 2
+	> **Section 1: The Basic Information**		
-	> **Section 2: Shoe Upper (Vamp, Quarter, Tongue)**		
-	>> **Primary Upper**		
	What is the primary material used for the upper?	Wool	- None -
	What % of the upper does this material cover?	100	0
	What % of the upper does this material cover as an overlay (	10	0
+	>> **Upper 2**		
+	>> **Upper 3**		
+	>> **Upper 4**		
+	>> **Upper 5**		
+	>> **Upper Blend 1**		
+	>> **Upper Blend 2**		
+	> **Section 3: Accessories**		
+	> **Section 4: Inner Lining and Foams (Include top-cloth of pe**		
+	> **Section 5: Non-visible Reinforcements**		
+	> **Section 6: Sole**		

In the shoe upper section, the user can select from a variety of materials and blended materials that compose the surface of the shoe (Figure 10.4). Sometimes, there will be one material in shoe superimposed upon another, requiring the user to fill in the overlay section of the interface. If a material, cotton for example, covers another material, leather, the user would enter the percent of the surface area the cotton covers.

10.4 Linings and Foams

In the linings and foams section, the user can input information regarding the materials used in the lining as well as non-visible material between the lining and the outer upper (Figure 10.5). In the accessories section, user can input discrete information such as shoelaces and eyelets. The user can input optional structural materials into the shoe in the reinforcements section. Finally, users can to input the insole, midsole, outsole and the heel into the interface in the sole section.

Aspects of the shoe that change little or not at all, such as insole, midsole, outsole, lace length, and distance traveled, were set as predetermined values that a user would not need to enter in to the model.

Figure 10.5: Picture of section 4, the lining component.

	Alias/Grouping	Shoe 1	Shoe 2
+	**> Section 1: The Basic Information**		
+	**> Section 2: Shoe Upper (Vamp, Quarter, Tongue)**		
-	**> Section 3: Accessories**		
	What material is used for the laces?	Organic Cotton	- None -
+	**>> Eyelets**		
+	**>> Snaps**		
+	**>> Buttons**		
+	**>> Buckles**		
+	**>> Zippers**		
-	**> Section 4: Inner Lining and Foams (Include top-cloth of pe**		
+	**>> Primary Lining**		
+	**>> Lining 2**		
+	**>> Lining 3**		
+	**>> Lining 4**		
+	**>> Lining 5**		
+	**>> Lining Blend 1**		
+	**>> Lining Blend 2**		
+	**>> Sockliner**		

10.5 Interface Testing

Informal tests were performed to test the I-Report interface for ease of use. Using an interface prototype in Excel, three subjects spent approximately 15 minutes with the spreadsheet: two Bren School students and a Bren School Professor. Subjects were told the reason behind the interface and to input the shoe design into the model. They were taught the necessary industry terms for the shoe components and were then instructed to input data into the spreadsheet. If sections were skipped, subjects were asked to return to a section and complete it. They were also asked for any overall comments or concerns about the interface. Once feedback on the interface was received, it was iteratively redesigned.

To learn how to design the model specifically for designer's needs, a focus group of four Deckers employees collectively entered a shoe profile into the prototype interface. Any areas of confusion in the model were recorded and later improved.

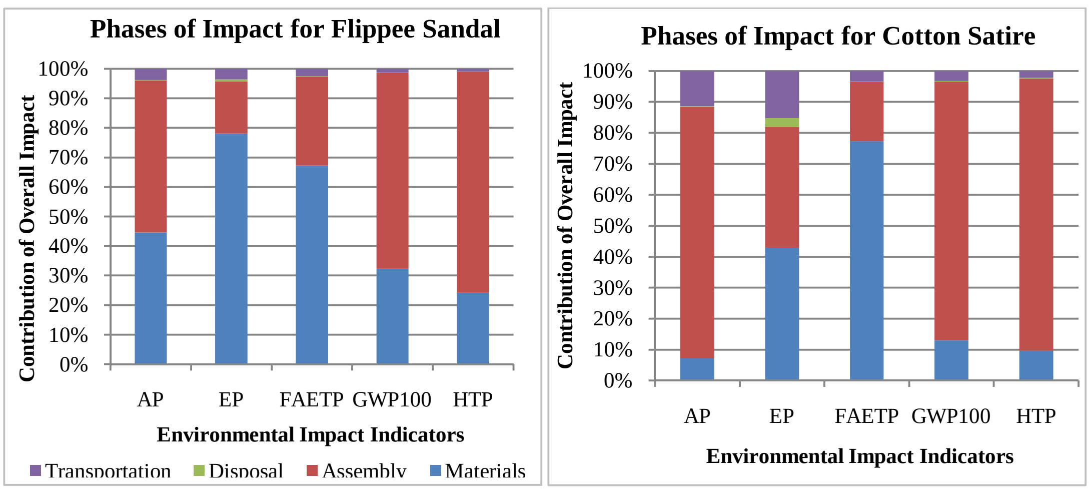
11. Results and Discussion /Interpretation

11.1 Life Cycle Stages

The life cycle stages are the areas of the supply chain, within the system boundary, where impacts occur. The stages were grouped together by materials, assembly, disposal, and transportation. By looking at the relative contribution of each stage to the impact of the whole shoe, the most environmentally harmful stages can be discovered.

To determine which stages have the largest contribution to environmental impacts, two different shoe models were run through the model and compared. A Satire low-top sneaker with a cotton upper and a Flippee sandal were analyzed. These two shoes were chosen because of their drastically different level of raw material requirements and designs.

Figure 11.1: Phases of impact for a cotton Satire sneaker and a Flippee sandal.



As Figure 11.1 shows, materials and assembly accounted for more than 90 percent of the impact across all five categories for the cotton satire, with disposal and transportation accounting for the rest of the impact. Similarly, 95 percent of the Flippee's impact in all categories can be attributed to materials and assembly. In both analyses transportation and disposal combined account for less than 10 percent of the overall impact.

Although transportation and disposal tend to be more visible to a consumer, the actual impacts from these two phases are small. Transportation is a relatively efficient process, especially on barges because the vehicle's fuel consumption is divided among its entire payload. For the purpose of the model, it was assumed that 5000 pairs of shoes were loaded into the shipping containers and then onto trucks. Therefore, the environmental burden of the transport of one pair of shoes was allocated a 1/5000th of the total impact of transporting the shipping container to the distribution center. Disposal also has a lower impact because shoes were not expected to decompose in the landfill. Comparatively, this small amount of material in the end-of-life contributes very little to the overall impact.

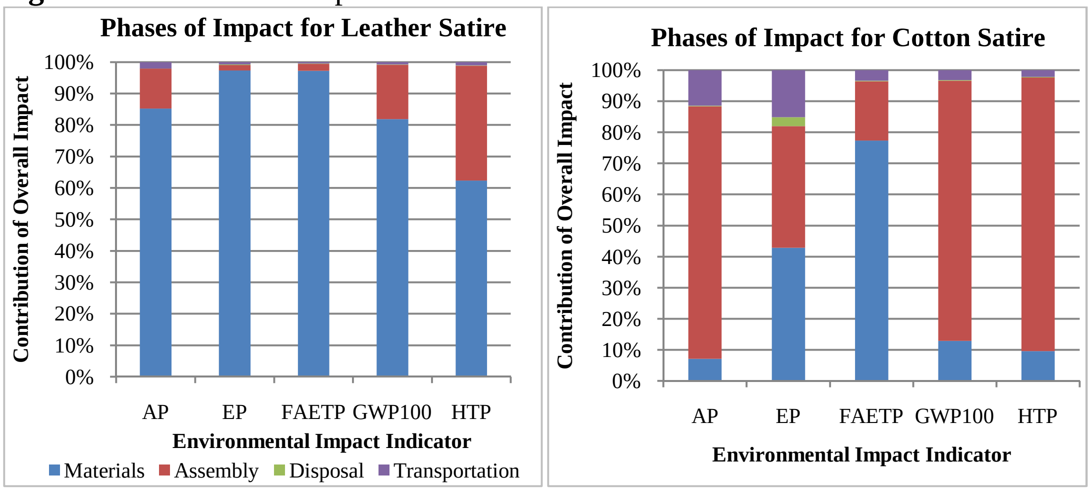
These results highlight that Deckers should focus on using more environmentally friendly materials and on improving energy efficiency of factories, rather than on disposal and transportation, to reduce environmental impacts.

11.2 Material Comparisons

11.2.1 Change in Upper Material Type

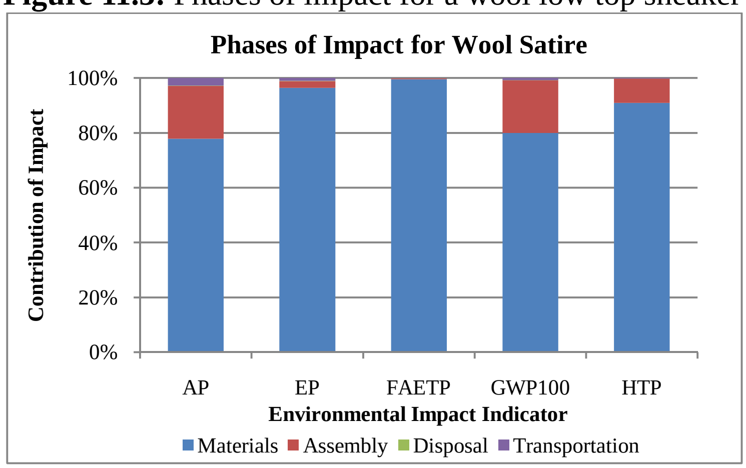
While the materials and assembly have the greatest impact on the environment, the comparative impact of these two processes varies depending upon the materials used. To demonstrate the importance of materials relative to assembly, several scenarios were run using different upper materials. First, the low-top Satire sneaker with a cotton upper was replaced with a leather upper and evaluated through its life cycle. In this scenario, materials had the highest environmental impact across all five categories (Figure 11.2).

Figure 11.2: Phases of impact for a cotton satire and a leather satire sneaker.



A similar result was recorded when a wool satire was run through the model (Figure 11.3). These higher impacts from materials come from the fact that animals need to be raised in order for these materials to be harvested, resulting in a higher environmental burden. In the case of leather, the tanning process also tends to use toxic chemicals and heavy metals, further raising the environmental impact (Albers et al., 2008).

Figure 11.3: Phases of impact for a wool low top sneaker

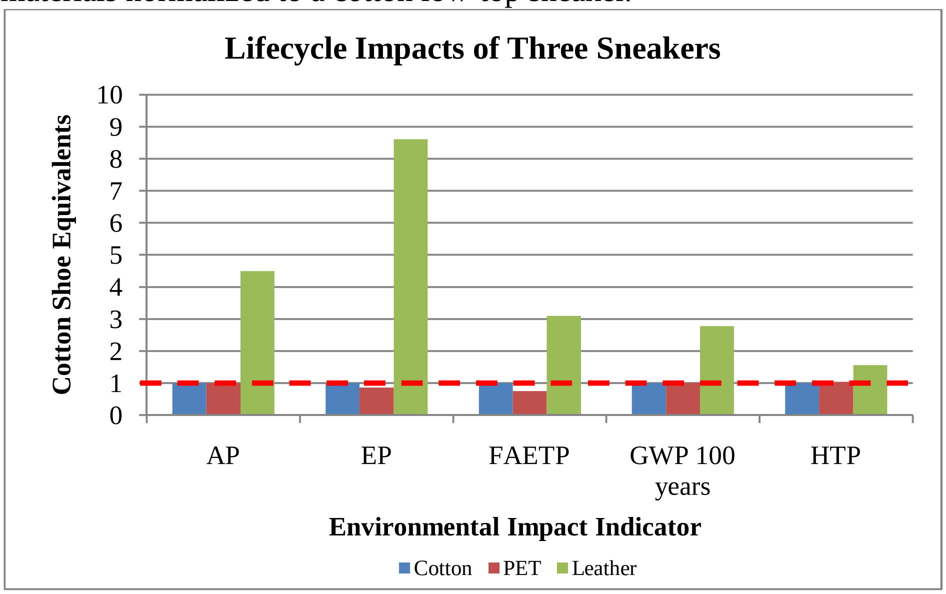


In comparison to the livestock derived materials, the majority of the environmental impact of materials for the cotton Satire and the Flippee (Figure 11.1) were only larger than assembly in two impact categories: freshwater ecotoxicity potential and eutrophication potential. Assembly was the largest contributor for Satire and Flippee in the global warming potential and human toxicity potential in addition to being the largest contributor to the cotton Satire's acidification potential.

These results demonstrate that Deckers should focus on minimizing livestock derived materials first and on encouraging energy efficiency at their factories second. Once these materials are replaced, assembly has a much more prominent impact.

Comparing livestock, natural, and synthetic products: Another comparison was performed to make further recommendations about material use. Low-top satire sneakers with a leather upper, a cotton fiber upper, and a PET upper were compared to one another. These three materials were used to represent materials from animals, natural fiber materials, and synthetic materials, respectively.

Figure 11.4: Lifecycle impacts of three sneakers comprised of different upper materials normalized to a cotton low-top sneaker.

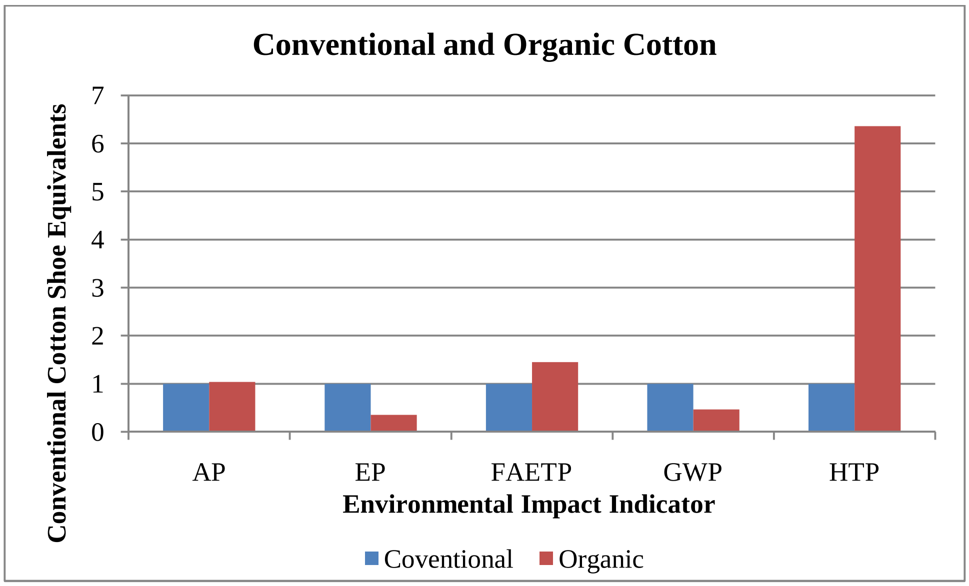


PET had a comparable impact to cotton across all categories but leather had a substantially higher impact across all categories (Fig 11.4). The eutrophication potential of leather was more than eight times higher than that of a cotton shoe. In other words, it would take eight cotton low-top sneakers to reach the eutrophication potential of one leather low-top sneaker. This marked increased in eutrophication is likely due to the grain-intensive diet of cattle. The grains were grown with manufactured fertilizers that can leach into nearby freshwater sources, causing algal blooms. These results further illustrate that Deckers should avoid the use of leather, suede, and wool whenever possible.

Comparing Conventional Cotton and Organic Cotton: Simple Shoes prioritizes the use of organic cotton over conventional cotton in accordance with their mission to produce environmentally benign products. In order to become certified as organic, cotton must be grown without herbicides, pesticides, or synthetic fertilizers (Simple Shoes, 2010). The organic process has other benefits as well. Simple Shoes notes that the cotton pickers would be less exposed to harmful chemicals; moreover, the local water table is less subject to the toxins. Citing similar concerns, Patagonia switched their entire line of cotton products to organic fiber sources (Chouinard & Brownm, 1996).

While organic cotton production prohibits the application of manufactured chemicals, natural fertilizers, such as animal manures, are applied instead (OTA, 2008). Animal fertilizers are thought to be substantially more environmentally benign than manufactured fertilizers due to their natural origins. However, the GaBi processes for cotton shows an increase in some selected environmental impacts when switching from conventional to organic (Figure 11.5).

Figure 11.5: Comparison of the environmental impacts of conventional and organic cotton.



Acidification potential is similar between conventional and organic cotton production. This result makes sense in light of the fact that the majority of acidification potential is the result of emissions from coal for energy, and the energy input should be similar for both types of materials. Eutrophication and global warming potentials are more than halved for organic cotton. Eutrophication is lower due to the elimination of nitrogen-rich synthetic fertilizers and the resulting decreased potential of runoff into nearby freshwater sources. Global warming potential is reduced as well because of the absence of the manufacturing burden of industrial agricultural chemicals.

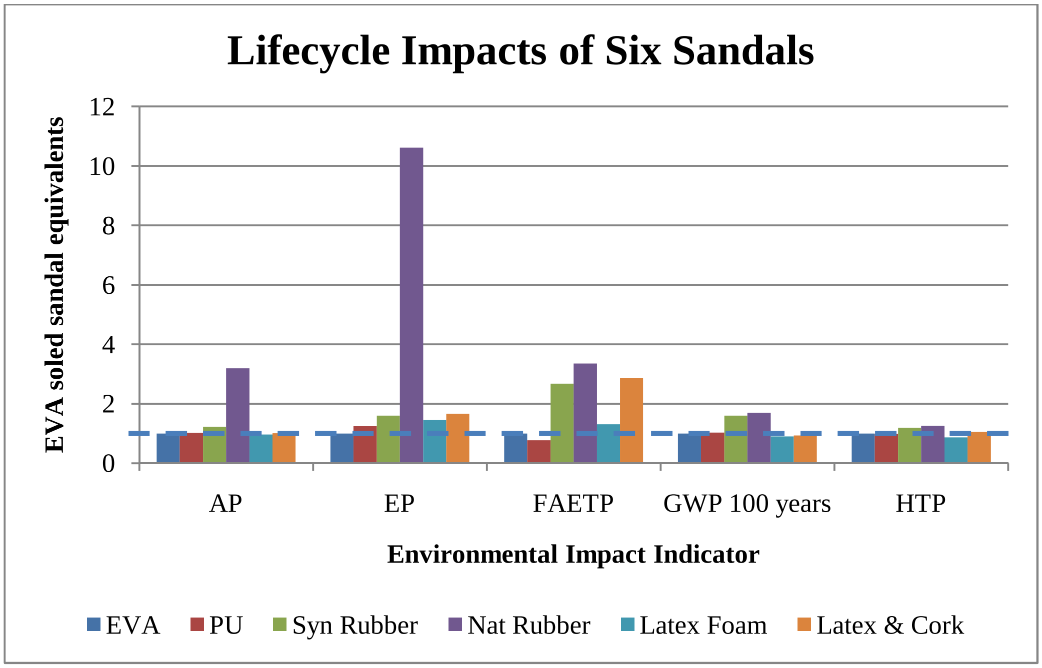
However, there are increases in freshwater aquatic ecotoxicity and human toxicity potentials. The human toxicity potential exhibits an especially high increase, with a six-fold increase in toxicity potential. This dramatic increase can be largely attributed to heavy metal emissions into soil that are incorporated in the organic cotton process in GaBi (P. Canepa, e-mail correspondence, 2010). The source of these elementary outflows can be traced back to studies that claim animal manures can contain toxic heavy metals (Wander, 2009; Han et al., 2000; Kentaro et al., 2002).

The allocation question addressed in Section 6.4 is important to consider for the organic cotton process, especially due to the marked increase in toxicities. The GaBi process for organic cotton contains the heavy metals that are present in the animal manures, and the impact categories in EcoSTEP reflect their potential health hazards. However, is it appropriate that the environmental burden of manure be entirely attributed to the organic cotton production process? The animal wastes were not produced for the sole purpose of providing fertilizer to crops; rather, they are by-products of another economic activity. Depending on the system boundary that is drawn, the heavy metal emissions could be partially or entirely attributed to livestock production, not cotton production. Due to the allocation decisions made during the data collection phase, the impacts of manure application were allocated to the organic cotton production process. Although it is not recommended that the increase in toxicity be ignored, it is important to recognize that the environmental impact categories reflect allocation decisions that were made in creating the GaBi processes. In the context of this example, Deckers should still use organic cotton over conventional cotton because the environmental impact of manure fertilizer would occur regardless of its allocation to the production of organic cotton.

11.2.2 Comparing sole materials

There are several material choices for the sole: it can be made of EVA, polyurethane, synthetic rubber, natural rubber, latex foam, or latex and cork blend. Using a Flippee sandal as a baseline model (which is simply a sole with a PET strap) the impacts of the six materials were compared to each other. Once these shoe models were inputted and the impacts calculated, every material was divided by the absolute impact of EVA, a common material used for sandal soles (Figure 11.6).

Figure 11.6: Lifecycle environmental impacts of six sandals with different types of soles normalized to an EVA sandal.



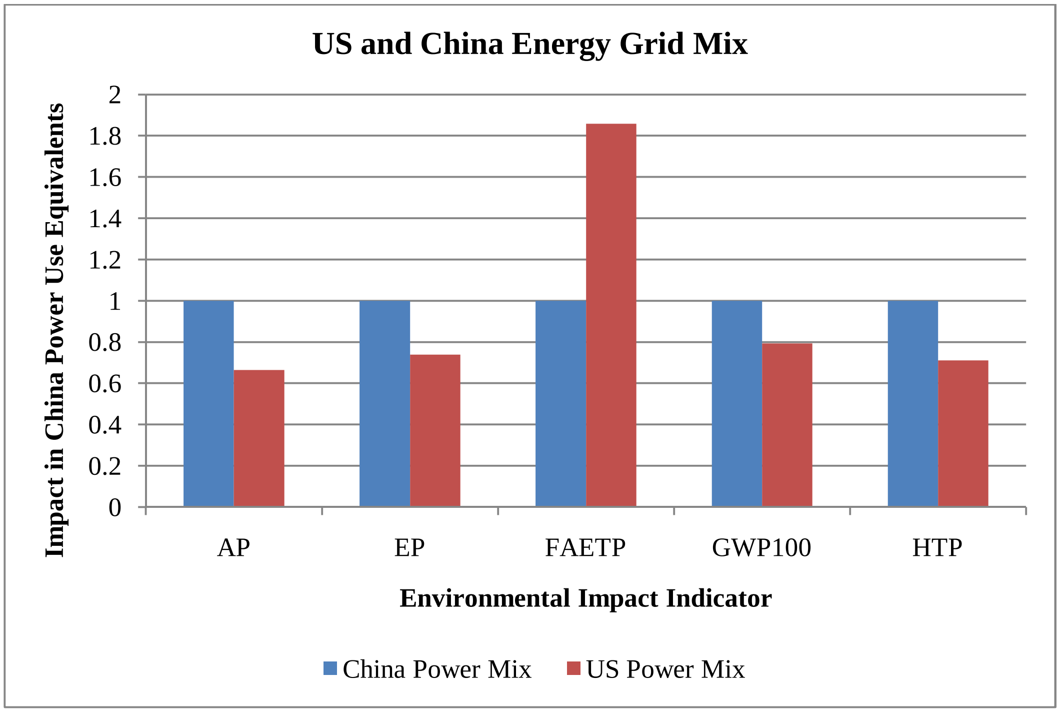
From this comparison it is clear that the synthetic materials EVA and polyurethane have the lowest impact relative to the other types of soles. Natural rubber, with the obviously high eutrophication potential, is particularly notable. This high level of eutrophication is due to the intense agriculture required to grow rubber trees and process the rubber sap. According to Asia and Akporhonor (2007) effluents from natural rubber processing facilities are contaminated with dissolved solids, ammonia, nitrates, and phosphates. These effluents are highly conducive to algal blooms which result in oxygen depletion that ultimately kill aquatic animals. A study conducted in the Niger Delta reported that there were significant reductions in the number of macroinvertebrates near effluent discharge points (Arimoro, 2009). Although latex materials go through the same agricultural and manufacturing process as natural rubber, the latex foam and latex cork blend have lower impacts due to the lower percentage of natural rubber compound in the sole.

11.3 Changes in energy mix

11.3.1 Changes in manufacturing location: China to the United States

One area of interest to Deckers is the possibility of bringing shoe manufacturing back to the USA. One consequence of such an action is that the energy mix used in assembly would change, thereby changing the environmental impact. To test the effect of this change, the energy source required for manufacturing was changed from a Chinese energy mix to an American energy mix for a cotton Satire, while holding all other inputs for manufacturing constant. As Figure 11.7 shows, manufacturing shoes in the US decreases the acidification potential by 34 percent, eutrophication potential by 26 percent, global warming potential by 20 percent, and human toxicity potential by 29 percent.

Figure 11.7: Relative comparison of the environmental impacts of the energy grid mix in the USA and in China

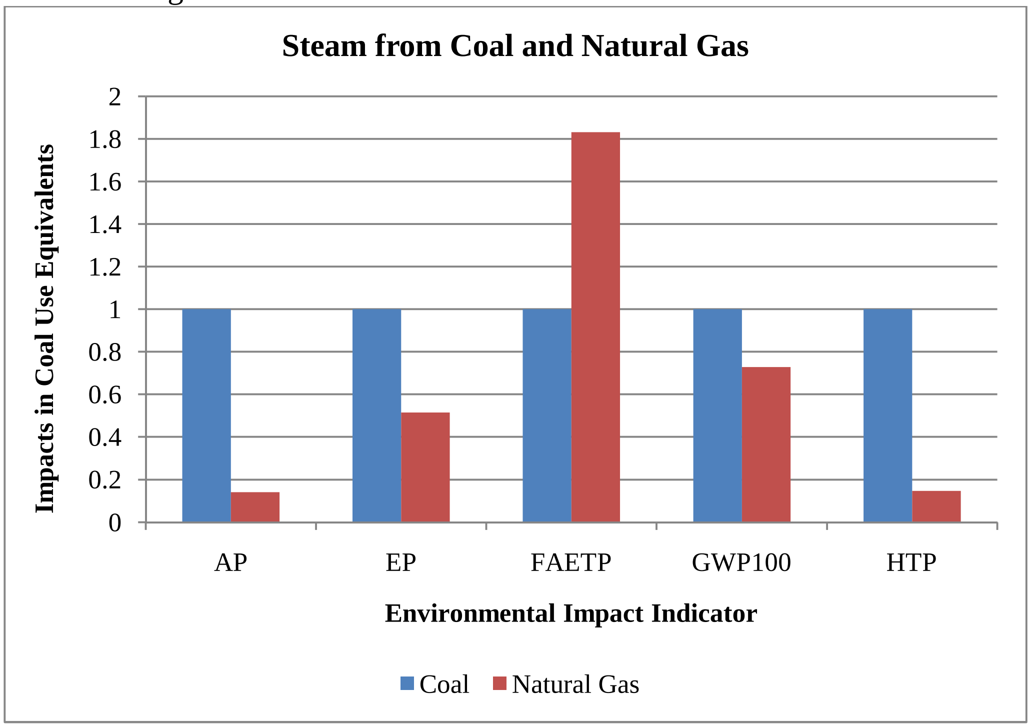


One notable exception from these decreases was freshwater ecotoxicity potential (FAETP), which increased by 85 percent with the US energy mix. One possible explanation is that 7.5 percent of natural gas produced in the US consists of coal bed methane, or CBM (USGS, 2000). CBM is produced by drawing up methane that is embedded in the coal. The challenge of CBM is that large volumes of subterranean water must be pumped out before the methane can be accessed (USGS, 2000). This water is known to be highly saline, and substantially interferes with growth of salt-intolerant plants (Stearns et al., 2005).

11.3.2 Changes in Steam Generation: Coal to natural gas

One of the most energy- intensive processes for shoe assembly is that of steam generation from coal-fired boilers. Steam is used as a way to activate adhesives in the shoe in order to bond layers together. However, this process is energy intensive and relies solely on coal, which has a fuel generates a higher environmental impact than natural gas (World Nuclear Association, 2010). One scenario was run to compare a coal boiler to a natural gas boiler, a feasible substitute technology.

Figure 11.8: Comparison of the environmental impacts of steam from coal to steam from natural gas.



When compared to a natural gas boiler (with 89 percent efficiency) the coal boiler (with 84 percent efficiency) had a higher environmental impact in four out of five categories (Figure 11.8). The coal boiler had six times greater impact than natural gas in both acidification and human toxicity potential and a slightly higher impact in eutrophication potential and global warming potential. However, coal had half the impact in the FAETP category. While, the information behind the data source in database remains unclear, it is likely this increase in FAETP may also be attributed to the use of CBM in the US natural gas mix.

12. RECOMMENDATIONS

Deckers should begin using the model and incorporating its results into their designs and decision-making. Dased on the scenarios already run through the model, several recommendations can currently be made to Deckers' shoe designers to improve the environmental performance. The most significant recommendations would be to:

1. **Avoid using leather and wool products whenever possible.**

   While leather does have high durability and may be aesthetically pleasing, it dwarfs the environmental impact of other materials. Wool, while less commonly used, also has comparable impacts on the environment and should avoided.

2. **Avoid cold cement.**

   Despite conventional wisdom, cold cement assembly has a higher environmental impact than vulcanization. While Deckers should look into the energy requirements for assembly thoroughly, data provided by shoe factories indicates that the difference in impact is due to the high energy requirements of cold cement over vulcanization.

3. **Focus on energy-efficient assembly.**

   Reducing energy use will greatly mitigate environmental impact. For low-top sneakers with an upper composed of non-livestock products, assembly energy use can have a greater impact than the material used in the shoe. For example, on-site coal burners used to create steam for manufacturing have high-energy consumption rates. If these burners were electricity based or used natural gas, it would greatly reduce environmental impacts.

4. **Verify impacts of existing and new materials.**

   Deckers has an opportunity to work with the supply chain to collect detailed quantitative information on the many innovative products used in the Simple Shoes brand. This additional information would allow Deckers to verify the perceived environmental benefits of unique products such as silk, beeswax, and Bio-D.

While Deckers should consider these recommendations when creating shoes, the users of this model will likely discover new ways of reducing environmental impact. Shoe designers will be able to apply EcoSTEP in many more scenarios than were assessed in this project. Therefore, Deckers should not solely rely on the recommendations from this project but rather use the model to inform decision-making.

Finally, Deckers should update EcoSTEP periodically to better reflect new materials, energy impacts and operation changes. These updates and suggestions can be accomplished with a future Bren School Group Project or through LCA consultants.

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APPENDIX A: USER'S GUIDE

This user guide was written to assist users of EcoSTEP to estimate the potential environmental impact of **a pair of shoes** made by Deckers' Simple Shoes Brand.

About EcoSTEP: EcoSTEP was designed by the Footprint Team at the UCSB Bren School of Environmental Science and Management during 2009 and 2010. This model utilizes GaBi, the leading life-cycle assessment (LCA) program as well as I-Report, a user-friendly interface designed for GaBi. Both products were made by PE International. For more information on this model and its authors, please visit http://fiesta.bren.ucsb.edu/~footprint/team.html.

Why EcoSTEP?

Every item that you purchase has an environmental impact but almost no one quantifies this impact, especially before the product is made. Even when the environmental impact is quantified, it is normally quantified *after* the item is made. But what if the impact of items, such as shoes, can be determined ***before*** it is made? If this capability existed, you could compare similar shoe designs to one another and then select the design with the lowest impact while avoiding making a high-impact shoe. Fortunately, that capability does exist within EcoSTEP.

Purpose: The purpose of EcoSTEP is to estimate the environmental impact of shoes *before* they are manufactured. When a shoe design or several designs are entered into this model, EcoSTEP estimates the environmental impact of a pair of those shoes. After the design is entered, the environmental impacts are given across several impact categories. You can then modify the pair of shoes to reduce the environmental impact.

Note: This program gives the projected environmental impact, which is based on assumptions of fabric weight, manufacturing practices, and distances traveled. Due to these assumptions, the environmental impacts do not fully reflect the actual environmental impact but are simply an estimate. For further information on these assumptions, please refer to the full report.

About the Model

EcoSTEP allows you to calculate the impact of a pair of shoes with relatively basic information. EcoSTEP was designed to have an interface that is similar to a program you would use in Excel or on a website. There are pull-down menus for all inputs that have a list of options such as manufacturing process (vulcanization, cold cement, die-cut) or material type (cotton, leather, hemp, etc.). More specific numerical information, such as the percentage of cotton or numbers of eyelets, must be entered.

The model is designed to work for people who have limited time and limited information. In order to do this, EcoSTEP is based primarily on visual approximations of shoes. This means that while you may not have the exact specifications about a shoe, like the surface area of the upper, you will need to make estimates for these values using guidelines that we provide in the model and this user guide.

For example, look at the following shoe:

The upper of this shoe is clearly all leather. So in the model, you would select leather as the material. When you are asked what percent of the upper does this leather cover, you would enter “100”. Simple, right?

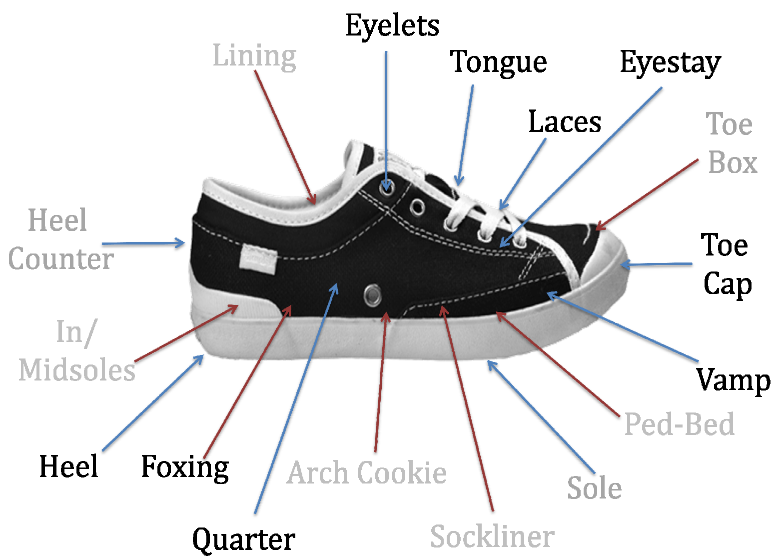
But do you notice that little piece of rubber on the heel above the foxing? If you want to accurately estimate the environmental impact of the shoe, you would have to include that rubber. Don’t worry, you don’t need to get out your measuring tape; EcoSTEP has a way to avoid time - consuming measurements. All you need to do is estimate how much of the upper that rubber covers.

Let’s say the area of the upper is equal to “100”. Now how much of the upper does the rubber cover? I would estimate that is covers about 5% of the upper. So in the model, you would select the time of rubber, and enter in “5” as the amount of upper area it covers. As you can see, EcoSTEP allows you to estimate area by comparing it to the rest of the upper, rather than requiring any complex calculations.

> **Note: The program calculates the environmental impact of a pair of shoes but you only need to enter the information about a single shoe into the model.**

To avoid any confusion over names of shoe parts, please refer to Figure A1.

Figure A1: Parts of the shoe. The visible parts are in black text, and the non-visible parts are in grey.



EcoSTEP Input Features

It is possible to enter up to seven shoes into the model at once for a direct comparison of the environmental impacts for different designs. Ideally, two or more shoe designs would be entered into EcoSTEP simultaneously. This will allow you to compare the environmental impacts of each shoe design.

There will be times you may only want to compare one part of a shoe to another, rather than entering two entire shoe specifications. Luckily, EcoSTEP can be used in two different ways.

If you are interested in a complete impact assessment of a pair of shoes, you can enter the shoe design as completely as possible.

If you are more concerned about a single shoe component, for example comparing a leather upper to a cotton upper, then you do not have to enter the entire shoe. You can simply fill in the component section that you are interested in and leave the rest of the input fields blank.

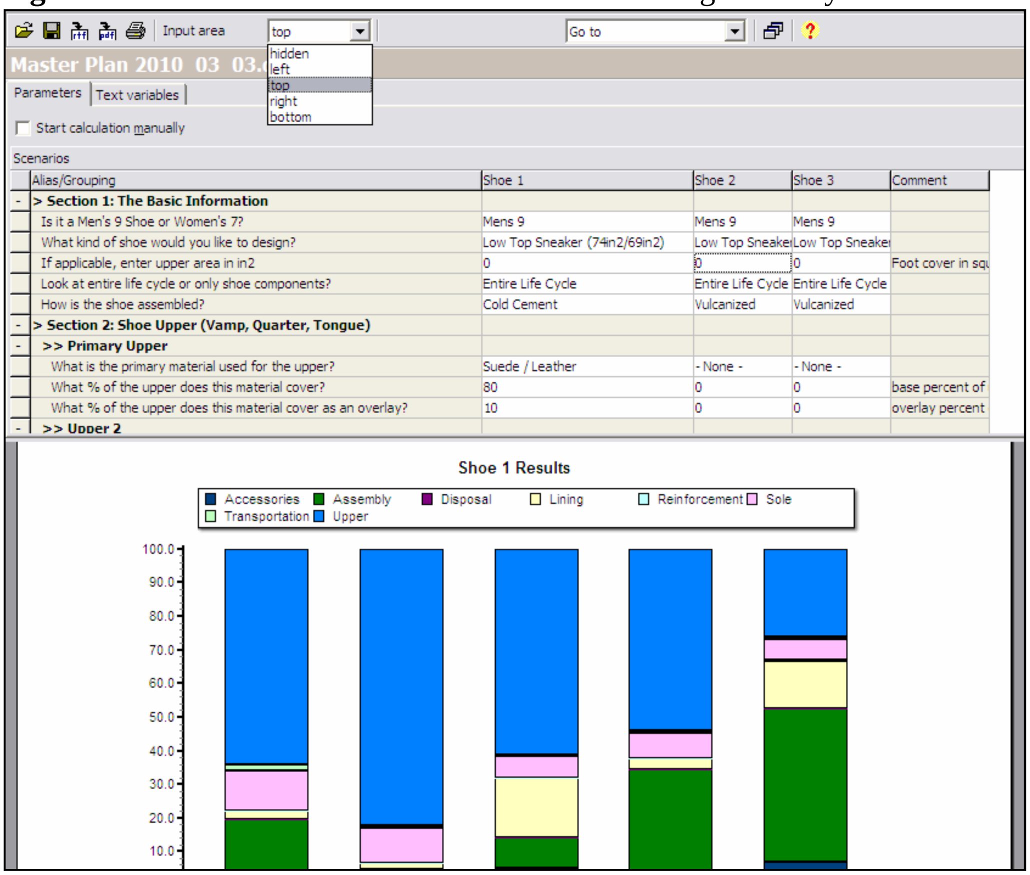
To elaborate on the second option, say you want to compare two shoes that are identical except that one shoe has a leather upper while another shoe has a wool upper. As a shortcut, all you would need to do is select leather and tell the model 100% of the upper is made of leather. Then, repeat this process for wool. So rather than having to enter information about the sole, laces, accessories and other parts of the shoe which are the same for both designs, you only need to enter into the model the parts that are different.

How to Open the Model

- Insert Dongle
- Open “Gabi Reader”
- Select “file” and select “open”.
- Open “EcoStep Model”.
- Select “view” and then select “report view”

After step 5, both the input page and output page will be displayed. However, due to the program design, they are initially oriented in an impractical way. To make it easier to enter inputs, select “top” from the pull down menu on the top of the screen. This action will place the input fields on top of the screen and outputs on the bottom(Figure A2).

Figure A2: Screen shot of the model when a shoe design is ready to be entered.

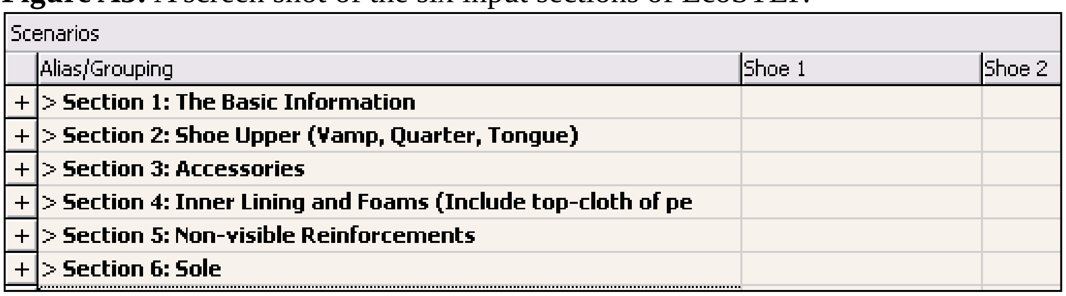


The Input Sections

This manual walks you through the process of entering a shoe by describing each field in detail while giving an example of how to enter a Cotton Satire the model. To follow the example, look for the  through the user's manual. First time users of this model should practice entering the Cotton Satire shoe into EcoSTEP by following the instructions embedded with the user manual. In doing so, you will become acquainted with the input fields for EcoSTEP. Also, note that Cotton Satire is also the shoe to which all other shoes are compared when assessing the environmental impact.

The interface is separated into six sections: basics, shoe upper, linings and foams, accessories, reinforcements, and the sole (Figure A3).

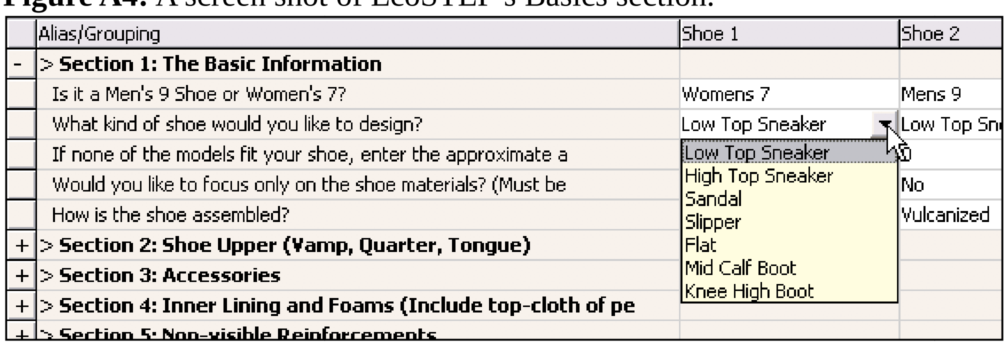
Figure A3: A screen shot of the six input sections of EcoSTEP.



<u>**The Basics**</u>

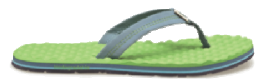
The "basics" section allows you to select the shoe type, construction method, and intended gender of the customer (Figure A4).

Figure A4: A screen shot of EcoSTEP's Basics section.



There are two options for entering the shoe area. If you are designing a shoe that falls into one of the 8 categories listed below, select that option in the pull-down menu (Table A1).

Table A1: Summary of the seven shoe categories, with the upper surface areas of men's and women's.

Shoe Category	Area of Women's 7 (in^2)	Area of Men's 9 (in^2)	Shoe Image
Sandal	8.94	9.62 in^2	
Flat	41.98 in^2	n/a	
Slipper	42.67 in^2	45.88 in^2	
Low-Top Sneaker	68.82 in^2	74 in^2	
High-Top	76.39 in^2	82.14 in^2	
Mid-Calf Boot	214.03 in^2	230.14 in^2	
Knee-High Boot	280.78 in^2	n/a	

However, if you want to design a shoe that does not fit into one of these categories, you can enter the approximate shoe upper area instead. You do not have to measure the shoe area but instead use the shoe areas on the pull-down menu or the chart above as guidelines.

<u>The Basics Fields</u>

Field 1: *Is it a men's 9 shoe or a women's 7 shoe?*

By selecting men's or women's shoe type, you are selecting the sole area for the shoe and, in combination with Field 2, the surface area of the upper type.


If you were entering a Cotton Satire, you would select "Women's 7" from the pull down menu.

Field 2: *What kind of shoe would you like to design?*

This section has a pull-down menu of the type of shoes that can be designed. Each shoe design corresponds to a specific upper area which is listed next to the shoe type in the pull down menu.


If you were entering a Cotton Satire, you would select "low-top sneaker."

Field 3: *If none of the models fit your shoe, enter the approximate area of the shoe upper in square feet.*

This section allows you to input the surface area of the upper in in^2. The purpose behind this section is to accommodate a shoe with an unusual upper. The typical upper areas are in the pull-down menu in the previous section. Therefore, if the size of the upper design you are modeling is between two other upper designs, you can estimate the upper surface area of the shoe you are designing. For example, if you want to create a shoe that is more than a flip-flop but is still a sandal, then you can enter something that is more than 8.94 in^2 but less than a flat (41.98 in^2). If you do not need to define your surface area, just leave it blank.


This section would remain blank if you were entering a cotton Satire.

Field 4: *How was the shoe assembled?*

In this section you have the option to select one of three assembly processes: die cut, vulcanization, or cold cement. Each process uses a different amount of energy and adds to the overall environmental impact.

If you were entering a Cotton Satire, you would select “Vulcanization” as the assembly process used.

The Upper

In the upper section, you can select the specific material type from a variety of materials and blended materials for the surface of the shoe. You can also select how much (in percent) of the upper the selected material covers (Figure A5).

Figure A5: A screen shot of EcoSTEP’s upper section.

	Alias/Grouping	Shoe 1	Shoe 2
+	**> Section 1: The Basic Information**		
-	**> Section 2: Shoe Upper (Vamp, Quarter, Tongue)**		
-	**>> Primary Upper**		
	What is the primary material used for the upper?	Wool	- None -
	What % of the upper does this material cover?	100	0
	What % of the upper does this material cover as an overlay (	10	0
+	**>> Upper 2**		
+	**>> Upper 3**		
+	**>> Upper 4**		
+	**>> Upper 5**		
+	**>> Upper Blend 1**		
+	**>> Upper Blend 2**		
+	**> Section 3: Accessories**		
+	**> Section 4: Inner Lining and Foams (Include top-cloth of pe**		
+	**> Section 5: Non-visible Reinforcements**		
+	**> Section 6: Sole**		

If one material is designed to layer on top of another, you can use the “overlay” section on the interface. For example, if a piece of cotton is laid over a basic hemp upper, you should enter the hemp as the upper material, and the cotton as a second overlay material.

Section 2: Shoe Upper

Field 1: *What is the primary material used for the upper?*

In this field, you select the material that covers the majority of the upper.

Select “cotton.”

Sub-field 1: *What % of the upper does this material cover?*

After the material selected, enter in the % of surface that material covers. For example, if half of the upper consisted of leather, you would enter “50”.

Enter “100”, since the entire upper is made of cotton.

Sub-field 2: *What % of the upper does this material cover as an overlay (or second layer)?*

If any of the material overlays another material in the upper, than enter in the amount of upper area is covered. Enter in the overlay even if it overlays the same material (i.e. leather overlaying leather).

Enter “10”, since about 10% of the upper has cotton overlaying cotton.

Fields 2-5: *Additional Upper Materials*

These fields are essentially identical to Field 1. Just repeat the steps for field 1 for each upper material.

Select synthetic rubber and enter “10” in the overlay category.

Field 6***:*** *If there is a blended material in the upper:*

A blended material is any woven material that consists of two or more fiber sources, such as a cotton/nylon blend.

Entering in information about blended materials is similar to entering in information about non-blending materials. The only difference is that you have to enter in the composition of the blend (i.e. a 50/50 mix, a 20/80 mix, etc.). Before you move on, make sure that the percentages in the blends add up to 100%.

SubField 1: *What is the 1st fiber in this blend?*

Similar to Field 1, simply select one of the types of material.

This subfield would remain blank if you were entering a cotton Satire.

SubField 2: *What % of the blend is this fiber?*

In this sub-field, enter in the amount of the previous material, in %, that is in the blend.

This subfield would remain blank if you were entering a cotton Satire.

Subfield 3-4: *Repeat this processes outlined in field 6. Make sure the percentages in the blends add up to 100%.*

Subfield 5: *What % of the upper does this blend cover?*

Similar to pervious fields, enter in the % amount of upper surface the blended material covers.

Subfield 6: *What % of the upper does this blend cover as an overlay?*

If this material overlays another material, enter in the amount of surface area of the shoe has this overlaid material.

This subfield would remain blank if you were entering a cotton Satire.

Field 7: *Upper Blend 2*

If there is more than 1 blended material used in the shoe upper, repeat field 6.

This field would remain blank if you were entering a cotton Satire.

<u>Section 3: Accessories</u>

The accessories section is for the entering of discrete information such as shoelaces and eyelets.

Field 1: *What material is used for the laces?*

You guessed it. Select the material used for the laces. For most Simple Shoes, the typical material would be either cotton or organic cotton.

You would select “organic cotton” as the lace material for the Cotton Satire.

Field 2: *Eyelets and vents*

Subfield 1: *What material is used for the eyelets and vents?*

Select a material used for the eyelets and vents. Typically, these components are made out of nickel.

You would select “copper” as the eyelet material.

Subfield 2: *How many eyelets and vents are on the shoe?*

Enter the number of eyelets on a single shoe.

Enter “12” as the number of eyelets and vents.

Fields 3-5: *Additional accessory information*

These fields are similar to eyelets but include snaps, buttons, and buckles. In each field, enter in the accessory material and the number of accessories.

For these sections, snaps and buckles and typically made of brass, and buttons are typical made of PET.

These fields would remain blank if you were entering a cotton Satire.

Field 6: *Zippers*

Similar to other accessories, enter in the material used to make the zippers in addition to the number of zippers. Additionally, enter in the average length of the zippers. Zippers are typically made of aluminum metal.

This field would remain blank if you were entering a cotton Satire.

Section 4: Linings

In the linings and foams section, you can enter information about the lining materials, including all non-visible materials between the lining and the outer upper.

This section is nearly identical to the upper materials section. The lining covers the entire inner-surface of the shoe.

Field 1: *What is the primary material used for the lining?*

In this field, you select the material that covers most of the lining. Cotton is the most commonly used lining material.

Select cotton.

Sub-field 1: *What % of the lining does this material cover?*

After the material selected, enter in the % of area that material covers. Frequently, one lining material covers 100% of the lining.

Simply input “100” into this field.

Sub-field 2: *What % of the lining does this material cover as an overlay (or second layer)?*

If any of the material overlays another material in the upper, than enter in the amount of upper area is covered. Enter in the overlay even if it overlays the same material (i.e. leather over laying leather).

This field would remain blank if you were entering a cotton Satire.

Fields 2-5- *Additional lining materials*

These fields are essentially identical to Field 1. Just repeat the steps for field 1 for each upper material.

These fields would remain blank if you were entering a cotton Satire.

Field 6: *If there is a blended material in the lining:*

Entering information about blended materials is similar to entering information about non-blended materials. The only difference is that you have to enter in the composition of the blend (i.e. a 50/50 mix, a 20/80 mix, etc.)

SubField 1: *What is the 1st fiber in this blend?*

Similar to Field 1, simply select one of the types of material.

SubField 2: *What % of the blend is this fiber?*

In this sub-field enter the amount of material, in %, that is in the blend.

Subfield 3-4: Repeat this processes outlined in subfield 1-2. Make sure the percentage of blends add up to 100%.

Subfield 5: *What % of the upper does this blend cover?*

Similar to previous fields, enter the % amount of upper surface the blended material covers.

Subfield 6: *What % of the upper does this blend cover as an overlay?*

If this material overlays another material, enter the amount of surface area of the shoe has this overlaid material.

These fields and subfields would remain blank if you were entering a cotton Satire.

Field 7: *Upper Blend 2*

If there is more than one blended material in the shoe upper, repeat Field 6.

This field would remain blank if you were entering a cotton Satire.

Field 8: *Sockliner*

Subfield 1: *What material is used for the pedbed?*

Select the material used for the pedbed. A typical pedbed would be made from polyurethane.

The material to select in this field would be polyurethane.

Subfield 2: *What material is used for the pedbed wedge?*

Enter in the material use for the pedbed. Often, the main material used in the pedbed will be the same as the pedbed wedge. Typically, pedbeds are made out of polyurethane or latex.

The material to select in this field would be polyurethane.

Section 5: Reinforcements

In the reinforcements section, you can enter optional materials that help to increase the structural integrity of the shoe.

Note: This section will involve entering components not visible to the naked eye and may require guessing the actual material used for the reinforcements. Check the specification sheets for further detail if possible. Recall that it is unnecessary to enter these if you simply want to compare, for example, a change in the material used for the upper.

Field 1-3: For these fields, simply select the reinforcement material used for the shoe. EcoSTEP will enter in the appropriate amount of material. Typically, shoes will have a toe box and heel counter made of sheet PET.

The material used for both the toe box and heel counter is "sheet PET". The arch cookie would remain "none".

Field 4: *Other reinforcements*

Use this field if there are additional reinforcements on the shoe not accounted for in the other sections. In this part, you need to select the material used for reinforcements in addition to the percent of upper that is reinforced by this material. For example, if half the shoe is reinforced by PET, enter in "50".

This field would remain blank if you were entering a cotton Satire.

<u>Section 6: Sole</u>

In this final section, you can input the numbers of insoles, midsoles, and outsoles into the interface, as well as a heel.

Field 1: *In/Midsoles*

Subfield 1-4: In these fields, enter in the material used for the insoles and the midsoles. These materials are used to strengthen the bottom of the shoe while still providing comfort. These components are assumed to be 2mm thick and the amount of material used is calculated within the model. Most shoes will have a layer of latex foam, redboard, and sheet PET

Select a layer of latex foam, redboard, sheet PET, and finally another layer of latex foam.

Fields 2-3: *Molded Midsoles (Midsoles have user-defined thickness)*

These fields allow you to enter in a midsole with a specific thickness. You only need to use this section if the thickness is different than 2mm, as it is assumed to be in Field 1.

First, select the material used for the sole. Second, select the thickness desired.

If you have already accounted for the insoles and midsoles with the standard 2mm thick options in Field 1, you can skip this selection.

These fields would remain blank if you were entering a cotton Satire.

Field 7: *Outsoles*

Subfield 1-2:

Input the outsole material and thickness in this section. Enter thickness in mm. Typical Simple Shoes are made out of recycled car tire and are 5mm thick.

Select “recycled car tire” and enter in “5” as the thickness.

Subfield 3: This section allows for the input for the foxing. Typical shoes use synthetic rubber.

Cotton satires use synthetic rubber for foxing.

Field 8: *Heels*

Subfields 1-2: Enter in the material type used in the heel as well as the heel length (in inches).

This section would remain blank if you were entering a cotton satire.

Calculating the Impact

When you are finished, click the “Calculate Now” button on the left hand side of the screen. The computer software will then calculate the impact of the shoe.

Additional Information and Options When Entering Data

Using the model to evaluate the impact of a single component.

Say you want to only want to assess the environmental impact of one component of the shoe and do not want to spend the time inputting an entire shoe. To do this, you simply enter information in the Basics section and then enter the fields you want to analyze.

For example, if you wanted to analyze the impact of a completely leather upper, first enter the required information in the Basics section. Next, select leather as the primary material in Field 1 of the Upper section and enter in “100” for the percentage of the surface area coverage. After you click “calculate now,” the environmental impact will be calculated.

Most Commonly Used Materials

Here are the most commonly used materials for different sections of the shoe.

Table A2: Most commonly used materials

Component	**Commonly Used Material**
Laces	Cotton
Eyelets	Copper, Nylon
Snaps	Brass, Nylon
Buttons	Brass, PET
Buckles	Brass
Zippers	Brass, PET, Nyon
Lining	Cotton
Pedbed	Polyurethane/ EVA foam
Pedbed Wedge	Polyurethane/ EVA foam
Toe Box	Sheet PET
Heel Counter	Sheet PET
Arch Cookie	Polyurethane/ EVA Foam
Other reinforcements	Sheet PET
In/Mid Sole Layers (3 layers are typical)	Latex foam, Redboard, and Sheet PET
Outsole (5mm thick)	Recycled Car Tire
Foxing	Synthetic Rubber

Materials to Avoid

The following three materials are the highest impact materials, in order of decreasing significance. These materials should be avoided whenever possible.

1. **Leather/ Suede**
2. **Wool**
3. **Natural Rubber**

Leather and wool require the raising of livestock, which in turn requires the raising of crops (which requires a large amount of fertilizers and pesticides), the consumption of water and processing of the material. Similarly, natural rubber comes from large plantations which use a large amount of fertilizers and pesticides.

Assembly Process to Avoid: Cold Cement

Cold cement has the highest environmental impact of all assembly process due to its high energy requirements. This process should be avoided whenever possible.

The Outputs

After you enter a pair of shoes into the model, you will get information about the projected environmental impact. The following is an explanation of the outputs.

There are 5 impact categories in which each shoe will be evaluated: human toxicity potential, global warming potential, eutrophication potential, freshwater ecotoxicity potential, and acidification.

Human Toxicity Potential: Potential harm to humans from toxins released to the soil, water, and the atmosphere.
Global Warming Potential: Potential climate change caused from atmospheric emissions.
Eutrophication Potential: Potential magnitude of anoxic water bodies caused by excess nutrients entering the ecosystem.
Freshwater Ecotoxicity Potential: Potential harm to freshwater ecosystems from toxins entering waterways.
Acidification Potential: Potential magnitude of acid rain caused by atmospheric emissions.

Further descriptions of these impact characters are below.

BOX A1: Characterization Factors	
Acidification Potential (AP)	The primary contributors to the impact category of acidification (AP) are NO_x and SO_2, which bond with water molecules to form their respective acids: H_2SO_4 and HNO_3. This interaction leads to a decrease in the pH of precipitation entering ecosystems (acid rain). The midpoint of this impact is acidification of ecosystems, which had potential for direct and indirect damaging effects. However, the potency of acidification of the emissions, the fate and transport of the emissions, and the sensitivities of the ecosystems on which acidic deposition falls can alter the resulting effect. Category endpoints of acidification are loss of biotic and abiotic natural environments, and loss of biotic and abiotic manmade resources. Acidification potential is measured in SO_2 equivalents.
Eutrophication Potential (EP)	Eutrophication is defined as excess nutrients in a particular system and is expressed in PO_4 equivalents. Nitrogen and phosphorus are essential elements in aquatic ecosystems, and are used by plants and algae for growth. However, excess nutrients can lead to increased algal production, which eventually die and deplete oxygen in the water body needed by fish and other animals. This creation of an anoxic environment is the category midpoint. Ecutrophication can result in an endpoint of fish mortality and completely altered biological assemblages.
Freshwater Ecotoxicity Potential (FETP)	Freshwater Ecotoxicity is toxicology concerned with the study of toxic effects measured in DCB equivalents, caused by natural or synthetic pollutants, to biological, chemical, or physical stressors that effect aquatic (not marine) ecosystems. Such stressors might occur in the natural environment at densities, concentrations or levels high enough to disrupt the natural biochemistry, physiology, behavior, and interactions of the living organisms that comprise the ecosystem. These harms are the midpoint of freshwater ecotoxicity potential. The category endpoint is a loss of biodiversity.
Global Warming Potential -100 years (GWP100)	Global Warming Potential is a measure of how much of a given greenhouse gas is estimated to contribute to the impact category of climate change, measured in kg CO_2 equivalents with a 100-year time horizon. Global warming is expedited by the emissions of greenhouses such as CO_2, CFCs and CH_4 that are trapped in the earth's atmosphere. Short wave solar radiation that reaches the earth is reflected as long wave radiation and may be trapped by the existing greenhouse gases in the atmosphere. This leads to a midpoint of increased average global temperatures and sea level rise. An endpoint of global warming that affects humans is loss of community and biodiversity.
Human Toxicity Potential (HTP)	The human toxicity potential, a calculated index that reflects the potential harm of a unit of chemical released into the environment, is based on both the inherent toxicity of a compound and its potential dose. Total emissions are evaluated in terms of dichlorobenzene (DCB) equivalents. The potential dose is calculated using a generic fate and exposure model, CalTOX, which determines the distribution of a chemical in a model environment. This model accounts for a number of exposure routes, including inhalation, ingestion of produce, fish, and meat, and dermal contact with water and soil. Toxicity is represented by the cancer potency $q1^*$ for carcinogens and the safe dose for noncarcinogens.

These five specific characterization factors were chosen out of many options for several reasons. First, they cover impacts on three spatial scales: local, regional, and global. For example, the release of toxins into the atmosphere affects human health on a local scale; the death of aquatic organisms caused by harmful substances entering freshwater systems is regional; damage to land through the deposition of acid rain is also regional; and climate change through greenhouse gas emissions is a global effect.

Another reason these characterization factors were chosen is that they cover a wide range of impacts. These impacts include negative effects on humans through HTP; water, through EP and FAETP; land, through AP; and air, through GWP.

Ten different characterization factors were originally assessed, but these five proved most substantial throughout the supply chain of shoes, whereas other impacts were negligible, and were therefore excluded. For example, toxicity potentials were usually the most significant impacts of shoe designs input into the model, but radiation potential was never a resulting impact.

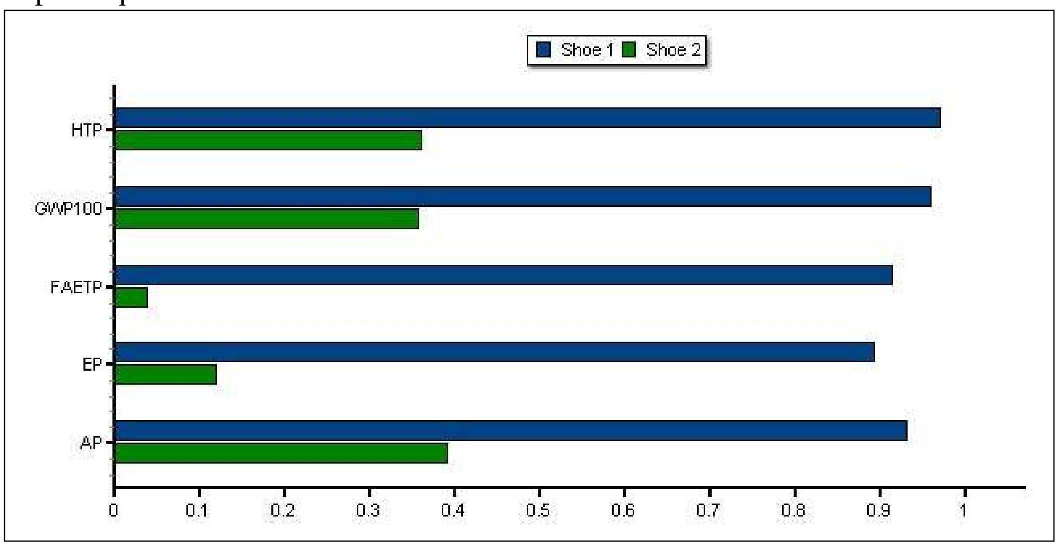
Finally, because these characterization factors portrayed the most substantial impacts, Simple Shoes' designers could use these them to know how their products were causing the most harm in hopes of mitigating that impact. In addition, Deckers management preferred these factors to others because they are easy concepts for consumers to understand. Deckers marketing strategy involves covering concepts in a simple manner. Human health, water, land, and air are categorical impacts that fit into this strategy (for details on the characterization factors, see Box A1).

Interpreting the Outputs

There are 4 sections in which the outputs are displayed and evaluated: *Comparing Shoe Design to a Cotton Satire Shoe*, *Environmental Impact of Shoe Components, Total Environmental Impact*, and finally *Translation of Global Warming Potential and Energy Required to Produce Shoes*.

Part 1: Comparing Shoe Design to a Cotton Satire Shoe (scoring system)

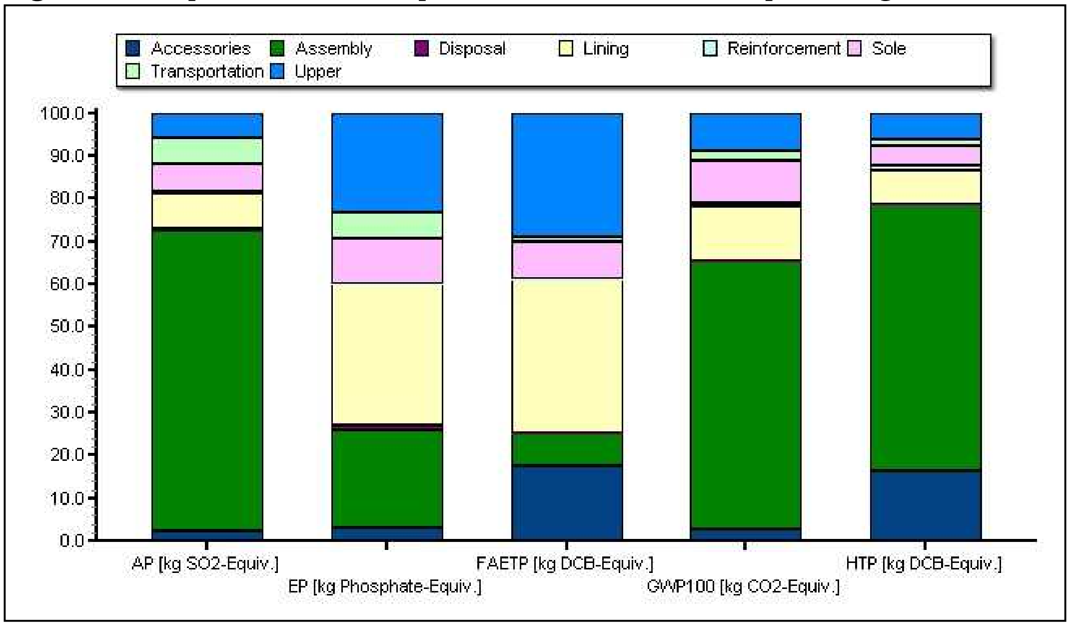
Figure A6: A comparison of two shoes. The units are in impacts of Cotton Satire impact equivalents



The first graph will compare in the impact of the shoe designs entered into EcoSTEP to a "standard shoe" (See Figure A6). For the purposes of this model, a traditional shoe has been defined as a Satire - cotton low-top sneaker. The impact of the standard shoe in all impact categories is "1". Therefore, if the results of your shoe are higher than one in an impact category, then your shoe has a higher impact than the traditional shoe. Similarly, if your shoe has an impact less than one in an impact category, than it has a lower impact than the standard shoe. Furthermore, if your shoe has an impact of two, then it has twice the impact of the standard shoe for that category.

Part 2: Environmental Impact of Shoe Components

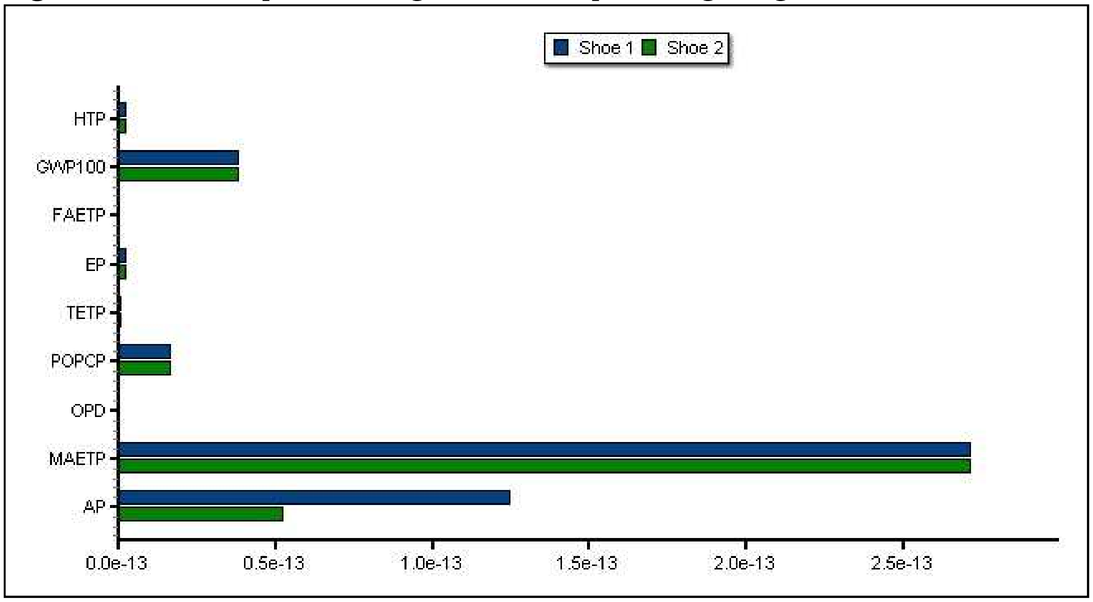
Figure A7. Impacts of shoe components across different impact categories.



After seeing the impact of complete shoes, you may want to find out which parts of the shoe contribute the largest environmental impacts (See Figure A7). This is what Part 2 is all about! In this section, the impact of each shoe is broken down by shoe section, followed by their impact categories. This feature allows you pinpoint the area of highest impact, change that aspect of the shoe, and then view the results to see if the impact is reduced.

Part 3: Total Environmental Impact

Figure A8: Total impact of designed shoes in percentage of global emissions



This section explains Part 1 of the report but in more scientific detail (Figure A8). The graphs in this section show the impact of the shoes as part of global world emissions (at 2001 levels). In other words, this section shows the shoe's contribution (in percent) to the overall environmental impact from all human activity in the world. As you would expect, the impact from one pair of shoes is VERY small (notice that the x-axis is in percentage of overall global emissions x 10^-13). While this section may not be used regularly, having this section allows the user to see what impact categories the shoes contribute the most.

Part 4: Translation of GWP and Energy used to produce shoes

Part 4 allows for a translation of the environmental impacts into the simplest terms possible. First, the impacts of global warming are translated into light bulb per year equivalents (how much greenhouse gases are released in terms of greenhouse gases generated a light bulb). This allows the user to have a frame of reference to the shoe's environmental impact.

Next, the energy used to make the shoes is estimated. The more energy used to make shoes, the higher environmental impact the shoe likely has, especially in global warming potential and acidification potential.

Additional Information

Thank you for using EcoSTEP. If you have any further questions about the model, please see http://fiesta.bren.ucsb.edu/~footprint/team.html.

APPENDIX B: LIFE CYCLE ASSESSMENT

Life Cycle Assessment

LCAs have proven increasingly popular tools as awareness of environmental issues has become more prominent. LCA was developed during the 1960s when natural resource scarcity first became a major concern (US EPA, 2006). The Coca-Cola Company was the first major firm to conduct a voluntary analysis and its approach became the basis for current LCA projects in the United States. The company determined that plastic bottles were less energy intensive than glass bottles due to the weight difference and its effect on transportation efficiency (ecomii.com, 2009). Interest in LCAs waned during the next decades until the issue of solid waste became prominent in the late 1980's (US EPA, 2006). Concerns over methodological inconsistencies were voiced by manufacturers, which led to the development of a standard LCA approach created by the International Standardization Organization (ISO) in 1997. These standards have been revised many times since their inception and are now in the 2006 edition. ISO 14040 and 14044 state that a comprehensive LCA consists of four stages: goal and scope definition, inventory analysis, impact assessment, and interpretation.

Goal and Scope

Goal and scope is the phase in which the product system is defined. The goal of an LCA states and justifies the aim or objective of the study, the intended application of the results. It also states the people involved with the study such as the stakeholders, the initiator, and the practitioner. The scope of an LCA defines the temporal, technological, and geographical coverage of the study.

While determining the scope of the LCA, the functional unit and reference flows must be defined. The functional unit describes the primary function(s) fulfilled by the product or system (USEPA, 2006). This unit serves as the unit of comparison that assures that one or more alternative products or systems can be treated as functionally equivalent. Careful selection of the functional unit will improve the accuracy and outputs of the study. Having defined the functional unit, the amount of product or products necessary to fulfill the function must be quantified. The result of this quantification is the reference flow (Guinee, 2001).

Inventory Analysis

The life cycle inventory analysis is essentially the data collection stage of a scientific study (ISO 14040). The processes within the system boundaries are assessed for their inputs and outputs. These inputs and outputs are the elementary and intermediate flows that are tracked throughout the product's life stages. The elementary flows of the system are the energy and material flows directly from the environment or directly entering the environment, such as extracted coal and carbon dioxide. Intermediate flows are energy and material flows within the product system, such as product parts. These flows are quantified to determine the potential environmental impacts associated with the functional unit (Guinee, 2001).

Two challenges of the inventory analysis are determining and justifying which processes are to be included and excluded, and allocation of elementary flows if a process has more than one economic output (Guinee, 2001). For example, recycling processes require assumptions concerning the allocation of environmental impacts. Recycled products that enter other supply chains (e.g. produced car tire made into shoe sole) present the challenge of where to allocate the environmental impact of the original product (ecodesignguide.dk, 2005). To address allocation, the LCA may include the additional system of the alternative economic output, or decide and justify where to draw the boundary of the study (Nyland et al., 2003).

Impact Assessment

A life cycle impact assessment (LCIA) is aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system (ISO14040). It is the phase in which the results of the inventory analysis are further processed and interpreted in terms of environmental impacts. According to ISO 14040, the mandatory elements of an impact assessment include these elements:

- the selection of impact categories, category indicators and characterization models
- classification, or assignment of LCI results to impact categories
- characterization, or calculation of category indicator results.

Choosing a comprehensive set of robust scientific impact indicators is one of the main challenges of an LCA because the chosen indicators to include in the study and these decisions must be justifiable. The modeling results are calculated in the characterization step and an optional normalization serves to convert the impact results into a percent contribution to a worldwide or regional total. Finally, the category indicator results can be grouped and weighed to include societal preferences of the various impact categories.

According to ISO14044, various impacts are classified into broad categories that are relevant and appropriate for the goal and scope of the LCA (for example, climate change). A category indicator, representing the quantifiable amount of impact potential, can be located at any place between the LCI results and the category endpoints (for example, kg CO2 equivalents). There are currently two main impact assessment methods: (1) problem oriented impact assessment (IA) methods stop quantitative modeling before the end of the impact pathway and link LCIA results to defined midpoint categories (or environmental problems) like acidification, and (2) damage oriented IA methods, which model the cause-effect chain up to the endpoints or environmental damages, link LCIA results to endpoint categories such as loss of biodiversity.

Environmental mechanisms, or impact pathways, must be understood by the conductor of the LCA in order to translate a system's environmental impacts. Impact pathways consist of linked environmental processes and express the causal chain of subsequent effects originating from an emission or extraction (environmental intervention). For example, sulfur dioxide emissions are the source of an impact pathway, which reacts with water to form acid rain. This rain deposits onto land and water bodies which may lead to the pathway's midpoint, an acidified lake. If the lakes pH balance decreases, fish mortality may increase which finally leads to the pathways endpoint - a loss in biodiversity.

Category endpoints (or consequences) must be identified for this impact category. For example, climate change endpoints are loss of community and loss of biodiversity. A suitable category indicator that clarifies the cause of the environmental impact must be defined. In the case of climate change, the category indicator is radiative forcing (in watts/meters^2). LCI results explain what contributes to the indicator and must be identified. A characterization model converts the assigned LCIA results to the common unit of the category indicator. The characterization model for climate change was developed by the Intergovernmental Panel on Climate Change (IPCC) and describes the global warming potential of different greenhouse gases. This characterization model is used to derive the characterization factor, or the potential environmental harm. The characterization factor of climate change is Global Warming Potential for a 100-year time horizon (GWP100) for each greenhouse has emission to the air (in kg carbon dioxide equivalent/kg emission).

Interpretation

Life cycle interpretation is the final phase of the complete LCA and aims to check the results of inventory analysis and impact assessment against the goal and scope definition of the study. This phase is when all choices and assumptions made during its course are evaluated in terms of soundness, robustness, consistency, and completeness. If the assumptions are determined to be sound, overall conclusions are drawn, limitations are recognized, and recommendations are made (ISO14044). The main elements in the interpretation phase are an evaluation of results and the formulation of the conclusions and recommendations of the study.

Sensitivity and uncertainty analyses study the effect of variations in process data, boundary, allocation choices, modeling choices and other variables. The objective of the sensitivity analysis is to assess the reliability and robustness of the indicator results. A consistency check determines whether the assumptions, methods, models and data are consistent with the goal and scope of the LCA study and with each other. Examples are consistency in data quality along a product life cycle or between different product systems, regional and temporal aspect, allocation rules and system boundaries, and impact assessment. Using this interpretation, conclusions can be made based on the significant findings and their robustness.

Appendix B References

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APPENDIX C: BUILDING THE GABI MODEL

Introduction

This appendix outlines the technical details for building the EcoSTEP model in the GaBi4 LCA software. As such, this section is intended solely for readers interested in a step-by-step direction for building the LCA model as well as the user interface. Such readers may be future Bren master's project groups working with Deckers or other companies exploring the incorporation of a flexible GaBi model into their decision-making process.

Creation of a GaBi model begins with conceptualizing the organizational structure of the various plans and processes. Hierarchical structure allows certain aspects of model-building, such as parameterization, to be built correctly into GaBi. Parameters serve various functions, and they are created and disseminated to different parts of the GaBi model calculations depending on their purpose. Once the GaBi model was built and parameterized, a user interface was created using I-report, an extension of the GaBi software. EcoSTEP interface was configured using the various features offered in the I-report extension.

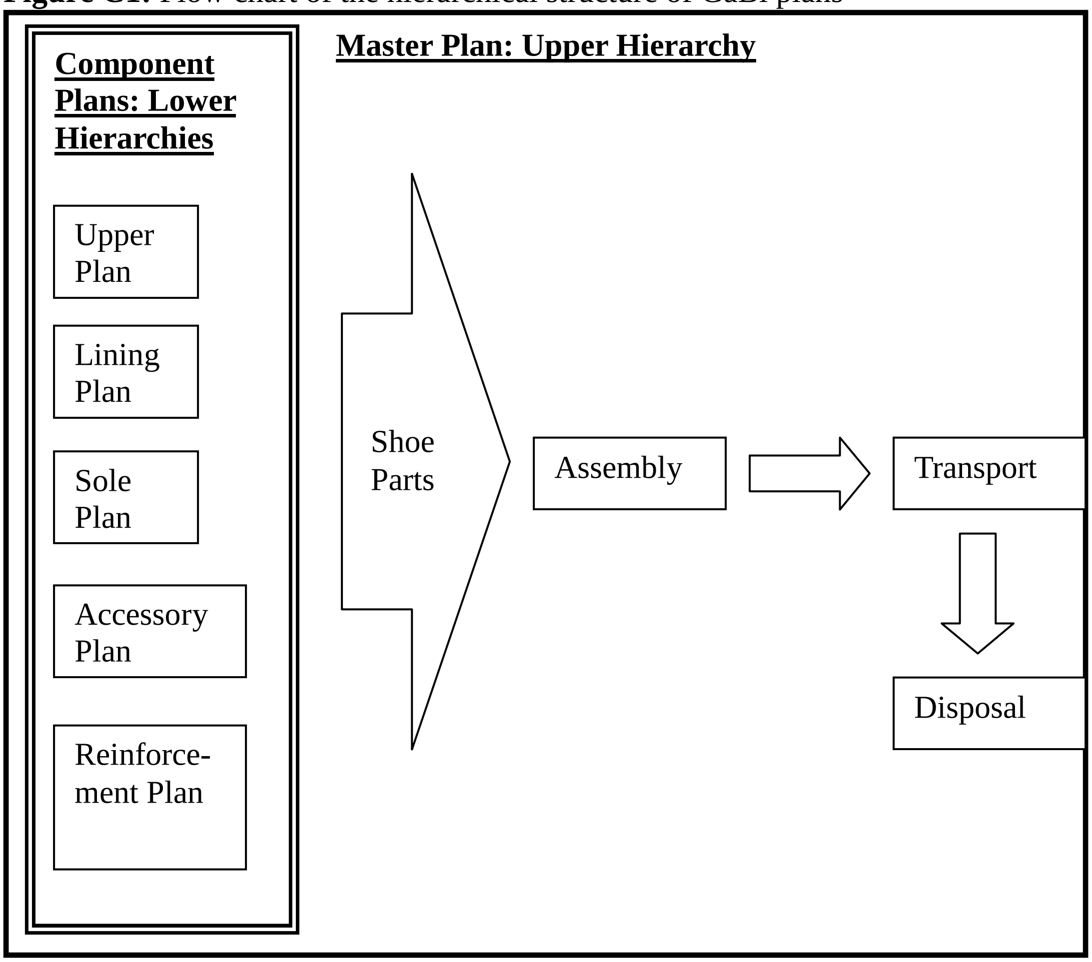
Outline

- GaBi Plan Organizational Structure
- Hierarchies and Types of GaBi Parameters
- Parameter Implementation in EcoSTEP: An Example
- Parameter Explorer and I-Report: Making EcoSTEP Possible
- Configuring the Parameter Explorer
- Subsets: The Face of EcoSTEP
- Indexing: Finishing Touches to EcoSTEP

GaBi Plan Organizational Structure

The GaBi plans were layered for the calculations to be executed correctly. A *plan* is a schematic of the manufacturing of the material or product in question. A plan may contain any number of processes representing the life cycle phases of the product: material production, assembly, transport, use, and recycling and disposal. Plan hierarchies allow for visual categorization of shoe components, allowing for easy navigation when building the model. Also, the hierarchies allow the modeler to identify and isolate specific sub-plans that may have calculation errors. EcoSTEP only consisted of the two plan hierarchies seen in Figure C1.

Figure C1: Flow chart of the hierarchical structure of GaBi plans



The lower level is comprised of the **shoe component plans**, which calculate how much of each material is needed for the shoe. The shoe component plans are nested within the upper mode, or ***Master Plan*,** which is where the assembly, transportation, and disposal occur. The Master Plan combines all components in the *Assembly* box, and the resulting shoe pair is transported and then disposed.

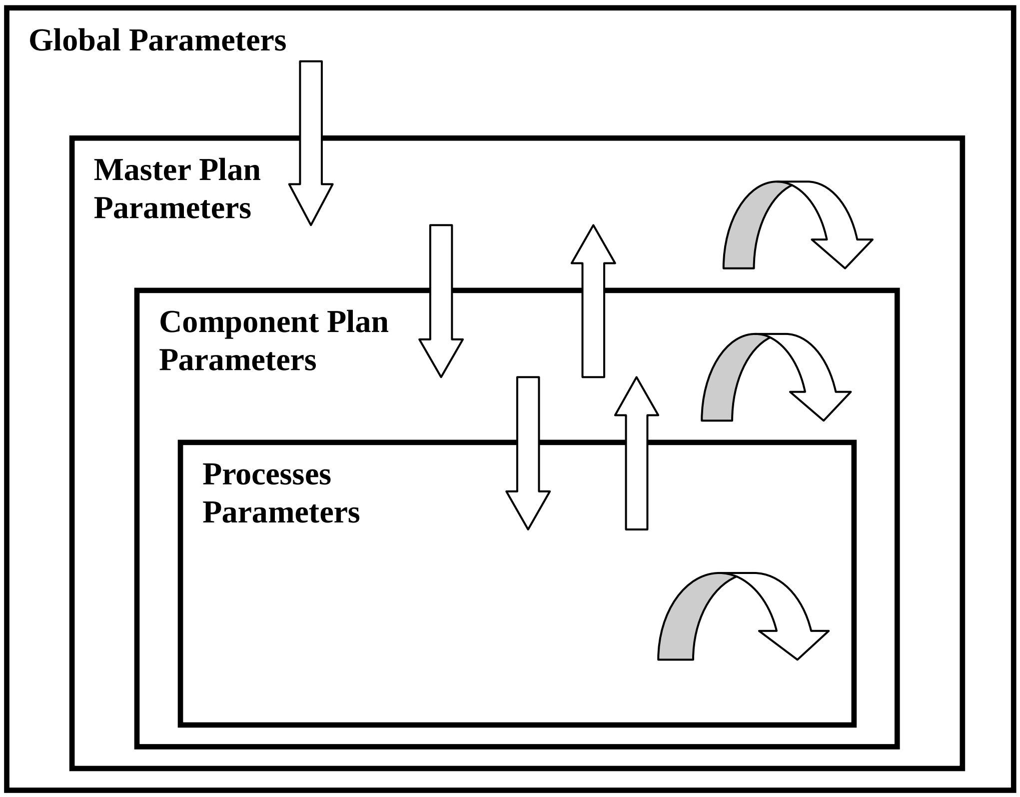
While it was possible to create the model in a single plan, the sheer number of material processes that needed to be displayed made this impractical. Therefore, related processes were categorized into the lower component plans that ultimately converged in the master plan.

Hierarchies and Types of GaBi Parameters

The GaBi model was set up to allow for input variations. The change in inputs results in the cascading of changes in the calculation of the environmental impact based on how much of which material are required for the chosen shoe. Varying inputs were reflected by the mass of intermediate flows changing in the model. The change of the elementary flows occurs throughout the product system. Consequently, the varying elementary flows affect the environmental impact category calculations. To allow user inputs, *parameters* were utilized extensively. The advantage of using parameters is that a single value can be utilized in multiple plans and processes in the model. According to the defined value of the parameter, change in calculations will cascade throughout the model. EcoSTEP allows the user to vary numerous parameters to accurately build different types of shoes in various materials.

In GaBi it is important to understand that there are three hierarchies of parameters - *global*, *plan*, and *process* – and to be able to use each appropriately. Essentially, parameters are critical for referencing important values and equations at one or more points in the model. Parameters in GaBi can reference one another and calculated values can be passed from process to process or from plan to plan (Figure C2). However, global parameters cannot be defined by another parameter; they are only defined by numerical values as determined by the user.

Figure C2: Flow of information among different hierarchies within a GaBi model, as indicated by arrows.



The arrows indicate the flow of information that can be passed from different hierarchies in the model. The curved arrows indicate that parameters can be passed within the same hierarchy as well. As the figure shows, all parameter values, except for global parameter values, can be defined by another element in the model. The properties of the different parameter hierarchies are summarized below:

- **Global parameter** values can be referenced by any plan or process within the GaBi database, but cannot be defined by any parameter in the database
- **Plan parameters** can be referenced by plans or processes.
- **Process parameters** can only be referenced within the process, other processes within the plan, or by the plan itself.

Parameters can also be categorized depending on its usage: value, formula, and conditional parameters. Regardless of the usage, parameters can be referenced by one another, given that they are defined in the appropriate hierarchy.

Value parameters are the most straightforward type of parameter. The value parameters simply represent numbers that were acquired through measurement, research, or provided by the client. Value parameters are extremely useful when certain values need to be disseminated to multiple parts of the model (e.g. mass to area ratio of a fabric) for the purpose of calculations. Value parameters can act like placeholders in various parts of the model calculations. Then, the parameter can be varied depending on the need of the user, and the formulas that reference the parameter will change accordingly. A majority of these parameters were mass to area ratio values found through measurement or research. Additionally, researched values such as volume density of foams and metals were part of value parameters. Since area and volume density and other value parameters were used by all component plans and some processes in the master plan, most were created as global parameters. However, there were some values that were largely irrelevant outside of a plan such as the volume of an arch cookie. These were created as plan parameters in the *Sole* plan. As long as the value can be correctly referenced in the Sole plan, it is inconsequential where the value is created.

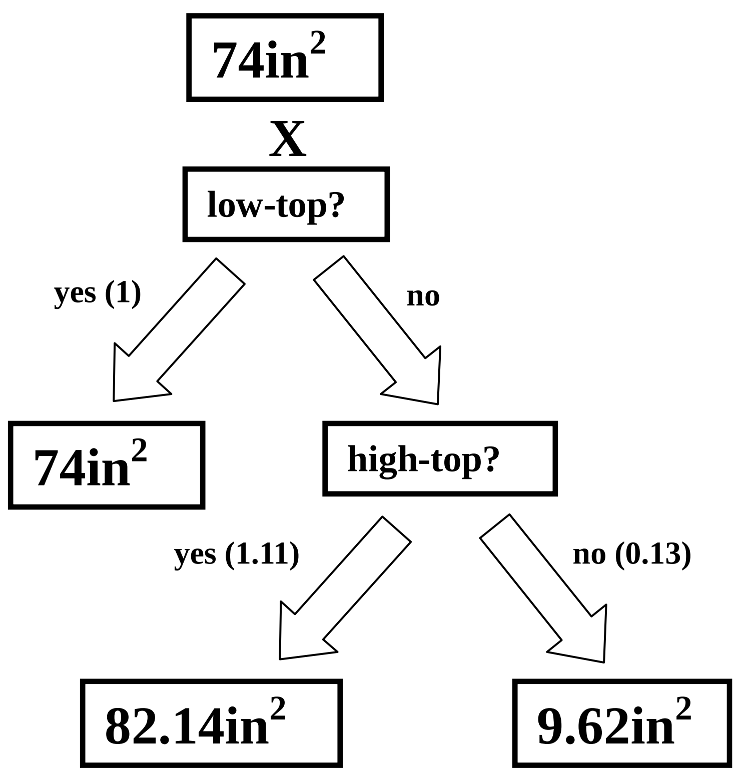
Another essential function value parameters fulfill is that they act as place keepers for future inputs made by users, such as the percent coverage of the upper by a certain material. These values need to be left flexible, so that the user can input the appropriate value, and the model can reference the value to make the correct calculation.

Instead of single values, **formula parameters** contain equations that calculate necessary values for the model. Formula parameters reference value parameters (and conditional parameters) extensively. Formula parameters are very powerful tools because they can be used to calculate any value that is needed in the model. The only disadvantage is that values calculated in formula parameters become “fixed” in the model. That is, formulas cannot be altered by the EcoSTEP user interface. However, the value parameter referenced in the formulas can be changed, altering the resulting calculation of the formula parameter. Formula parameters were used extensively in calculating essential factors of shoes, such as the area, volume, and ultimately mass of various shoe components. The resulting values were passed on and referenced in calculations further down the chain of the model.

Although correct calculations can be made through value and formula parameters, they cannot determine whether certain values are necessary for the user. How does the model know that the user wants the mass of cotton and not hemp? How does the model know that it should calculate the area of a men’s 9 low-top sneaker? These are essential factors to consider in the calculations. For these purposes, the **conditional parameter** is the cornerstone of the EcoSTEP model. Conditional parameters, while technically identical to value parameters, introduce the flexibility needed for a predictable model. These parameters are simply whole integers where each number, depending on the parameter, is assigned a specific task to alter calculations in the model.

Essentially, conditional parameters allow for a mathematical expression of a decision tree. By utilizing if-then statements, the model was able to calculate the correct values by following the chosen “branches.” These conditional parameters were referenced extensively in formula parameters to create flexibility in the aforementioned formula parameters. Conditional statements allow the model to calculate different results depending on certain criteria (conditions) as determined by the inputs. Conditional parameters were used in formula parameters by using *if-then* statements. If-then statements work by verifying whether a certain condition is true. If the condition is true, a certain value (or parameter) is used; otherwise, a different value is used. However, GaBi parameters cannot be defined by non-numerical values. You cannot simply enter the word *cotton* into the formula; instead, you must enter a numerical value or a pre-defined parameter. This is where the conditional parameters are incredibly useful. For example, in the formula to calculate the upper surface of the shoe, the model can use a conditional parameter of the shoe style: low top, high top, or sandal. It was decided that the baseline area of a shoe upper would be a men’s size 9 low-top sneaker, which was measured to be 74 square inches. However, depending on the defined value of the conditional parameters, the model made additional calculations (Figure C3).

Figure C3: Flowchart of the decision tree expressed using equations in GaBi.



Using conditional statements, a formula parameter can be set up to calculate the correct area of a shoe upper. Since conditional parameters are technically identical to value parameters, and therefore not “fixed”, users can freely change their values on EcoSTEP. As this example shows, conditional parameters allow EcoSTEP to be the flexible, predictable model that is required by the client.

Parameter Implementation in EcoSTEP: An Example

Once the concepts of parameterization and the model calculations are grasped, actual development of EcoSTEP is as simple as creating the appropriate type and hierarchy of parameters and ultimately assigning them to the correct *intermediate flows*. Intermediate flows are the valuable materials and components that are transformed into the product. While these flows are not considered to have environmental impacts in the model *per se*, producing these materials results in *elementary flows* being extracted or released into the environment, causing impacts. A running example can best illustrate the process of building a flexible GaBi model. Here, a simple plan of producing a shoe upper will be shown with the following choices:

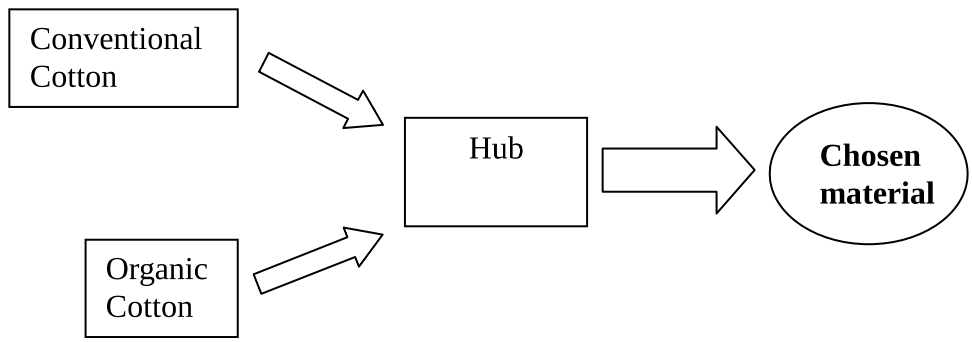
- Men’s or women’s shoe
- Low-top or high-top sneaker
- Conventional cotton or organic cotton for the shoe upper

Depending on the above decisions made by the user, the final type and amount of shoe upper material will vary.

Initial setup of the conceptual GaBi plan and the global parameters

GaBi operates strictly by linking the output flow of one process to the input of another process. Breaking this connection by faulty parameterization can lead to errors. For example, the upper component sub-plan has more than ten materials with which the upper can be manufactured, and a process is used to attribute the environmental burden of the extraction of the raw material. For the purpose of illustrating the concept, a simple choice between two materials will be shown (Figure C4). In this example, a central “hub” is created where all the available materials converge.

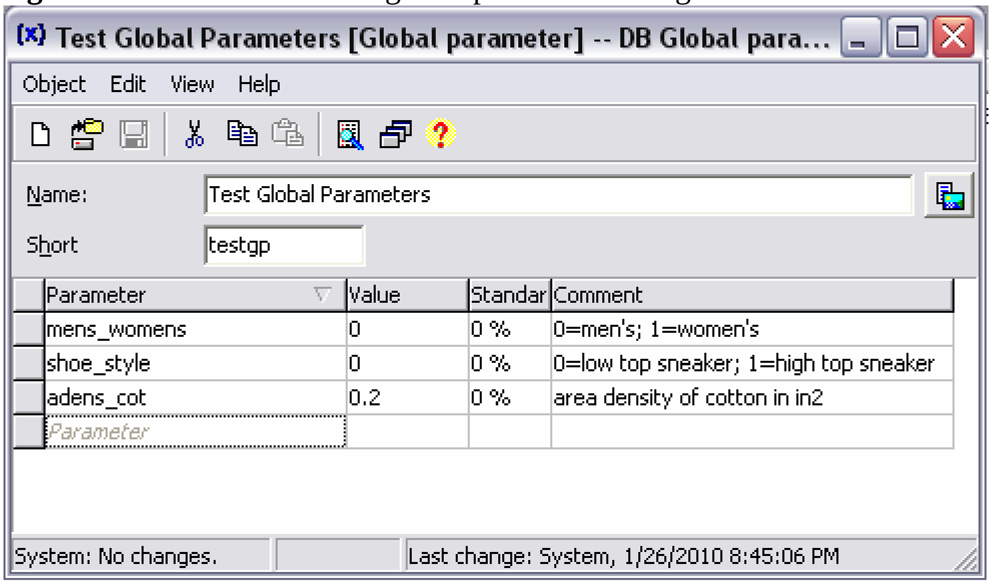
Figure C4: Simplified flowchart of the conventional and organic cotton processes connected to a hub, with the correctly chosen material leaving the hub.



Here, two materials—conventional cotton and organic cotton—are connected to the hub, or the material mixer. Each box represents the process necessary to produce the material represented by the name of box. The "Conventional Cotton" process represents all necessary raw material extraction and the pollutant release required to produce a certain amount of conventional cotton. This explanation is sufficient but highly simplistic; each process data is highly dependent on a series of assumptions and clearly established system boundaries. The hub process is the "material mixer" that has all the necessary parameters to ensure the mass of the chosen material is correctly calculated.

The foundations for setting up the correct calculations begin with first creating the conditional parameters as global parameters. A conditional parameter must be created in the model for each choice that must be available to the user. The choices for men's and women's shoe, and the style of shoe will be set up as global parameters so that they can be called up anywhere in the database. Also, the mass to area ratio of cotton, assumed to be the same between conventional and organic in this example, will be defined in the global parameter.

Figure C5: Screenshot of the global parameter configuration menu on GaBi



Creating equation parameters in plan and referencing global parameters

Using these conditional global parameters, the proper calculations can cascade down to the plan. The conditional, or if-then statements, is expressed in GaBi by the following equation:

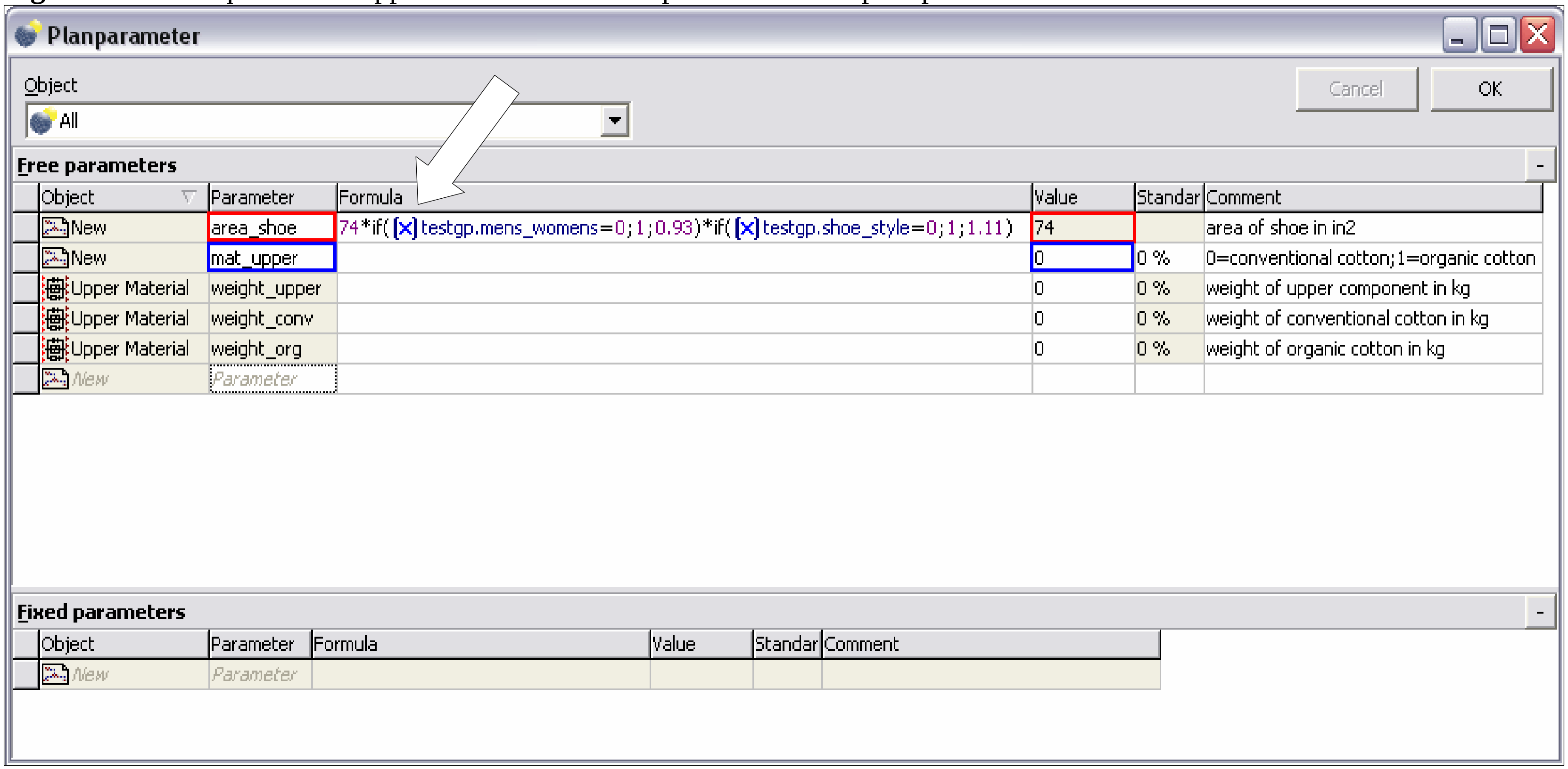
$$if\,(condition\,;Value1;Value\,2)$$

The formula is such that if the *condition* is found to be true, then *Value1* is used in the equation; if the *condition* is not met, then *Value2* is used instead. In the global parameters above, two conditional parameters are defined for calculating the upper area. In the model, the choice of a women's shoe must be made so that the baseline area of 74 square inches must be reduced by 7 percent. Also, high-top shoes have greater upper area, due to ankle area coverage; therefore, if the shoe style choice is high top, the model must increase the upper area by 11 percent. To correctly execute this calculation, the following equation is used:

$$Area_{Shoe} = 74 \times if\,(mens\_womens = 0;1;0.93) \times if\,(shoe\_type = 0;1;1.11)$$

By multiplying the two conditional parameters together, the correct upper area of any combination of men's and women's, and low top and high top shoe can be calculated in the model. The calculation of the actual shoe upper area is handled in the plan parameter, which is accessed by clicking the  icon in the main plan window (Figure C6).

Figure C6: The equation for upper area calculation expressed in GaBi plan parameter



The arrow in the image indicates the formula parameter that calculates the area of the shoe using the equation previously mentioned above. The first conditional statement deals with men's/women's. Global parameter *mens_womens* was created to represent this choice. As mentioned above, *0* is men's and *1* is women's. The conditional statement reads:

"if the shoe is a men's shoe (*mens_womens* = 0), then multiply the baseline by 1 (no change); otherwise multiply by 0.93. Also, if the shoe style is low top (*shoe_style* = 0), then multiply by 1 (no change); otherwise multiply by 1.11."

Because it was measured that a women's sneaker tends to be approximately 93 percent of a men's sneaker, this factor was used to scale the shoe upper if *mens_womens=1*. The same concept applies to *shoe_type*: if *shoe_type=0* (low top sneaker), then no change; if otherwise (high top sneaker), multiply by 1.11. Through measurement, the upper area of a high-top sneaker was found to be about 111 percent of a low-top sneaker. Conditional statements can also be nested, so that unlimited number of choices can be introduced, much like decision trees having multiple branches:

$$if\,(shoe\_type = 0;1;if\,(shoe\_type = 1;1.11;0.13))$$

Here, when the *shoe_type* parameter is not equal to 0, then instead of giving a value, the equation calls for another conditional formula. If the shoe type choice is not a low top, then the equation asks whether the shoe is a high top (*shoe_type* = 1). If it is, then the multiple of 1.11 is used as in the example above. If not, then another multiple, 0.13, is used to multiply with the baseline area of 74 square inches. By nesting the if-then formula, a string of options can be offered for a certain decision, much like a decision tree.

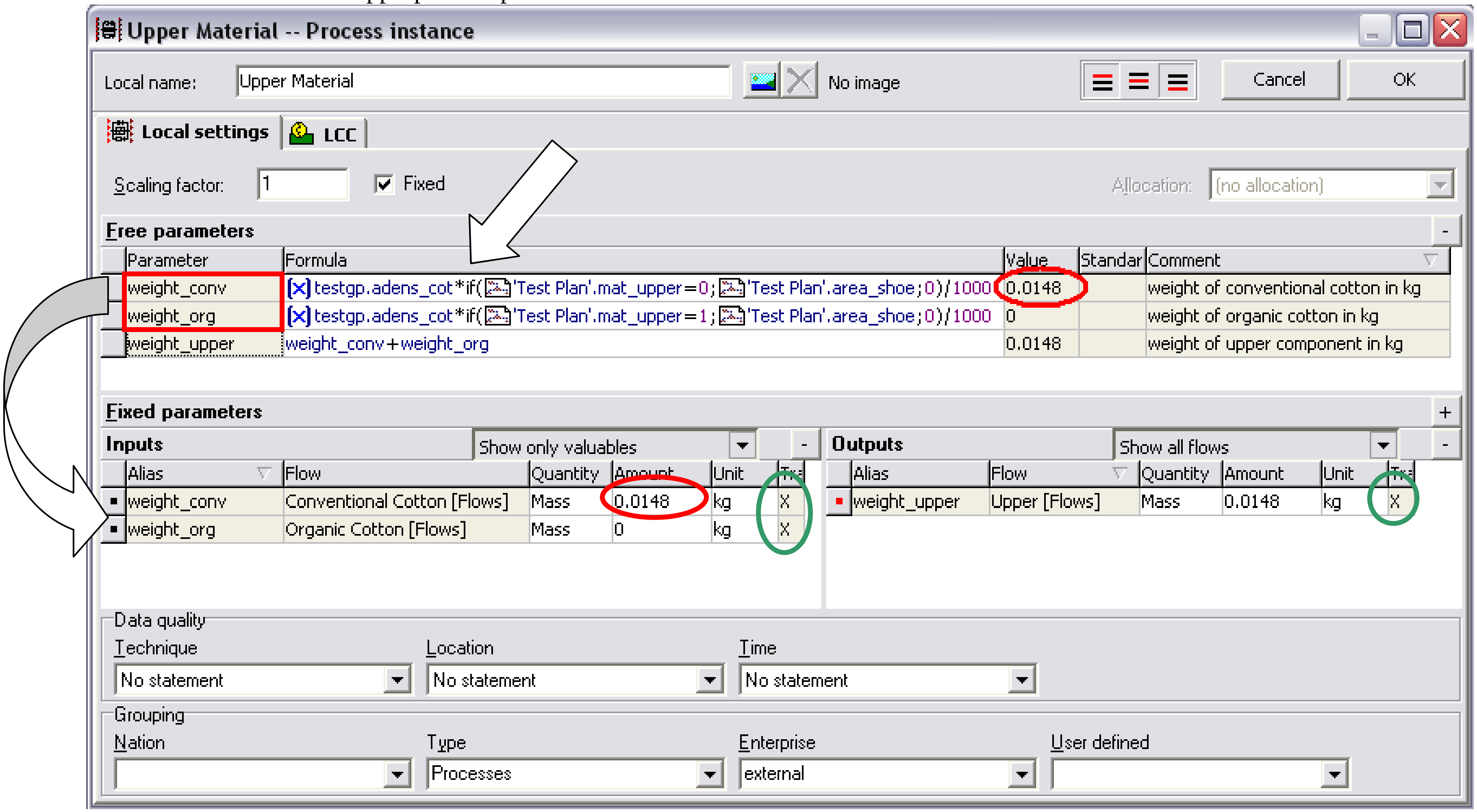
The parameter containing the equation to calculate the correct shoe area has been named *area_shoe* (highlighted in red in Figure C6) in the plan parameter window. The current global parameter setting results in the current shoe area as the baseline area of 74 square inches. However, the *area_shoe* formula parameter is dependent on the underlying global conditional parameters *mens_womens* and *shoe_style*. Also, the plan parameter *mat_upper* (highlighted in blue in Figure C6) is the conditional parameter between conventional and organic cotton. As the "comment" column explains, 0 means conventional and 1 means organic cotton. This choice will determine which process, conventional or organic cotton, will be triggered in the model.

Creating flows in processes and assigning values calculated in formula parameters

This sample plan has determined the shoe upper area and material choice; the model is now ready for creating parameters at the process level, then assigning the calculated values to flows. The material mixer process must now be set up to calculate the correct material and its mass using the area calculated in the plan parameter above. When a new process is created in a plan, there will be no flows or parameters when its details are accessed. It is important to recognize that there must be one input flow for each material under consideration. In this case, two materials, conventional and organic cotton, are considered. Therefore, there must be two flows that must be created under the input frame (Figure C7). Since the intended output of this process is a single material - cotton upper, only one output flow needs to be created.

After the flows are created, parameters must be created under the “Parameters” pane on the top of the process detail window. Formula parameters must be used to correctly calculate the mass of the required amount of cotton. Names must be assigned to each parameter under the “Parameter” pane at the top. Also, it is important to input a factor of *1* in the “Factor” column that appears once parameters are created. Once parameters are created, “Alias” columns become available in the input/output panes. A drop-down menu is created for each parameter created, and the correct parameter must be assigned to the appropriate flow. The two input flows, conventional cotton and organic cotton, will be assigned to the formula parameters *weight_conv* and *weight_org*, respectively. These formula parameters will calculate the correct mass of cotton as determined by the conditional parameters. The one output flow, the shoe upper component, will be assigned with the parameter *weight_upper* (Figure C7).

Figure C7: Screenshot of process editing window with the parameter creation pane showing the calculation and assigning of the correct value to the appropriate input flow



Also, it is important to check the "Tracked?" column with an *X* (highlighted in green in Figure C7); otherwise, the flows will not be considered intermediate materials that can get passed between processes. GaBi will instead recognize the flows as an elementary flow. In GaBi, elementary flow is not considered a valuable material, and is assumed to be a raw material that is extracted or released directly into the environment. Only tracked flow, or the intermediate valuable flow, can be passed along the product chain.

The creation of parameters and assignment to the correct flow can only occur in the *Database Process.* Database Process is the detail of the process that can be accessed from the main database window (titled "GaBi4") or right-clicking on the process in a plan and selecting "Details." The words *DB Process* can be seen on the window label. While formulas can be created at the DB Process window (preset GaBi processes often do), it is critical that any formula that utilizes *plan parameters and process parameters from other processes within the plan* are not created in the DB Process, but rather in the *Process Instance*. The Process Instance can be access through the plan where the process is being used. Instead of right-clicking to access the DB Process, the process is simply double-clicked. The words "Process Instance" should now be visible in the window label, as in the image above. Since this example uses plan parameters, the formula must be input from the Process Instance. The equation calculating the material weight is expressed as follows:

$$Weight_{Cotton} = adens\_\mathrm{cot} \times area\_shoe$$

The global parameter *adens_cot* is referenced in this equation as the conversion factor from area to weight of cotton. The plan parameter *area_shoe*, which is calculated in the plan parameter window, is also referenced and multiplied with the conversion factor *adens_cot*. The *weight_upper* is a simple formula parameter that adds the two previous parameters to find the total weight of the resulting cotton upper, which is 0.0148kg or 14.8g. This should have already been assigned to the output flow.

However, if this equation is applied to both *weight_conv* and *weight_org*, both parameters will calculate the amount of cotton needed, thus there will be double-counting of the required mass. The process must allow the choice of choosing either conventional or organic cotton. Therefore, the conditional parameter *mat_upper* from the plan parameter (Figure C6) is used to "switch off" the material that is not chosen. To do so, the above equation is altered:

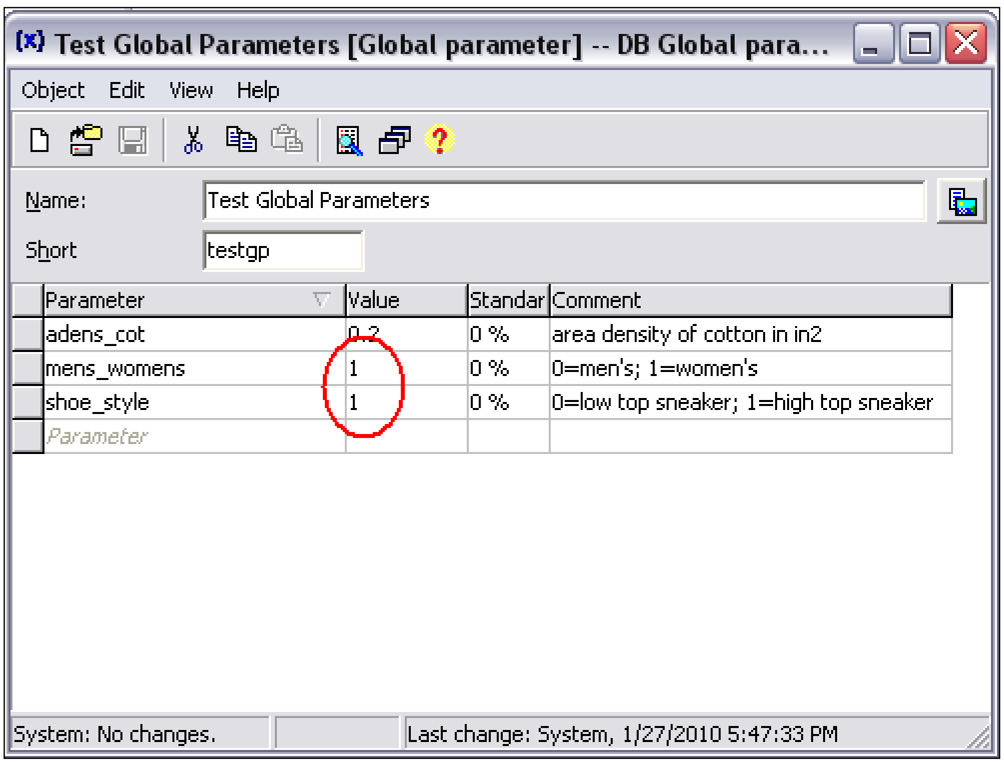
$$Weight_{CottonX} = if\,(mat\_upper = X; adens\_\mathrm{cot} \times area\_shoe; 0)$$

If the desired cotton material is conventional, then as dictated by the "comments" column of Figure A5.6, the conditional parameter *mat_upper* must be set to 0. In the formula parameter *weight_conv*, the value of X in the above equation is set to 0. As the if-then statement dictates, if *mat_upper* is 0, then the weight of the cotton will be correctly calculated in the *weight_conv* parameter. This calculated value will then be automatically assigned to the conventional cotton input flow. In the formula parameter *weight_org*, the value of X will be 1. Therefore, when *mat_upper* is 0, then the equation in the parameter will return a value of 0, as dictated by the if-then statement. The calculation of the weight of organic cotton has effectively been "switched off", because the material choice has been decided to be conventional (*mat_upper* = 0).

Testing the conditional parameters by changing the choices in conditional parameters

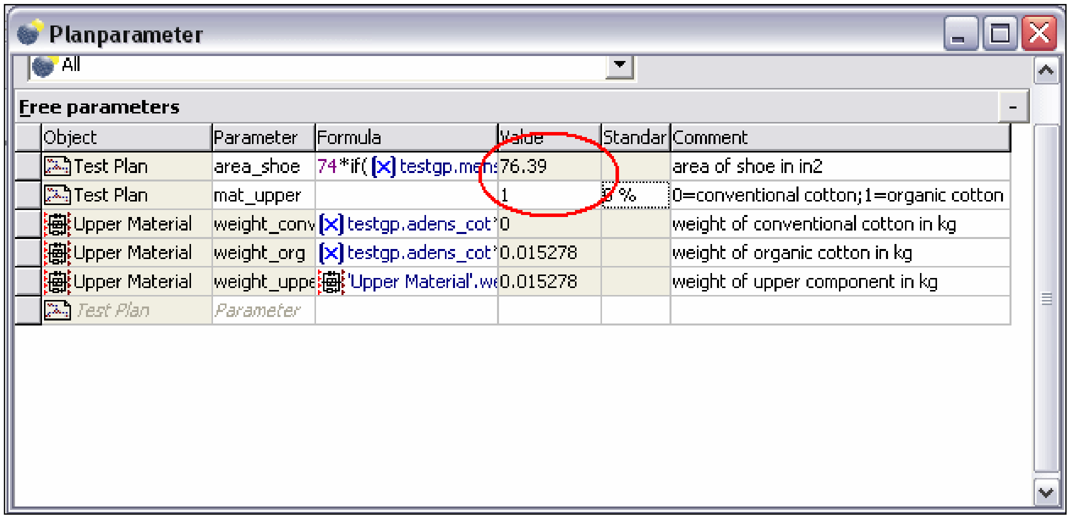
To determine whether the process is responding correctly to the conventional/organic and men's/women's choices, the appropriate parameters will be adjusted. The global parameter *mens_womens* will be changed from 0 to 1, to indicate a women's shoe (Figure C8).

Figure C8: Choices changed to women's shoe, high-top in global parameter window as circled in red



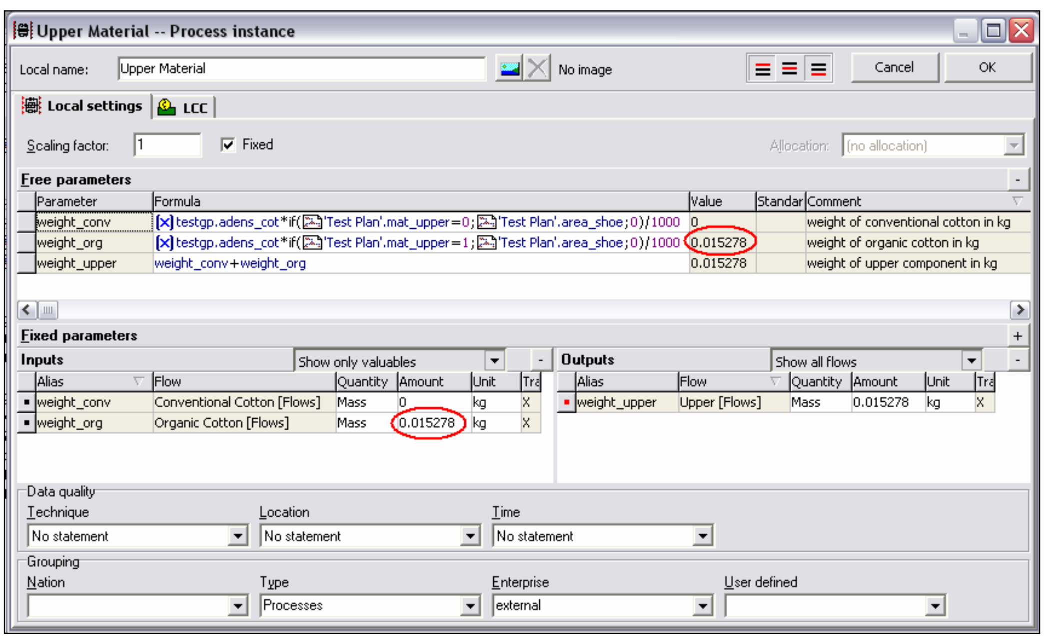
Also, the plan parameter *mat_upper* will be changed from 0 to 1, to indicate a high-top sneaker (Figure C9).

Figure C9: The area of shoe upper changed from the baseline of 74 square inches, circled in red



As expected, the calculated area of the shoe type (women's high-top sneaker) changes from 74in^2 to 76.39in^2 (Figure C9). The change in the surface area of the shoe upper cascades to a change in the calculation of the mass of cotton within the "hub" process. By changing the material choice to organic cotton (*mat_upper* = 1), the equation for conventional cotton can be switched off, and the equation for organic cotton can be switched on (Figure C10).

Figure C10: The amount of cotton needed is increased to 15.2g, and *weight_conv* parameter is switched off, while *weight_org* is switched on, circled in red



While this is a simple example with limited material choice, this technique allowed for the flexibility needed to have a predictive model that correctly calculates the required material of any style of shoe. By utilizing every type of parameters at all levels, EcoSTEP was created under the framework of the plan hierarchies.

Parameter Explorer and I-Report: Making EcoSTEP Possible

Once the sub-plans are connected with the master plan, with parameters referencing one another correctly, the underlying GaBi model is complete. However, the challenge of creating a simple user interface remains. At this point, the only way to change the material choice is to change the conditional parameters in the model directly in the master and sub-plans. It is cumbersome and impractical for a designer to learn the inner working of the GaBi model to make the appropriate changes. Moreover, clients without the proper GaBi license cannot access or change the models.

To avoid these problems, GaBi provides the *Parameter Explorer* feature that allows the modeler to compile all *free parameters* in the model. Free parameters include all parameters created in the model that are not fixed by a formula; that is, value and conditional parameters at all levels. Parameter explorer allows the user to view all the available parameters in one window, alter the parameters as needed, and run scenario analyses of the results.

In essence, I-Report is simply an additional GaBi feature that integrates the Parameter Explorer with customized environmental impact report. EcoSTEP is reality simply an I-Report file that uploads a Parameter Explorer configuration, allowing the designer to input the necessary information regarding a shoe being analyzed easily. The Parameter Explorer is also coupled with environmental impact results that are valuable and informative to the client.

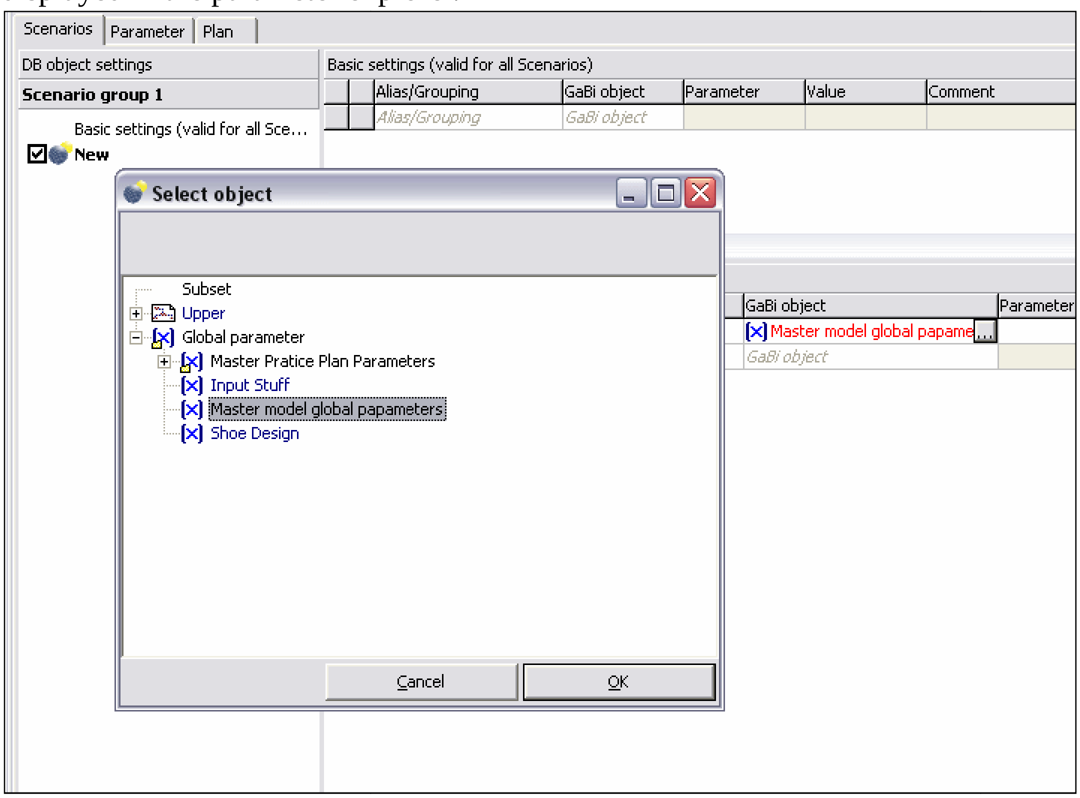
Within the model, the conditional parameters representing material choices are numerical integers (e.g. parameter *mens_womens* is defined as 0 = mens and 1 = womens). While conditional parameters are very powerful tools, it is not practical to require users to change numerical values of conditional parameters to the correct integer on the parameter explorer. Designers simply want to choose a men's shoe, they should not have to know to set the parameter *mens_womens* to 0. For this purpose, the *subset* features are extensively utilized in Parameter Explorer to further simplify the user inputs. Subsets assign non-numerical names to free parameters as needed. This allows the user to select the correct conditional parameter via a pull-down menu instead of having to change a numerical value.

Configuring the Parameter Explorer

The Parameter Explorer can compile all free parameters created within the plan or process, as well as the global parameter. Moreover, it can reference any plan or process parameters from sub-plans nested under the master plan. This function allowed the sub-plans and the master plan to work together. The Parameter Explorer function is accessed by clicking on the icon in the Master Plan window.

A window will open with the upper left tab set to the "Parameter" tab. All parameters available to change are shown here. Scenarios can be created under the "Scenarios" tab to the left of the "Parameter" tab. By default, a "Scenario group 1" will be activated with the scenario "New." These names can be changed as needed. For example "Scenario group 1" can be renamed to "EcoSTEP", and "New" changed to "Shoe 1." Initially, there will be no parameters selected for scenario analysis; therefore, the necessary parameters need to be selected from the list of available parameters. To browse the available parameters, the "GaBi object" column is selected. Once the gray box is clicked, another window will open for selecting the appropriate GaBi object from which to select the necessary parameters (Figure C11). A GaBi object range from global parameters, plans, sub-plans, and processes at all levels.

Figure C11: GaBi selection window with the global parameter selected to be displayed in the parameter explorer.



Once a GaBi object is selected, any parameters defined within the object can be displayed on the Parameter Explorer. Under the "parameter" column to the right, the parameters are shown in a pull-down menu; there is also a choice for “all free parameters” within the object. This is a useful option when creating many free parameters within one object. When “all free parameters” is selected, all global parameters created for EcoSTEP are displayed (Figure C12)

Figure C12: All free parameters from global parameter GaBi object

Scenarios

Alias/Grouping	GaBi object	Parameter	**Shoe 1**	Shoe 2	Comment
adens_cardboard	[x] Master mo	adens_cardb	0.27824	0.27824	area density in g/in2
adens_carpet	[x] Master mo	adens_carpet	0.41	0.41	area density of carpet
adens_cotton	[x] Master mo	adens_cotton	0.22371	0.22371	area density of cotton
adens_crepe	[x] Master mo	adens_crepe	1.7325	1.7325	area density of 3mm cr
adens_hemp	[x] Master mo	adens_hemp	0.17141	0.17141	area density of hemp ir
adens_jute	[x] Master mo	adens_jute	0.36667	0.36667	area density of jute (c
adens_latex	[x] Master mo	adens_latex	0.13476	0.13476	area density of latex ir
adens_linen	[x] Master mo	adens_linen	0.1006	0.1006	area density of flax line
adens_petfoam	[x] Master mo	adens_petfoam	0.195	0.195	area density of PET fo
adens_redboard	[x] Master mo	adens_redboard	1.4058	1.4058	area density of redboa
adens_rubbahyde	[x] Master mo	adens_rubbahyc	0.47641	0.47641	area density of rubbah
adens_rubber	[x] Master mo	adens_rubber	0.86312	0.86312	area density of rubber
adens_shpet	[x] Master mo	adens_shpet	0.32	0.32	area density of SH-PET
adens_suede	[x] Master mo	adens_suede	0.74	0.74	area density of 1.5mm
adens_synthetic	[x] Master mo	adens_synthetic	0.15799	0.15799	area density of synthe
adens_wool	[x] Master mo	adens_wool	0.34419	0.34419	area density of wool in
area_m9lowtop	[x] Master mo	area_m9lowtop	73.99	73.99	area of lowtop men's 9
area_m9sole	[x] Master mo	area_m9sole	33.62	33.62	area of men's 9 sole in
dens_aluminum	[x] Master mo	dens_aluminum	2.7	2.7	density of aluminum in
dens_brass	[x] Master mo	dens_brass	8.575	8.575	average density of bra
dens_carpet	[x] Master mo	dens_carpet	0.12	0.12	density of carpet pad i
dens_coconut	[x] Master mo	dens_coconut	1.2159	1.2159	density of coconut she
dens_copper	[x] Master mo	dens_copper	8.96	8.96	density of copper in g/
dens_crepe	[x] Master mo	dens_crepe	0.76694	0.76694	density of crepe rubbe

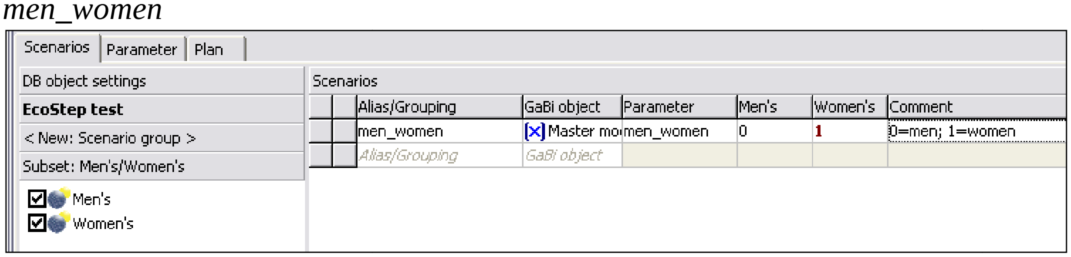
It is important to note that *only value parameters* should be displayed in the Parameter Explorer in this way. This includes the “place keeper” parameters that were created for future user inputs. Incorporation of the conditional parameters will be discussed in the following section. As shown above, the scenario “New” has been renamed “Shoe 1”, and another scenario named “Shoe 2” was created. New scenarios can be created from the left pane of the window. Up to 7 scenarios were created in EcoSTEP to allow multiple comparisons if desired. The “Alias/Grouping” column allows the parameters to be renamed only for the purpose of the scenario analysis; it will not change the model in any way. Instead of the parameter name *mens_womens*, which is not self-explanatory, the alias can be changed to a more understandable description, such as “Is the shoe a men’s or women’s shoe?” This feature further allows EcoSTEP to be user-friendly. This process is repeated for the master plan and the sub-plans to compile all the parameters needed for EcoSTEP.

Subsets: The Face of EcoSTEP

While conditional parameters introduce the flexibility needed in EcoSTEP, it is not very useful to a designer, who does not want to learn how to input the correct integer to get the desired result in EcoSTEP. Therefore, the *Subset* feature within the Parameter Explorer is used for every conditional parameter needed for EcoSTEP. As the name suggests, Subsets are sort of sub-scenarios that can be incorporated into the main scenario group, i.e. EcoSTEP. Subsets assign names to numerical values within a parameter, so that users can select these names from a simple pull-down menu instead of having to input a number. Subsets allow the EcoSTEP interface to be as simple as GaBi allows user inputs to be. Therefore, it is the most essential feature in terms of usability.

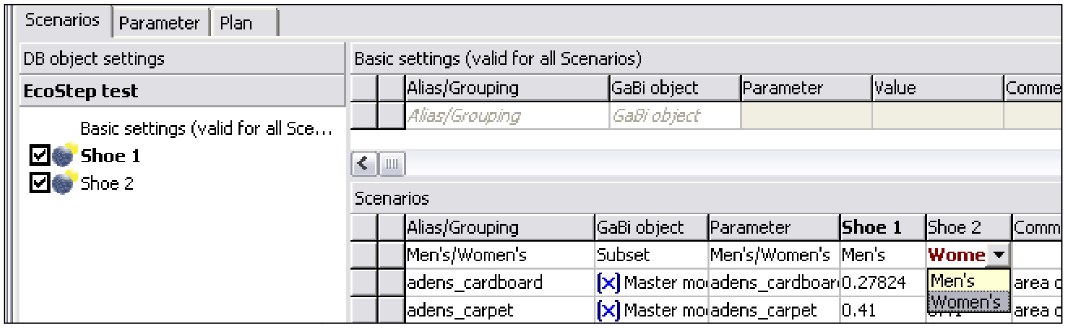
A new subset is created by clicking on the *<New: Subset>* tab on the left pane. Next, a name is given for the subset (e.g. “Men’s/Women’s”). Then, a blank frame is shown on the right pane. A new subset is created by right-clicking on the blank space on the left pane under the newly-created subset tab, and selecting “Add scenario.” Here, naming is important because the user will be making a selection between these scenario names. Then, the options to select GaBi objects will appear. Here, the conditional parameter that this subset will replace is selected. It is important that the parameter in question is not already displayed in the main Scenario group. If a single parameter is displayed twice in the window, GaBi will display an error. In this example, the global parameter *mens_womens* will be selected (Figure C13). Then, a numerical value will be displayed under the column of the created scenario “Men’s.” The default is 0, which is convenient since a choice of men’s shoe is set up to be *mens_womens=0* in the model. Another scenario is created, then named “Women’s”, to represent a women’s shoe in the model. Here, the value must be changed to 1, to allow the model to perform calculations when *mens_womens=1*.

Figure C13: Subset “Men’s/Women’s” that will replace the conditional parameter *men_women*



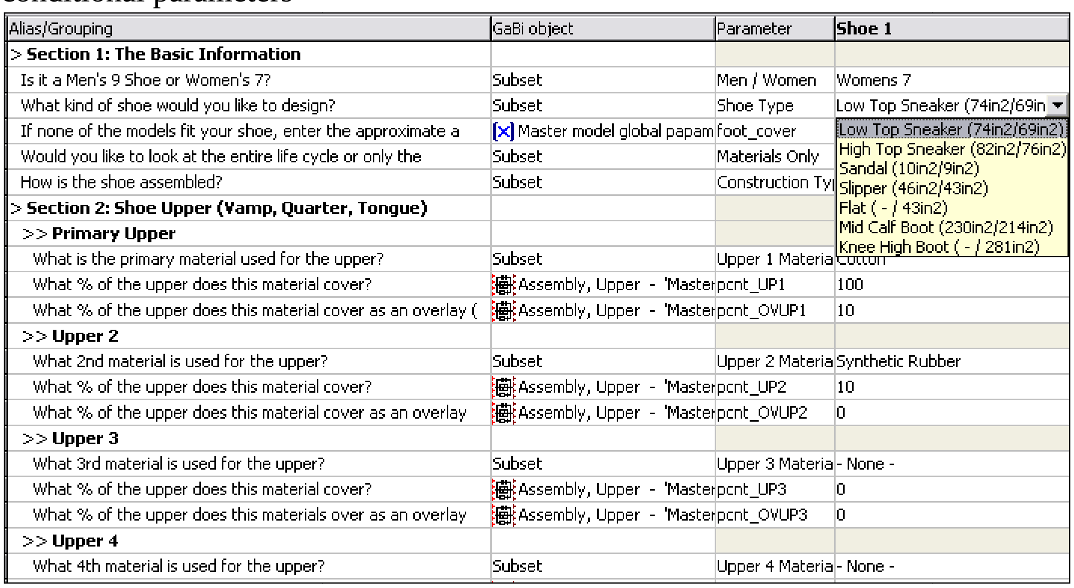
Once a subset has been created, it can be referenced as a GaBi object on the main EcoSTEP tab. When the conditional parameter is displayed as a subset instead of a global parameter, the user can choose between easily understandable choices while still harnessing the power of conditional parameters (Figure C13).

Figure C14: Subset "Men's/Women's" shown in parameter explorer, with the pull-down menu displayed



Once all value parameters and conditional subsets necessary for calculation are displayed in the main scenario group, it will look much like the EcoSTEP user interface, as displayed below (Figure C15).

Figure C15: EcoSTEP interface shown with extensive use of subsets in place of conditional parameters



Indexing: Finishing Touches to EcoSTEP

If the current scenario group is linked to the I-Report display, it will appear as a long list of questions and inputs in spreadsheet form. It is expected that designers may not want to see certain parts of the inputs that are not important to them (e.g. the designer does not care about the sole material). Therefore, the indexing feature of the Parameter Explorer was used to organize inputs into hierarchies.

Indexing allows the user to display or hide certain parts of the inputs depending on the needs of the user so that they are not overwhelmed with more than a hundred input lines. For example, if the designer only wants to assess the differences among materials in the upper, the inputs for accessories are not relevant in the analysis.

The concept is exactly like the folder system in computers. Under the “Folders” view in Windows, a list of folders will be displayed with “+” to the left of the folders. When these +’s are clicked, the folders and files contained within it will be displayed. The same logic is followed with indexing in the Parameter Explorer, except the files will be parameter inputs. The process will be very similar to creating folders, then inserting whatever files or other folders needed for further indexing.

In the Parameter Explorer window, the “Alias/Grouping” column can be edited before a GaBi object is selected. When text is entered into a row without selecting a GaBi object, the text in the cell becomes bold and becomes a “folder.” The folder can be right-clicked and dragged to any row in the right pane. Alternatively, there is an option to send the row to the very top or bottom. As the folder moves positions, the parameters or other folders below the folder being moved will be indented, to indicate that these objects have been indexed below the folder. As the folder is moved, default indexing will happen automatically; however, objects can be reorganized using the arrows that are now displayed in the two gray boxes to the very left of the rows. These arrows indicate which direction an object—folder, subset, or parameter—can be moved. Clicking the left arrow will move the object to a higher index, and the right arrow to a lower index.

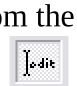
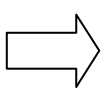
The indexing can be verified by accessing the I-Report (if there is no dongle available to access I-Report, GaBi analyst can be used instead) under the “balance calculation” menu. If the correct dongle is inserted into the computer’s USB port, the  icon should be available; otherwise, the result of the indexing can also be seen in the GaBi analyst. In the I-report window, the left-most pull-down menu at the top should be set to “hidden.” When the “hidden” menu is set to “top”, the Parameter Explorer pane should appear. On the left pane of the Parameter Explorer pane, the scenario group *EcoSTEP* should be available as a tab. The EcoSTEP interface can be activated by right-clicking on the tab and selecting “activate.” Once the interface is activated, I-Report must exit from the *edit mode* to *read mode* to verify the indexing. To go to the read mode, the icon  is un-clicked (Figure C16). In the read mode, the “folders” created in the Parameter Explorer should be visible; also, parameters, subsets, and other folders nested inside should appear to be slightly indented.

Figure C16: The indexes created shown in read mode of I-report

	Alias/Grouping	Shoe 1
-	> **Section 1: The Basic Information**	
	Is it a Men's 9 Shoe or Women's 7?	Womens 7
	What kind of shoe would you like to design?	Low Top Sneaker (74in2/69in2)
	If none of the models fit your shoe, enter the approximate a	0
	Would you like to look at the entire life cycle or only the	Only Shoe Components
	How is the shoe assembled?	Vulcanized
-	> **Section 2: Shoe Upper (Vamp, Quarter, Tongue)**	
-	>> **Primary Upper**	
	What is the primary material used for the upper?	Cotton
	What % of the upper does this material cover?	100
	What % of the upper does this material cover as an overlay	10
-	>> **Upper 2**	
	What 2nd material is used for the upper?	Synthetic Rubber

There is a "-" to the left of folders to indicate that line is a folder, and that it can be collapsed to hide all object nested under it. When the "-" is clicked, all objects under the folder should be hidden. For example, the "Section 2" folder is collapsed (Figure C17).

Figure C17: Section 2, the upper inputs, hidden by clicking the "-" beside the cell, indicated by the arrow



	Alias/Grouping	Shoe 1
-	> **Section 1: The Basic Information**	
	Is it a Men's 9 Shoe or Women's 7?	Womens 7
	What kind of shoe would you like to design?	Low Top Sneaker (74in2/69in2)
	If none of the models fit your shoe, enter the approximate a	0
	Would you like to look at the entire life cycle or only the	Only Shoe Components
	How is the shoe assembled?	Vulcanized
+	> **Section 2: Shoe Upper (Vamp, Quarter, Tongue)**	
-	> **Section 3: Accessories**	
	What material is used for the laces?	Organic Cotton
-	>> **Eyelets**	
	What material are used for the eyelets and vents?	Copper
	How many eyelets and vents are on this shoe?	12
-	>> **Snaps**	
	What material is used for the snaps?	- None -

The input rows for section 2, the upper, has been collapsed and hidden. Section 3, the accessories, inputs are now visible for entry. By creating folders in appropriate sections and having them collapsed when EcoSTEP is first opened, designers can access only the desired components without being overwhelmed by hundreds of rows (Figure C18).

Figure C18: All but Section 1 hidden by indexing

	Alias/Grouping	Shoe 1
-	> **Section 1: The Basic Information**	
	Is it a Men's 9 Shoe or Women's 7?	Womens 7
	What kind of shoe would you like to design?	Low Top Sneaker (74in2/69in2)
	If none of the models fit your shoe, enter the approximate a	0
	Would you like to look at the entire life cycle or only the	Only Shoe Components
	How is the shoe assembled?	Vulcanized
+	> **Section 2: Shoe Upper (Vamp, Quarter, Tongue)**	
+	> **Section 3: Accessories**	
+	> **Section 4: Inner Lining and Foams (Inside layer of sh**	
+	> **Section 5: Non-visible Reinforcements**	
+	> **Section 6: Sole**	

APPENDIX D: MEASURED / RESEARCHED GABI VALUE INPUTS

Parameter name	Value	Comments	Reference
adens_cardboard	0.27824	mass to area ratio in g/in2	GP measurements – samples
adens_carpet	0.41	mass to area ratio of carpet pad in g/in2	GP measurements - shoe disassembly
adens_cotton	0.22371	mass to area ratio of cotton (conventional & organic) in g/in2	GP measurements
adens_crepe	1.7325	mass to area ratio of 3mm crepe rubber in g/in2	GP measurements – samples
adens_hemp	0.17141	mass to area ratio of hemp in g/in2	online research: www.envirotextile.com
adens_jute	0.36667	mass to area ratio of jute (cotton blend) in g/in2	online research: www.alibaba.com
adens_latex	0.13476	mass to area ratio of latex insole in g/in2	GP measurements - shoe disassembly
adens_linen	0.1006	mass to area ratio of flax linen in g/in2	online research: www.fabrics-store.com
adens_petfoam	0.195	mass to area ratio of PET foam in g/in2	GP measurements - shoe disassembly
adens_redboard	1.4058	mass to area ratio of redboard in g/in2 (covers half of sole)	GP measurements - shoe disassembly
adens_rubbahyde	0.47641	mass to area ratio of rubbahyde in g/in2	GP measurements – samples
adens_rubber	0.86312	mass to area ratio of rubber overlay in g/in2	GP measurements – samples
adens_shpet	0.32	mass to area ratio of SH-PET	GP measurements – samples

adens_suede	0.74	mass to area ratio of 1.5mm suede/leather in g/in2	GP measurements - shoe disassembly; online research
adens_synthetic	0.15799	mass to area ratio of synthetics (virgin & recycled) in g/in2	online research: http://www.alibaba.com
adens_wool	0.34419	mass to area ratio of wool in g/in2	GP measurements - shoe disassembly
area_m9lowtop	73.99	area of lowtop men's 9 upper in in2	Measured and estimated using best fit polynomial
area_m9sole	33.62	area of men's 9 sole in in2	Calculations done in ImageJ
dens_aluminum	2.7	density of aluminum in g/cm3	online research
dens_brass	8.575	average density of brass in g/cm3	Measured from jeans zipper
dens_carpet	0.12	density of carpet pad in g/cm3	GP measurements - shoe disassembly
dens_coconut	1.2159	density of coconut shell in g/cm3	GP measurements - shoe disassembly
dens_copper	8.96	density of copper in g/cm3	online research
dens_crepe	0.76694	density of crepe rubber in g/cm3	GP measurements – samples
dens_EVA	0.12797	Density of EVA in g/cm3	GP measurements - shoe disassembly
dens_latexcork	0.53972	density of latex & cork blend in cm3	GP measurements - shoe disassembly
dens_latexfoam	0.20767	density of latex foam in g/cm3	GP measurements - shoe disassembly
dens_nickel	8.912	density of nickel in g/ cm3	online research
dens_nylon	1.15	density of nylon in g/cm3	online research

dens_PET	1.41	density of PET in g/cm3 (average of amorphous and crystalline)	GP measurements
dens_PU	0.13	Density of polyurethane in g/cm3	GP measurements - shoe disassembly
dens_rubber	1.3	density of car tire rubber, synthetic rubber, recycled rubber in g/cm3	GP measurements – samples
foot_cover	0	Foot cover in square footage	GP measurements – samples
loss_fabric	0.03	cutting loss percentage of fabric	Specification sheets
loss_leather	0.15	cutting loss pecentage of leather	Specification sheets

APPENDIX E: SHOE AREAS

Within the GaBi model, the shoes are defined relative to one particular shoe design. Specifically the baseline model is the men's low top sneaker, which has an upper area of 74 in^2 and a sole area of 33.6 in^2.

Upper Area Ratios (Baseline area 74 in^2)		
Shoe type	**Multiple**	**Comment**
Sandal	0.13	Ratio of Flippee:Tuba
Flat	0.61	Ratio of Flat:Satire
Slipper	0.62	Ratio of Slipper:Satire
Low top sneaker	1	Tuba (same upper area as Satire)
High top sneaker	1.11	Ratio of Carwalk:Tuba
Mid calf boot	3.11	Ratio of Ugg:Satire
Knee high boot	4.08	Ratio of extrapolation:W7Satire
Mens	1	
Womens	0.93	Ratio of mens Tuba:womens Satire

Sole Area Ratios (Baseline 34 in^2)	
Sneaker	1
Non-Sneaker	1.25
Mens	1
Womens	0.77

APPENDIX F: LCA ASSUMPTIONS

LCA Assumptions

In life cycle assessment, there are series of decision-making processes that substantially affect the resulting environmental impacts of the model. Upon initial discussion of the environmental impacts results of an LCA report, it may seem self-explanatory. However, many assumption and approximations were made which led to the impact results. One such assumption is the drawing of the system boundaries, which dictate what part of the product chain is included in the assessment. In addition, if an LCA software is being used for the assessment, much like EcoSTEP uses GaBi4 software, then decisions must be made regarding which data to use from an array of options. Because LCA software cannot always be expected to have the exact data needed for the specific product, EcoSTEP often uses data that are considered to be similar or approximate to the information needed.

It is important to recognize the assumptions that are behind the LCA results to develop a deeper understanding of the environmental impacts that result. To gain a thorough understanding of the presented results, it must be recognized what types of information were included or excluded through assumptions.

System Boundaries

In life cycle assessment, it is crucial to clearly define the system boundary of the analysis: what goes in and what goes out. A product life cycle typically has five phases: material extraction, manufacturing, distribution, use and maintenance, and finally disposal. This project diverges from the norm due to the nature of the product. Since it is assumed that shoes rarely undergo maintenance and repair, the impact of use phase is considered negligible. Therefore, it is excluded from the analysis.

Within the manufacturing phases, the model also focused on certain aspects of the process. EcoSTEP does not include any inputs for the facility resource use beyond those attributed specifically to the manufacturing process. Simple Shoes are manufactured in factories that also produce other shoe brands and it was not possible to determine the proportion of Simple Shoes compared to other brands. Therefore, facility components such as ambient heating, lighting or building infrastructure were not included.

Packaging, which is another portion of the manufacturing phase, is also excluded from the LCA. This exclusion is more due to lack of information on the various types of packaging; moreover, the current GaBi database lacked sufficient data on the disposal and recycling of cardboard and plastics. The project aimed to focus primarily on allowing designers to compare similar types of shoe designs under consideration.

Therefore, packaging type and material was expected to be similar and did not contribute to determining relative differences between scenarios.

Adhesives and other additives, which are essential for the assembly process, were not included in the model. One primarily reason adhesive were not includes was that the data for producing the glue was not available in the GaBi database. Also, the scope of the model did not include assessing for how assembly inputs of material and energy vary depending on the type of materials used by the design. However, the potential harm of using solvent-based glue was assessed in GaBi. According to a 2009 Timberland CSR report, an average of approximately 70 grams of VOC (volatile organic compounds) was emitted per pair of assembled shoes. While this is a substantial amount of pollution to the air, it was found to be inconsequential when comparing to the total human toxicity potential of the entire life cycle of the shoe. The 70 grams of VOC emitted was estimated to be less than 1 percent of the harm done by the electricity generation and coal-fired boiler attributed to the assembly process.

Transportation beyond the distribution center was also not considered. Because Simple Shoes ships their product nation-wide, there was high uncertainty in modeling transportation. Also, EcoSTEP focused on the elements in the supply chain that can be controlled by the designer. The users of the model are expected to have little to no control over where the manufactured products are sent.

General Assumptions and Limitations in LCA Processes Data

Similar to how assumptions made in the EcoSTEP model can affect the resulting environmental impacts, assumptions made when collecting the LCA data for a specific process can affect the results. PE and ecoinvent often draw their system boundaries differently. For example, PE databases tend to exclude the building infrastructure when considering a process, while ecoinvent database typically incorporates the infrastructure. A truck transportation process in PE considers only the operation of the truck, while ecoinvent will also take into consideration the construction and maintenance of the road system. Therefore, EcoSTEP used PE database processes whenever possible, utilizing ecoinvent data only when unavoidable. Also, there was a need to compare the environmental impact results with the 2008 model, which used PE processes exclusively.

The processes stored in GaBi databases are also often region-specific, as denoted by ISO geographic acronyms. For example, a process for producing cotton may be specific for China (denoted *CN*). Therefore, the elementary flow emissions accounted for in GaBi associated with producing a certain amount of cotton is specific to a typical supply chain in China. The geographic specificity of processes does not necessarily denote the production of the material in the region; instead, it indicates the resources needed to make the material available in the region. Therefore, a process for cotton in Germany may require cotton sourcing from China or Turkey. Because GaBi is developed in Germany, many of the processes utilized in EcoSTEP have European origins, although US inventory data are becoming more common. Also, inventory data for Chinese industrial processes are very rare. Although Deckers may have information regarding the material source origin, it can not be modeled if the GaBi database lacks processes with the appropriate geographic origin.

Proxy Processes Utilized in EcoSTEP Model[7]

Due to the limitations posed by the LCA database, some tradeoffs must be made between accuracy and abundance of options for the user. If there is too much emphasis in ensuring that the process used in the model is specific to Deckers, then there may not be enough material options to choose from in the EcoSTEP interface. Therefore, *proxies* were often used as the next best process available in the database. It is important not to select proxies without careful considerations of the implications for selecting a process not specific to the product life cycle under analysis. When interpreting the environmental impacts of the model, there needs to be an understanding of why a certain result may vary from expected values since this may be due to the proxies used in the model. For example, if the impact the transport phase of the LCA model proves to be smaller than expected, then the LCA practitioner would need to know how the proxy processes for truck operation and fuel production may have contributed to this result.

Often, data for only a generalized global average process is available for a material, so there are no options for selecting the correct origin. If there are multiple options and the correct geographic origin is unavailable, some background research may be required to select the most likely scenario. For example, research was needed to determine which truck emission standard from Europe is comparable to the standard in the United States. Sometimes, the desired material is simply not available in the database. In this case, there may be other processes that closely reflect the type of industrial activities that are needed for the desired material. For example, one type of plastic that is unavailable in GaBi may have very similar inputs as another plastic process that is available. If no information is available to choose a reasonably proxy, the worst case scenario process that has the highest impact may also be used. Proxies were utilized throughout the model, including all phases of the product life cycle.

Material Process Proxies Utilized in EcoSTEP

Simple Shoes often utilizes innovative materials that are often unavailable in the GaBi database. For example, Simple Shoes plans to incorporate beeswax coated materials in their future designs. This material is unavailable in the current database, and can, therefore, not be modeled. However, reasonable proxies were available for some materials. Simple also utilizes lyocell fiber, which is essentially rayon derived

[7] A complete summary of the proxies used in the EcoSTEP model is available at the end of this Appendix.

from hardwood (Patagonia, 2010). Process data for lyocell was not available in GaBi per se, but general data for rayon (viscose) was available; therefore, the viscose process in GaBi was used as a proxy to lyocell, as the production methods were comparable. The viscose process in particular was a global average, which means that the sourcing information for this material had been averaged from worldwide production. Proxy processes were also used for crepe rubber, coconut shell, and nickel.

The most commonly used proxy process in EcoSTEP was the fabric weaving process. This process is the production of woven fibers in Germany, including all the transportation needed to make woven fabric available there. As such, the incorporated transportation in the process was used as a proxy to the transportation needed within China to deliver cotton fibers to the mill. The process is set up so that there is an input flow of a fiber and an output of a woven fabric. Although the process is specific to cotton, it was considered to be a sufficient proxy for all types of fibers available in EcoSTEP, including natural and synthetic fibers (P. Canepa, e-mail correspondence). That is, the activities which the process models is general enough that it can be used to produce textiles of any fiber in the model.

Transport Phase

Just as proxy material processes were often utilized in EcoSTEP, geographic proxies were used extensively in transport, assembly, and disposal. Again, this is mostly due to the lack of LCI data from China, since the GaBi processes are primarily of European origin. Because most transportation processes are of Eurpean origin, they are modeled to reflect the emission standards set by the EU. Therefore, the diesel truck emission standards of EU and the US were compared so that the most appropriate proxy can be selected for EcoSTEP.

EcoSTEP only models transport that occurs between the Port of Yantian and the Port of Long Beach, then to the distribution center in Camarillo. Therefore, only two modes of transport are used, a cargo ship and a 40-foot truck, along with the associated fuel production processes. The GaBi database only offered one cargo ship process, and it was a generalized, global average of a 27,500 tonne cargo ship operation. However, GaBi offered a vast array of options when selecting trucks from different capacities to emission standards. The capacity was assumed to be roughly 30 tonnes, since the 40-foot containers that all Simple Shoes products are transported in are estimated to have a maximum capacity of 30 metric tonnes (Emase, 2010).

The emission standards posed a greater challenge to select the appropriate proxy. The emission standards specified in GaBi are European standards and US trucks clearly have no requirement to follow these standards. Instead, trucks in the United States must follow a federal standard (DeiselNET, 2009). Emission standards are usually gauged on four factors: total hydrocarbons (THC), carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter (PM). According to The Port of Long Beach, 1994 was the average model year of heavy-duty trucks visiting the port in 2006; therefore, the federal emissions standard applicable to model year 1994 was used to compare with the EU emission standards given in GaBi. The comparisons of the US and EU emission standards are summarized below:

Table F1: Summary of EU emission standards compared to US federal emission standards applicable to 1994 model year trucks (in g/kWh)

	US (1994)	Euro I	Euro II	Euro III	Euro IV	Euro V	Euro VI
THC	1.8	1.1	1.1	0.66	0.46	0.46	0.13
CO	21.2	4.5	4.0	2.1	1.5	1.5	1.5
NOx	6.8	8.0	7.0	5.0	3.5	2.0	0.4
PM	0.10	0.36	0.25	0.10	0.02	0.02	0.01

Although the US standard for carbon monoxide is dramatically higher than the European standards, the other three criteria are relatively similar. Euro II standard has the closest target values for THC and NOx (highlighted in green). However, Euro III standard has the same target for PM as the US standard. While Euro III has the same target, it was not considered a viable proxy because of the low THC target, which drives global warming and smog. Also, Euro I standard has a slightly closer CO target to the US standard than Euro II, but Euro I was not considered because the relative increase of the CO target from Euro II and I was substantially smaller than the increase in the PM target from Euro II to I. Therefore, Euro II truck process was used as a proxy for 40-foot trailer trucks operating in California. After the Euro II truck process was chosen, the process for diesel fuel production was needed. Fortunately, a US-based process for diesel fuel production was available, so it was utilized in EcoSTEP.

While there are many processes available for trucks, there was only one process, a global average process, available for the containership. A container ship process was needed to transport the assembled shoe from the Port of Yantian, China to Port of Long Beach. A US-specific process on heavy fuel production was linked to the global average process of a container ship. This was considered acceptable because the ship is assumed to refuel at US ports.

Assembly Phase

Like the transport phase, the assembly consisted of only a few processes: electricity and steam. Initial data was obtained for the replacement of machinery parts. However, this data was not used for two reasons. First, the exact weights included a high level of uncertainty due to a lack of information on the specific part. Second, when the amount of secondary inputs was determined for each pair of shoes, the weights were insubstantial due to the high volume of shoes produced in each factory every year. Therefore, we assumed that only energy inputs would contribute significantly to the model.

Instead of the indirect inputs in a factory, direct energy inputs were accounted for in EcoSTEP, which included electricity to power the assembly machines and steam that is needed for some machines. Electricity is used to power the various machines required to assemble the shoe components. In addition to electricity, press machine and autoclave heaters require steam inputs. Currently, coal-fired boilers in the factories supply the steam (J. Hadap, e-mail correspondence).

The power grid that supplies the electricity for assembly was assumed to be China's average mix. China's electricity mostly originates from coal and hydroelectricity at approximately 81% and 15%, respectively (Table F2). A hypothetical scenario of changing the electricity source from a China grid mix to the US was conducted because Deckers is exploring the option of moving their assembly efforts to the US. In this scenario, the hypothetical factory was assumed to have identical machinery with the same energy input requirements as the one currently in place in China.

Table F2: Comparison of electricity source mix between US and China

Production from:	US Grid Mix	China Grid Mix
- coal	48.71%	81.01%
- oil	1.80%	1.03%
- gas	21.04%	0.93%
- biomass	1.14%	0.07%
- waste	0.51%	0.00%
- nuclear	19.24%	1.89%
- hydro	6.34%	14.80%
- geothermal	0.39%	0.00%
- solar PV	0.00%	0.00%
- solar thermal	0.02%	0.00%
- wind	0.80%	0.27%
- other sources	0.03%	0.00%

The relative change in impacts was assessed for the shift to a US power grid mix. Acidification, eutrophication, global warming, and human toxicity potentials all see a decrease in impacts by over 20%. However, there is an increase of 180% in the freshwater ecotoxicity potential when shifting to a US power grid mix. This increase in FAET is likely attributed to the use of coal-bed methane.

End-of-life Phase

The disposal of the designed shoe has been dramatically simplified in EcoSTEP. Since the model was built for designers, a single landfilling process was used for all shoes designed. Since there were no GaBi landfill processes for apparel products, the disposal of inert materials (rather than municipal or industrial wastes) was chosen as a proxy. The organic wastes in the municipal or industrial waste processes would have resulted in inappropriately high levels of greenhouse gas emissions from decomposition. Taking these factors into consideration, landfilling of inert waste, such as glass, was selected as a proxy for discarding a pair of shoe.

Table F3: List of processes used.

Process Name	Component Use					Process type	Region	Proxy for	Database
	Upper	Lining	Accessories	Reinforcement	Sole				
Cotton production conventional (10% H2O)	X	X	X	X	X	Plant	-		PE
Organic Cotton production	X	X	X	X	X	Plant	-		PE
Hemp long fibre	X	X	X			Plant	Germany		PE
Jute fibres, irrigated system, at farm	X	X				Plant	India		Ecoinvent
Viscose fibres, at plant	X	X				Plant-derived	Global	Lyocell	Ecoinvent
Fabric Production	X	X	X	X	X	Fabric weaving	-	Fiber weaving	PE
Coconut fibre (Type bristle, brown)			X			Plant-derived	Sri Lanka	Coconut shell	PE
Cork slab, at plant		X				Plant-derived	Europe		Ecoinvent
Leather (uncoated; 1 qm)	X	X	X			Animal-derived	Germany		PE
Wool, sheep, at farm	X	X				Animal-derived	US		Ecoinvent
Polyethylene terephthalate granulate (PET, amorph)	X	X	X	X	X	Plastic	Europe		ELCD/PlasticsEurope
Polymer granulate unspezific sekundary (mechanical)	X	X	X	X	X	Plastic	-		PE
Nylon 6.6 granulate (PA 6.6)	X	X	X	X		Plastic	Europe		ELCD/PlasticsEurope
Acrylonitrile (AN) PlasticsEurope	X	X				Plastic	Europe		PlasticsEurope
Ethylene Vinylacetate Copolymer		X		X	X	Plastic	US		PE
Polyurethane flexible foam (PU)		X		X	X	Plastic	Europe		PlasticsEurope
Styrene-butadiene rubber mix (SBR)	X				X	Rubber	Germany		PE
Latex concentrate (60% Latex)		X			X	Rubber, natural	Thailand	Crepe rubber	PE
Natural rubber (NR)	X				X	Rubber, natural	Germany		PE
Aluminum sheet mix			X			Metal	Europe		PE
Brass			X			Metal	Germany		PE
Ferro nickel (29%)			X			Metal	Germany	Nickel	PE
Copper mix (99,999% from electrolysis)			X			Metal	Germany		PE
Fuel oil heavy at refinery						Fuel	US		PE
Deckers Container ship / approx. 27500 dwt / ocean						Transport	Global		ELCD/PE-GaBi
GLO: Truck 28 - 32 t total cap. / 22 t payload / Euro 2						Transport	Global	40-ft US Truck	ELCD/PE-GaBi
Diesel at refinery						Fuel	US		PE

Power grid mix						Power	US		PE
Steam from hard coal 84%						Steam	US	Steam, China	PE
Steam from natural gas 89%						Steam	US	Steam, China	PE
Landfill for inert matter (Glass)						Disposal	Europe	Disposal	PE

Summary of processes used in EcoSTEP GaBi Model

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