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Validating the Sustainability of Eco-Labeled Products Using a Triple-Bottom-Line Analysis

Reference

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ABSTRACT

Sustainability considerations are becoming an intrinsic part of product design and manufacturing. Today's consumers rely on package labeling to relay useful information about the environmental, social, and economic impacts of a given product. As such, eco-labeling has become an important influence on how consumers interpret the sustainability of products. Three categories of eco-labels are theorized: Type I labels are certified by a reputable third party; Type II are eco-labels that are self-declared, potentially lacking scientific merit; and Type III eco-labels indicate the public availability of product Life Cycle Assessment (LCA) data. Regardless of the type of eco-label used, it is uncertain if eco-labeling directly reflects improved product sustainability. This research focuses on exploring if eco-labeled products are veritably more sustainable. To do this, we perform a comparative study of eco-labeled and comparable conventional products using a triple-bottom-line sustainability assessment, including environmental, economic, and social impacts. Here we show that for a selected set of products, eco-labeling does, in fact, have a positive correlation with improved sustainability. On average, eco-labeled products have a 47.7 % reduced environmental impact, reduce product lifespan costs by 48.4 %, and are subject to positive social perception. However, Type II eco-labeling shows a slight negative correlation with product sustainability and economic cost. We found only one eco-labeled product (with Type II labeling) that had an increased environmental impact over the conventional alternative. In general, the results confirm that most eco-labels are indicative of improved product sustainability. However, there is evidence that suggests that eco-labeling, though accurate, can omit truths with intention to improve marketability.

Keywords

eco-labeling, consumer product sustainability, green product, sustainable design, data-driven design, eco-design

Introduction

Manufacturing industries are currently experiencing a paradigm shift in that they are not only focusing on profit but also considering the effects of sustainability in manufacturing.[1] Sustainable manufacturing is defined by the National Council for Advanced Manufacturing USA as "the creation of manufactured products that use processes that are nonpolluting, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers."[2] Sustainability, in the context of this work, has a triple bottom line featuring environmental, economic, and social considerations.

In addition to manufacturing shifts toward sustainability, consumers are caring more about product sustainability. The 2013 Green Gap Trend Tracker by Cone Communications found that 71 % of American consumers consider the environment when purchasing goods.[3] According a study of 10,000 online consumers conducted by the Natural Marketing Institute (NMI), 40 % of consumers choose sustainable product alternatives compared with conventional products; of this 40 %, 50 % of these consumers were millennials (ages 21–25). The study concludes that millennials are three times more likely to check for sustainable labels and spend more on sustainable products than Generation X (ages 35–49), and 12 times more likely to do so than Baby Boomers (ages 50–64).[4] In tandem to these finding, current research shows that consumers are willing to pay more for products that are sustainable.[5] This effect is amplified by eco-labels that differentiate the levels of sustainability.[6] This research shows that sustainability-labeled products have a growing economic and social impact when considering younger consumers.

Sustainable thinking coupled with self-branding initiatives has led to more consumer goods manufacturers to employ eco-labeling on product packaging. Eco-labeling is "an environmental label or declaration that provides information about a product or service in terms of its overall environmental character, a specific environmental aspect or number of environmental aspects."[7] Marketing products as "sustainable" is intended to affect end customers, as it lends a sense of responsibility to the user and perceived product performance.[8] Research has also shown that eco-labels affect consumers' response toward the product company and that the perceived corporate social responsibility connects to corporate credibility and brand attitude.[9] However, though eco-labels influence a consumer, the consumer understanding of what a label actually means is limited.[10] There is concern than unregulated eco-labels may be used in a dubious nature to increase market share.

ECO-LABELING

The International Organization for Standardization (ISO) has classified eco-labels into three types: Type I, Type II, and Type III.[11] The validity of an eco-label varies with its certification authority. Type I labels are third-party–certified labels that indicate a product adheres to specific environmental guidelines. Third-party certifications are given by either public or private entities unassociated with the product manufacturer.[12] Type II eco-labels address a single attribute of environmental information and are self-declared. Products with first-party certifications (Type II eco-labels) are not tested or validated by an independent agency and can be added to any product. "Green" labeling, such as flowers or other imagery that invoke a sense of environmental friendliness, are also examples of Type II labels. Type III labels are third-party–certified labels based on Life Cycle Assessment (LCA) information,[11] which is usually found on a product website.[12]

POTENTIAL CONCERNS WITH ECO-LABELING

Eco-labeling on product packaging is designed to inform consumers of the environmental impact or relative sustainability of the product. It is known that eco-labeling is a marketable strategy to increase market share.[13,14] One concern with eco-labels is that they may not represent the overall improved sustainability of a product.[15] For example, Type II labels that indicate the use of recycled packaging may reflect sustainability improvement of the packaging but not the product within. This indicates that there is "information asymmetry" between the eco-label's actual meaning and the consumers assumption of the label's meaning.[15,16] Bratt et al.[17] suggests that the rise of eco-labeling practices promote confusion toward customers identification of what eco-labels mean. In contrast to this increased confusion, studies have shown that consumers will still view companies using Type II eco-labels and external corporate responsibility labels as sincere in their intentions to promote sustainable causes.[9] Recent research highlights that customers do instill trust in companies based on eco-labels, but that "visual-only" labels (Type II) do not relay proper information and can create consumer doubt.[18] Beyond customer trust and confusion, evidence shows that customers are willing to pay more based on specific unsubstantiated environmental claims (Type II labels), and that the claims evoke positive attitudes within consumers.[19] Consumer confusion in tandem with perceived trustworthiness suggests that there is a possibility companies can use eco-labeling to "game" the market with predatory marketing strategies and instill a competitive marketing advantage.[20]

Predatory marketing strategies are possible because of the complexity in understanding how eco-labels are classified. A recent example of this is Volkswagen, which marketed cars that were defined to be within the emission levels set by the US Environment Protection Agency but were found to be fabricated after being tested. The vehicles in question were creating emissions outside the range of acceptable values.[21] There is reason to believe that companies can provide misinformation or increase confusion about sustainability performance to manipulate the market. One study suggests that consumer confusion can weaken the market for more sustainable alternatives, and companies may use imperfect information to greenwash less sustainable alternatives.[22]

We hypothesize that Type II eco-labels are the most likely eco-labels to be subject to increased manipulation because of their first-party nature. For Type I labels, there is focus on further regulating eco-labeling certification, including involving standardization under the International Organization for Standardization and global certification networks.[23] Additionally, there is research into streamlining and improving the Type I eco-labeling process.[24] Type III eco-labels often follow published methodology that reduces the count of fallacy in the eco-label. Furthermore, Type III labels require an expertise to understand and are less likely to be presented to a consumer in a marketing fashion. We suggest that Type II eco-labels can benefit from the same regulation movements found in Types I and III eco-labels. As such, this article focuses on the validity of unregulated Type II eco-labeling.

PURPOSE AND SCOPE

The purpose of this research is to characterize the relationship between the three pillars of product sustainability and product eco-labeling. This can be achieved by comparing eco-labeled consumer products with unlabeled counterparts with respect to environmental, economic, and social impacts. This research solely focuses on comparison through LCA methods; by doing so, we can provide a quantitative analysis of product sustainability. Previous research has developed frameworks to evaluate the triple-bottom-time sustainable impact of firms (manufacturers) and proposed the creation of sustainable indexes to reduce eco-labeling information asymmetry toward firms.[25,26] In contrast with this research, we suggest a methodology to look at specific consumer products on the market. It is our intent that this research contributes to the growing interest in understanding the life cycle impact of consumer goods and aids in encouraging substantiated sustainability claims in influencing consumer purchasing decisions.

In addition, this work aims to discover if eco-labeling is indicative of improved product sustainability. To discover these trends, we use environmental LCA, life cycle cost analysis (LCCA), and social LCA (S-LCA) to measure the triple-bottom-line impact of eco-labeled products. These eco-labeled products are then compared with conventionally labeled alternatives to benchmark the sustainability performance of the eco-labeled products. There have been similar studies performed by comparing the environmental sustainability of innovative products with that of common products,[27] the outcome of which indicated that new-to-market, innovative products did not have improved sustainability over conventional products.

The study consists of 16 consumer products within seven product categories: water bottles, trash bags, hand dryers, chainsaws, coffee makers, foils, and toothbrushes. These products are chosen because they represent a wide breadth of products that consumers may commonly use. Water bottles, trash bags, foils, and toothbrushes are chosen to represent consumables that are widely ubiquitous. Chainsaws, hand dryers, and coffee makers are chosen to represent more industrial products that see both home and commercial use. Furthermore, these products have higher consumable use over their life spans compared with the other two categories.

The triple-bottom-line impact of these products are measured using ReCiPe via GaBi, a modified Stanford building LCCA, and an in-house S-LCA.[28] The LCCA and S-LCA methods are chosen because they align more closely with the consumer bottom line. ReCiPe is chosen as the environmental LCA because it offers extensive measurements of environmental impact over many impact indicators, ensuring that our analysis does not oversimplify the areas of impact.

Background

LCA

The LCA is a means of assessing the environmental impacts of a product from its cradle to grave (from raw material processing into materials, manufacturing, assembly, distribution, use, and end of life).[29] LCA studies have become widespread and are employed in applications ranging from research linking product design decisions and environmental impact to industries using LCA in building certification.[30,31] Today, LCA has been extended to assess all three pillars of sustainability.

Economic LCA methods estimate the material and energy resources required and environmental impact resulting from activities in our economy.[32] Some of the tools used for conducting Economic LCA are Economic Input-Output LCA (EIO LCA) and LCCA.[33,34] For the purposes of this research, LCCA has been chosen as the economic LCA because it measures dollar cost and is thus more applicable to the consumer. LCCA is a method that assesses the total cost of a product; this includes national product cost and consumable cost over time. A consumable is considered to be any resource that is required to operate the product during its lifetime.

S-LCA measures both the positive and negative sociological impacts of a product through its life cycle. S-LCA makes use of generic and geographic-specific data and varies from quantitative to qualitative datasets, complementing the environmental LCA and LCCA.[35] S-LCA is an emerging LCA area of interest. It allows researchers to qualify how people themselves are affected by a product or process. This includes, but is not limited to, how a product affects a user emotionally, mentally, and physically; along with understanding the social implications on human health and happiness of manufacturing in a given location.

SUSTAINABLE DESIGN REPOSITORY

Life cycle inventories (LCIs) provide a comprehensive database about the process or product on which the LCA will be performed. LCI data are often personalized to only include the data required to complete a given LCA method. The LCI data used to facilitate the study presented in this article are sourced from the Oregon State University Sustainable Design Repository (SDR).[36]

The SDR currently houses LCI and LCA information for 50 conventional consumer products. Specifically, the LCI schema includes common name, model number, manufacturer, manufacturing location, price, data sources, picture, and detailed bill of materials. The primary LCA data set includes assessment of three LCA methods for each product. These methods are Eco-Indicator 99, SolidWorks Sustainability, and ReCiPe via GaBi. The methods are chosen to represent a hierarchy of complicity/accessibility ranging from widely available and simple (Eco-Indicator 99) to costly license (limited accessibility) with high fidelity (ReCiPe via GaBi). The LCI/LCA methods and assumptions presented in this article mirror the methodology of the SDR. This allows for assumptions to be held constant across the sourced conventional products (from the SDR) and added eco-labeled product from this study.

Materials and Methods

The methods employed in this research are applied to a nine-product case study. The case study is designed to look at the triple bottom line of product sustainability by comparing conventional, non–eco-labeled products with their eco-labeled counterparts. To measure the overarching sustainability of each product in the case study set, we employ ReCiPe via GaBi, a modified Stanford LCCA for economic impact analysis, for environmental impact analysis and an in-house S-LCA for social impact analysis.

PRODUCT SELECTION

The 7 product categories and the 16 products explored in the study are selected to represent a variety of common consumer products, that is, we expect that most first-world users have used or purchased some version of the chosen products. Table 1 displays the 16 products and 7 product categories selected for use in this study.

Water Bottle Product Family

This product group features three products: a metal reusable bottle, a disposable plastic bottle, and a plastic reusable bottle. These bottles all represent the 16.9 oz. format for a drinking water container. The metal reusable bottle has insulated stainless steel construction with a removable high-density polyethylene lid.

The single-use bottle is a standard disposable water bottle commonly found in stores around the world. The selected model is a reduced-plastic single-use water bottle that has become increasingly common.[37] This bottle represents the conventional product for comparison.

The plastic reusable bottle is made of polycarbonate with a polyethylene lid and strap. The metal reusable bottles and plastic reusable bottles are considered to be the more environmentally friendly alternatives to the single-use bottle. Both of these products use Type II eco-labels, stating that by using their product consumers are reducing "single-use water bottle" plastic waste, which in-turn promotes less environmental impact and increased sustainability.[38,39]

Trash Bag Product Family

The conventional trash bag is made from polyethylene film. The eco alternative is made from 55 % recycled plastic with 16 % postconsumer recycled plastic content. The eco trash bag packaging includes a Type II eco-label, stating the bags are a more sustainable choice than 100 % virgin plastic bags.

Electric Hand Dryer Product Family

This family is unique in that both products are made by the same manufacturer. The two products chosen for the study are a standard hand dryer model and the eco hand dryer. Both of these products have sustainability claims and have eco-labels Types I and II. Both products feature Type I eco-labels by Leadership in Energy and Environmental Design (LEED), GreenSpec, Greener Product, and Green Business Bureau as well as Type II labeling stating that these products will save money compared with paper towels. In addition, the standard hand dryer models were the subject of a company LCA, enabling it to also have Type III labels.[40]

TABLE 1
List of conventional and eco-labeled products selected for comparison

#	Product	Eco-Labels	Category
1	Metal reusable bottle	Type II	Water bottle
2	Single-use bottle	…	
3	Plastic reusable bottle	Type II	
4	Conventional trash bag	…	Trash bag
5	Eco trash bag	Type II	
6	Hand dryer	Types I, II, III	Hand dryer
7	Eco hand dryer	Types 1, II	
8	Gas chainsaw	…	Chainsaw
9	Eco electric chainsaw	Types I, II	
10	Single-serving pod	…	Coffee pods
11	Single-serving recyclable pod	Types II, III	
12	Reusable pod	…	
13	Conventional foil	…	Foil
14	Eco foil	Type II	
15	Manual toothbrush	…	Toothbrush
16	Eco manual toothbrush	Types I, II	

Chainsaw Product Family

The conventional chainsaw is gas powered, and the eco alternative is an electric chainsaw. The eco power tool company makes Type II claims stating their products are zero emission, do not pollute, or require maintenance. They also claim to have a Type I Energy Star label but do not display the Energy Star seal.[41]

Single-Use Coffee Pod Product Family

All three of these products are marketed and manufactured by the same company. Single-use pods are disposed of in landfills. Single-serve recyclable pods are recyclable in certain local municipalities. The reusable pod is not disposed of between single servings of coffee. This company primarily has Type II eco-labels.[42] However, the sustainability report offered by the company employs the use of LCA. It is unclear whether these are third party (Type III) or self-reported (Type II).[43] The Type II labels include claims of lowering greenhouse emissions (using the recyclable pod), green imagery on marketing pages and within the company logo, and positive environmental cases stated for the use of #5 polypropylene plastic. It should be noted that these claims are only found relating to the recyclable pod option. The reusable pod has no such environmental claims or eco-labels. The LCA, LCCA, and S-LCA for each pod type was performed, including the same coffee brewer machine. Assuming each pod is used in the same machine removes potential variation caused by coffee brewer choice. The machine selected was able to take all three of the pod types presented.

Aluminum Foil Product Family

The environmentally minded product is foil food wrap made from 100 % recycled foil. The conventional foil is made from both pre and postconsumer recycled aluminum. The company only uses the Type II eco-label, primarily in the form of green imagery on the packaging. The conventional product is also manufactured by the same company. In this study, we are only looking at the foil and not the cardboard packaging (as the packaging is consistent for both products).

Toothbrush Product Family

The eco-labeled toothbrush displays Types I and II claims. The toothbrush handle is made from 100 % recycled plastic, and the packaging includes green imagery. The product is also certified by the B Corporation, which certifies companies that use business to solve social and environmental markets.[44] The conventional product is similar in look and function and is manufactured by a popular toothbrush manufacturer using conventional methods and materials.

PRODUCT LCI ANALYSIS

The LCI product information includes product name, make, model, description, manufacturing location, consumer price, consumables price, use phase characterization, and bill of materials. The bills of materials include component name, quantity, material, manufacturing process, and component weights.

All LCI information (excluding the bills of materials) was sourced using manufacturer websites; much of this information is listed in the cited product sources. The bills of materials were informed by the Carnegie Mellon University Design Decisions Wiki or were determined empirically for simpler products, such as the water bottles and trash bags.[45] The bill of materials information, such as component weight, was found via SolidWorks, requiring user-created CAD models or source models from GrabCAD.[46,47] Material and manufacturing processes were identified by referencing Manufacturing Processes for Design Professionals.[48]

The use phase of the products was defined by a functional unit featuring 1 year of normal use per product.[49] Normal use is defined by the statistically informed average consumable use of each product. The functional unit was kept consistent for each product within a product category. The functional unit of each product category was informed using relatable use statistics or recommendations of intended product use by the manufacturer. For example, the water bottle product category has a functional unit based on consuming eight 8-ounce glasses of water a day. Use information that could not be derived by this method were found via consumer usage information from internet sources, such as forums and product reviews. The functional unit does not define the lifespan of a product but does define use as a common comparable unit. Table 2 lists the functional units for each product family.

TABLE 2
List of functional units per product family

#	Product	Category	Functional Unit
1	Metal reusable bottle	Water bottle	Eight 8-oz servings of water, per day, per year
2	Single-use bottle		
3	Plastic reusable bottle		
4	Conventional trash bag	Trash bag	Two bags per week, per year
5	Eco trash bag		
6	Hand dryer	Hand dryer	125 30-s runs per day, per year
7	Eco hand dryer		
8	Gas chainsaw	Chainsaw	1 h per month, per year
9	Eco electric chainsaw		
10	Single-serving pod	Coffee pods	3 cups of coffee, per day, per year
11	Single-serving recyclable pod		
12	Reusable pod		
13	Conventional foil	Foil	150 sq ft. per year
14	Eco foil		
15	Manual toothbrush	Toothbrush	Toothbrush replaced every 3 months
16	Eco manual toothbrush		

OVERVIEW OF LCA METHODS

Through this study, we focus on the triple bottom line of sustainability by employing LCA, LCCA, and S-LCA. LCA focuses on quantifying the environmental impacts of the product. LCCA explores the economic impacts of the products. Lastly, S-LCA focuses on the social implications and impacts of the products of the study. All software and methods used for the LCA and LCCA follow ISO 14040, *Environmental Management — Life Cycle Assessment — Principles And Framework*, and ISO 14044, *Environmental Management — Life Cycle Assessment — Requirements And Guidelines*. The LCA allocation is mass based, and the LCCA is market value–based. For both assessments, the system boundary is cradle-to-grave. In the next sections, we will detail the selection of the specific methods employed and how they are used.

Environmental LCA – ReCiPe via GaBi

The LCA method chosen for this study is ReCiPe implemented in the software GaBi. The GaBi program aids in the implementation of many LCA methods with the use of extensive databases regarding material selection, manufacturing processes, and disposal.[28] GaBi displays the indicators relevant to the chosen LCA method. For this project, the ReCiPe LCA method was implemented using the LCI for each product.

ReCiPe is a robust LCA tool that features 21 unique output indicators.[50] Of these 21 indicators, 18 are midpoint indicators, whereas 3 are normalized from the midpoints as endpoint indicators. Midpoint indicators are information such as global warming potential, environmental toxicity, and CFC-11 emission. The three normalized endpoint indicators are human health (DALY), ecosystem quality (species depletion), and resource cost. DALY is the measure of damage to human health by the addition of the indicators "years of life lost" and "years of life disabled." The loss of species per year is a normalized measurement of the damage to the ecosystem and represents the fraction of species lost over a given area during a set time. Lastly, resource usage is the measure of damage to resource availability quantified by dollar cost per kilogram. These normalized endpoint indicators offer an easy-to-understand alternative to the midpoint indicators in the form of human health, species loss, and resource loss.

Economic LCA – Stanford Building LCCA

The economic LCA chosen for this study is a modified version of Stanford's Building LCCA. This LCCA method is employed to quantify the life cycle cost of an entire building.[34] This method looks at the lifetime cost indicators of building utilities, maintenance, service, system replacements, and initial project cost indicators. A theorized building is separated into seven categories: energy systems, mechanical systems, electrical systems, building envelope, siting, and structural systems. The user of this method then selects potential options for each building category. Each alternative is compared using a cost-benefit analysis that is extrapolated to the indicators listed above to provide the lifetime cost of the specific option.

Because the study presented in this article focuses on consumer products and not buildings, the Stanford LCCA method was adapted and simplified to quantify the consumer cost of products. The cost indicators used for this study are consumable cost (running cost) and initial cost to the consumer (purchase price). The LCCA method was adapted to look at alternatives for consumable cost and initial consumer cost via product comparison instead of systems comparison as shown in equation (1).

$$\text{Yearly Cost} = \frac{\text{Purchase Cost}}{\text{lifespan}} + \text{Yearly Consumable Cost} \tag{1}$$

Using the modified Stanford LCCA framework allows for understanding the economic impact of associated products within each product category. The LCCA was implemented using the information from the product LCI. Product purchase prices are found primarily on manufacturer websites when possible or were otherwise sourced from popular aggregated product sale websites. Product lifespan is calculated empirically by personal use and aggregated manufacture warranty information. Product lifespan is held consistent for all products throughout a given product family. The water bottle family is subject to special assumptions listed in the following sections. Consumable costs were calculated using average cost of the consumable across the United States (e.g., water as a consumable was calculated to cost the national average USD per gallon). Furthermore, yearly consumable consumption calculations are sourced from the functional unit LCI data listed above and held constant throughout the product family.

Social LCA – In-House S-LCA

An in-house method was created to explore the social impact of the products in the study. This S-LCA method includes four impact categories based on relevant literature that addresses social impacts. These categories are as follows: the location of manufacturing as it relates to labor laws,[51] social outlook or perception,[52,53] user safety,[54] and ease of maintenance.[55]

- The location of manufacturing category looks at where the product is made and the surrounding labor laws and practices that could have impacted the product's social sustainability. This information was gathered based on the LCI manufacturing locations that were found during the sourcing of product information. Labor laws are sourced from the published laws of a given manufacturing country. Real-world labor practice is aggregated from multiple current news articles.
- Social outlook is the general public opinion of a product informed by external surveys on how the product is perceived, thereby answering the question, "Is the product viewed positively or negatively?" These surveys are sourced from online opinion text mining and news articles and then are empirically summarized.
- The user safety category includes text-mined online reports of injuries that have occurred when using a specific product. This category also lists any warning about potential product dangers that are stated by the manufacturer either on the manufacturer's website or on the product.
- The ease of maintenance category explores the variation in maintenance required for different product alternatives. Maintenance ease is an empirical aggregation defined by manufacturer guidelines for maintaining a product, tools involved, required specialists, and perceived time spent. This information is sourced online or is included in product manuals.

ASSUMPTIONS AND LIMITATIONS

As with many previous works that employ LCI data, there are several assumptions made for the data acquired for this study. The use phase is assumed to be consistent over time and is informed by statistical data based on use of the product. For example, eight 8-ounce glasses of water a day is consistent for every day of the year and does not fluctuate.

Assembly is omitted from the S-LCA manufacturing category. It is recognized that assembly can have a social impact, depending on the assembly location. However, assembly locations for a single product can vary depending on intended market, so in order to limit assumptions, it was deemed best to assume assembly is done during manufacturing.

Because of the limitations of the data available in GaBi, all manufacturing and assembly is modeled as having taken place in the United States, regardless of the LCI information on manufacturing location (note that this only affects the environmental LCA portion of the study). However, GaBi only has manufacturing data for processes that take place in Europe. It is assumed that the input/output for each manufacturing process itself are the same anywhere in the world. In order to assume that manufacturing takes place in the United States, manufacturing inputs such as lubricating oils, water, and electricity are sourced from the U.S. database within GaBi. To coincide with this assumption, all product use phases are assumed to have occurred in the United States; consumable resources are also from the U.S. database. Products that have components that share manufacturing and material types have identical manufacturing flows, making the only variable component weight. This assumption ensures that similar components across all products don't have variation in impact due to differing consumable sources (western United States versus eastern United States) and differing disposal methods.

Transportation is omitted from the LCI to avoid introducing significant uncertainty to the study, as transportation data for consumer products are generally not made publicly available; it is instead assumed that all products see the same transportation distances and methods.

The disposal method for all products is assumed to be landfill. This was selected as over 50 % of U.S. garbage is placed in landfills.[56] It is recognized that disposal methods have a large impact on LCA data. However, assuming separate disposal methods for each product could further skew the data; there is large variation in the disposal methods used from person to person.

The perceived lifespans of the products used to generate the results of the LCCA were determined empirically. Product lifetime, for the most part, is inconsequential because most products within a given product category have the same perceived lifespan; the water bottle family is the only exception (water bottle lifespans were chosen empirically based on personal use). Furthermore, manufacturing location is known to have an effect on initial product costs, and because of this, initial cost is only a product of purchasing price (in the United States).

DATA

The ReCiPe indicator data are available in **Table A.1**. These data are the raw indicator data collected through the GaBi software that highlights each product's individual impact per indicator category. **Table A.3** shows the individual product results of the five impact categories of the S-LCA study. Because of sizing constraints, **Tables A.2**–**A.3** appear in the Appendix.

Results and Discussion

ENVIRONMENTAL LCA RESULTS

The results for the environmental impact analysis were developed by calculating the percent change (either positive or negative) between the ReCiPe endpoint analysis of the eco-labeled products and their conventional alternatives. The selection of showing only the endpoint indicators was chosen as these indicators are aggregated and normalized via the accepted methodology of the ReCiPe LCA method. These endpoint indicators are the easy-to-understand quantitative representation of the environmental impact of a product delineated by the ecological, human, and resource impact (species. yr, DALY, and resource usage). **Table 3** shows the percent change in endpoint impact when an eco alternative is compared with the conventional product in the same product category.

Water Bottle Product Family

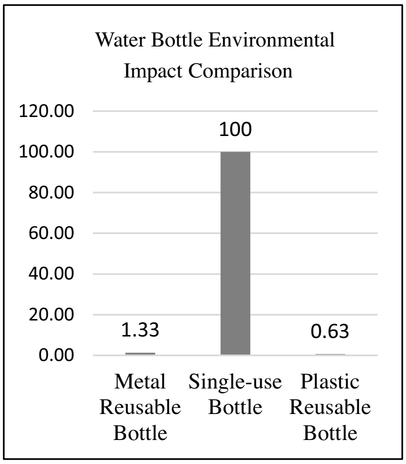
From the quantitative results shown in **figure 1**, it is clear that the plastic reusable bottle is the best alternative to a single-use water bottle. However, both eco-alternative bottles are nearly 100 % less impactful across all of the endpoint indicators. Overall, by a slight margin, the eco-alternative bottles performed the best in reduction of resource usage. As expected, in the case of the eco-alternative water bottles, the eco-labels are indicative of a more sustainable product.

TABLE 3
Average percent change of ReCiPe endpoint impact indicators

#	Product	Species.yr	Impact Change (%)	DALY	Impact Change (%)	Resource Usage	Impact Change (%)
1	Metal reusable bottle	8.69E-09	−98.5	2.37E-06	−98.3	5.41	−99.2
2	Single-use bottle	5.92E-07	Control	1.37E-04	Control	6.71E+02	Control
3	Plastic reusable bottle	4.19E-09	−99.3	8.47E-07	−99.4	4.3	−99.4
4	Conventional trash bag	1.52E-10	Control	3.13E-08	Control	0.246	Control
5	Eco trash bag	1.15E-10	−24.34	2.43E-08	−22.36	1.39E-01	−3.50
6	Hand dryer	3.27E-06	Control	6.73E-04	Control	1.95E+03	Control
7	Eco hand dryer	1.33E-06	−59.33	2.78E-04	−58.69	806	−58.67
8	Gas chainsaw	1.04E-07	Control	2.69E-05	Control	117	Control
9	Eco electric chainsaw	1.30E-07	+25.00	2.83E-05	+5.20	84.3	−27.95
10	Single-serving pod	2.05E-06	Control	3.96E-04	Control	1.40E+03	Control
11	Single-serving recyclable pod	2.00E-06	−2.44	3.89E-04	−1.77	1.10E+03	−21.43
12	Reusable pod	1.89E-06	−5.50	3.67E-04	−5.66	1.02E+03	−7.27
13	Conventional foil	3.85E-08	Control	9.59E-06	Control	21.9	Control
14	Eco foil	5.43E-09	−85.90	1.58E-06	−83.52	3.97	−81.87
15	Manual toothbrush	1.05E-09	Control	1.98E-07	Control	0.909	Control
16	Eco manual toothbrush	6.99E-10	−33.43	1.28E-07	−35.35	0.142	−84.38

FIG. 1

Average impact percentage change over all categories for the water bottle product family (aggregated).



Trash Bag Product Family

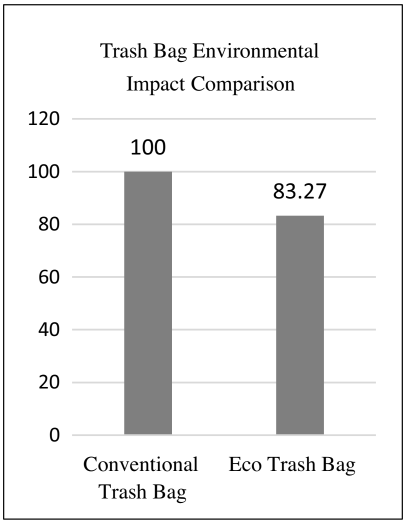
The eco-alternative trash bags are roughly 20 % less impactful, as shown in figure 2. The highest impact reduction was in the ecological category. It should be noted that there was only minute reduction in resource impact. These results suggest that Type II eco-labels, in the form of green imagery (easily correlated with ecological sustainability), are accurate. However, the slight reduction of resource impact suggests that Type II eco-label competitive statements such as, "Our product used 55 % postconsumer materials" can be misleading or irrelevant.

Hand Dryer Product Family

In the hand dryer category, shown in figure 3, the eco-dryer is ~60 % less impactful than the conventional dryer. These results can suggest that products that feature three forms of eco-labels in tandem are likely to be truthful and should increase buyer confidence in respective sustainability claims.

FIG. 2

Average impact percentage change over all categories for the trash bag product family (aggregated).



Chainsaw Product Family

Figure 4 shows that the eco electric chainsaw is the only product represented that has an increased environmental impact over the conventional alternative. The ecological impact is 25 % more impactful than the gas-powered chainsaw, suggesting that Type II eco-labels (green color usage) is not indicative of better ecological or human impact performance. The human impact of the eco-alternative chainsaw is increased by 5 %. Lastly, there is a 28 % decrease in resource impact. Despite the inaccuracies of Type II eco-labels used on the eco chainsaw, the Type I eco-label (one focused on quantifying the resource usage of the product) is shown to still be accurate. This important result suggests that Type I eco-labels are significant, meaningful, and accurate.

Coffee Pod Product Family

In studying the coffee makers (fig. 5), both the single-serving recyclable pod and reusable pod show a positive correlation between eco-labeling and environmental sustainability. The reusable pod results show a decrease of ecological and human impact over the marketed "green" recyclable pods. However, the recyclable pods do have a significate decrease in resource impact in the first year of use. Because the results indicate that the reusable pods are more sustainable in two categories, there is a potentially dubious reasons to market single-use pods over an alternative that is more sustainably sound. This finding resonates the sentiment that eco-labels should be made with all product alternatives in mind. Furthermore, marketing sources claim that the company chose a recyclable

FIG. 3

Average impact percentage change over all categories for the hand dryer product family (aggregated).

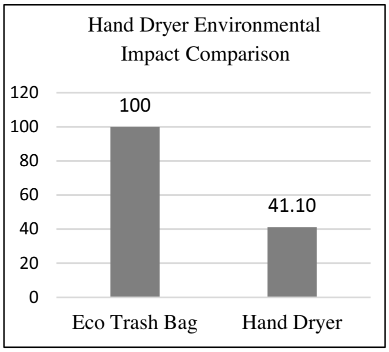


FIG. 4

Average impact percentage change over all categories for the chainsaw product family (aggregated).

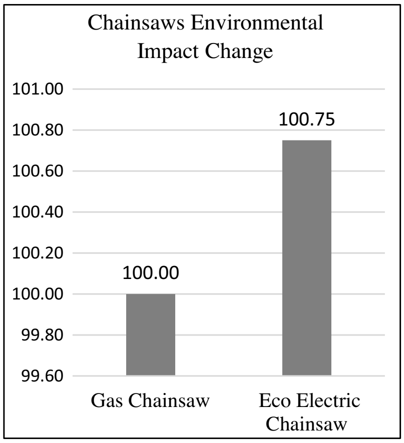
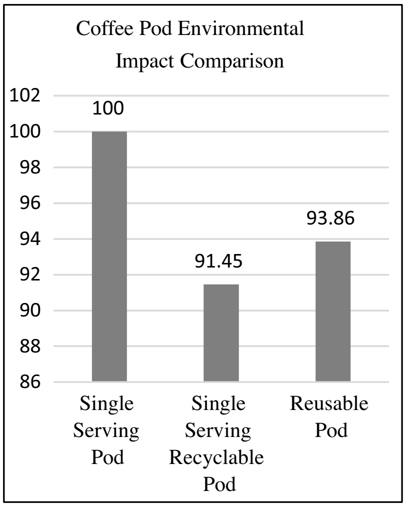


FIG. 5

Average impact percentage change over all categories for the coffee pod product family (aggregated).



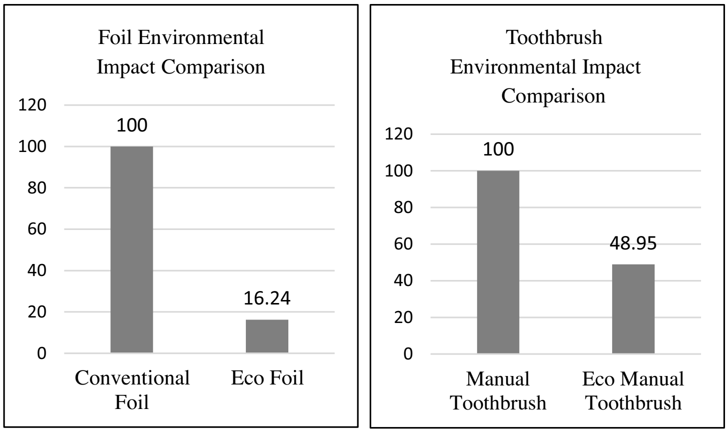
pod design because of the claim that 94 % of the U.S. population has access to a recycling program; however, this claim is misleading as only 61–70 % of municipalities recycle pod product cups and tubs.[57] In closing, the marketed green product is more sustainable and further suggests that products with multiple types of eco-labels have a high confidence of improved sustainability. However, this portion of the study does uncover the idea of not eco-labeling products that are known to be more sustainable as a means to avoid internal competition.

Foil and Toothbrush Product Families

Lastly, in figure 6, the eco-labeled toothbrush and food foil have a reduction in impact in all categories. Specifically, the foil results show that Type II eco-labels (in the form of green imagery and color) are indicative of a more sustainable product. However, the lowest category of improvement is resource impact. Again, this suggests that making statements about postconsumer content is meaningful but not fully representative of sustainability performance of a product. The eco-labeled toothbrush has the most reduction of impact in the resource category. The overall results of the eco toothbrush point to Type I eco-labels being accurate and representative of the environmental performance of the product.

FIG. 6

Average impact percentage change over all categories for the foil and toothbrush product families.



ECONOMIC LCCA RESULTS

The LCCA data were developed by extrapolating the use phase information for product consumables and relating those use scenarios to the cost of the consumables. This information was then added to initial cost of the products. The initial cost of each product is divided by the assumed lifetime of the product. These data were sourced via statistical averages. Table 4 shows the cost results for the studied products.

In our preliminary analysis (the first nine products), it was found that eco-labeled products generally correlated with increased cost savings.[58] However, in the extended study, the data show that there is no definitive correlation between cost savings and eco-labeled products. The eco trash bags, foil, recyclable pods, and toothbrushes all have equal or increased cost over the conventional alternative. The largest differences in costs (based on percentage) were evident in the reusable bottles when compared with the single-use water bottles. Furthermore, the plastic reusable bottle has a lower economic impact (to the consumer) than the metal bottle. However—though this consideration is outside of the scope of this study— the metal bottle should last longer than the plastic bottle under

TABLE 4

Product cost during 1 year of use

#	Product	Initial Cost (USD per unit)	Lifespan (yr)	Consumable Cost (USD)	Total Cost per Year (USD)
1	Metal reusable bottle	30.95	5	1.14	7.33
2	Single-use bottle	0.8	SU	…	110.6
3	Plastic reusable bottle	9.00	3	1.14	4.14
4	Conventional trash bag	0.21/bag	SU	…	21.84
5	Eco trash bag	0.34/bag	SU	…	35.36
6	Hand dryer	480	12	67.3	107.3
7	Eco hand dryer	450	12	24.82	62.32
8	Gas chainsaw	329	10	1.56	34.46
9	Eco chainsaw	249	10	0.58	25.48
10	Single-serving pod	200	SU	684.4	884.4
11	Single-serving recyclable pod	200	SU	684.4	884.4
12	Reusable pod	216	1	305.35	505.4
13	Conventional foil	8.99	SU	…	8.99
14	Eco foil	12.40	SU	…	12.40
15	Manual toothbrush	1.48	0.25	1.48	5.92
16	Eco manual toothbrush	3.00	0.25	3.00	12

Note: SU = single use.

normal use conditions. The current results show that there is no definitive connection between the improved or diminished economic sustainability of a product. It can be stated that Type II labels are not indicative of cost savings to a consumer and fail to provide a guaranteed positive effect of economic sustainability. Type II eco-labels are potentially dubious in one pillar of sustainably. However, it can be argued that the average consumer associates "sustainability" and Type II labels with only environmental sustainability.

S-LCA RESULTS

The in-house S-LCA rendered both quantitative results and more qualitative results based on the four identified impact categories. The results of the S-LCA are shown in Table A.3 in the Appendix. From these results, some of the key points are that reusable plastic bottles are better than both metal reusable bottles and single-use bottles if the country of production has better labor laws and has fewer reported incidents; additionally, carcinogenic content is not found in these bottles. The only study in which single-use water bottles have improved S-LCA indicators are when they are used during events of natural distress or calamity, due to the fact that they are easy to transport and are perceived as safe. In comparing conventional trash bag with eco-friendly trash bags, the eco-friendly trash bags are considered to be more socially sustainable. Similarly, eco hand dryers and the eco electric chainsaw gain an advantage over their conventional counterparts. One primary concern with the eco electric chainsaw is the possibility of the electronic circuit malfunction, which might cause severe injuries, but there are no reports of such incidents. The eco foil and conventional foil have the same social impact, but both are subject to controversy regarding the potential negative health effects of aluminum. Regardless of the scientific fact proving or disproving these claims, aluminum food products are still subject to some apparent negative social perception. The eco toothbrush data show that they are more socially sustainable compared with the conventional alternative, largely because they are being manufactured in the United States (improved labor laws as compared with China).

The recyclable pods share similar S-LCA results. The recyclable pods are not fully available on the market, and do not look different from the conventional pods. Since the recyclable alternative is not well established in the market, social perception of the eco pod is inconclusive. There is a negative social perception about the conventional coffee pods.[59,60] The recyclable pods score worse with respect to the maintenance indicator. In order for the pods to be recyclable, the consumer need to remove the foil top, filter, and grounds. It is unclear if these instructions are available in the box. The results show that the recyclable pods are yet to be subject to social opinion as they are new to the market, but will likely have an improved social perception. However, like the recyclable pod, the reusable pod requires a higher level of maintenance. Contrary to recyclable pod's unsolidified social perception, the reusable pod is subject to social praise.[61]

Discussion

Overall, the eco-labeled products are indicative of a more sustainable product when compared with conventional alternatives within their families. The water bottle family saw vast improvements in all three areas. It is interesting to note that the plastic reusable bottle is the most sustainable option of the three products. As such, it had less instances of human health hazards, less environmental impact, and was roughly half the cost of the metal reusable water bottle. The trash bag family was the least improved, sustainability-wise, over the conventional product. There is only a slight improvement in the social aspects of the trash bag comparison and a negative impact on cost. The eco hand dryer is a notable improvement over the conventional alternative in all areas of sustainability. The eco hand dryer costs less than the conventional hand dryer, had a reduced environmental impact, and had improved social characteristics, namely improvement in maintenance and user safety. The chainsaws perform similarly socially; however, the eco alternative excels in cost but actually has a higher environmental impact. Socially, it can be argued that the lack of interaction with hazardous fuels increases the user safety of the eco chainsaw, thus giving the social advantage to the eco chainsaw. The recyclable coffee pod has improved environmental sustainability but lacks improvements in economic or social sustainability. Though the reusable coffee pod lacks any sort of eco-labels, it performs better than both alternatives in all three sustainability areas. The eco foil has only improvements in

TABLE 5

Product performance as related to originally assigned eco-labels

Eco-Label Type	Product	Environmental Impact	Economic Impact	Social Impact
Type 1	Eco hand dryer			
	Eco chainsaw			
	Eco toothbrush			
	Total			
Type II	Eco chainsaw			
	Eco foil			
	Eco hand dryer			
	Metal reusable bottle			
	Plastic reusable bottle			
	Single-serving recyclable pod			
	Reusable pod			
	Eco toothbrush			
	Eco trash bag			
	Total			
Type III	Eco hand dryer			
	Total			

Note: Light/Dark green is indicative of decreased impact*. Red is indicative of increased impact*. Grey shows inconclusive results.
* when compared to conventional alternatives.

environmental sustainability, which is offset by diminished economic sustainability performance. The eco toothbrush is generally more sustainable than the conventional alternative, with the exception of costing more. Table 5 shows the relationship of product impact performance as related to their original eco-labels. Green tiles indicated improved performance. Red tiles indicate reduced performance. Totals show the dominance of improvement or nonimprovement given a label type and category. Gray tiles are inconclusive results.

Conclusions

The purpose of this study is to discover if eco-labeling correlates to improved product sustainability by using three LCA methods: ReCiPe via GaBi, Modified Stanford LCCA, and S-LCA. This was done by comparing the LCA indicator results between eco-labeled products and their conventionally labeled alternatives. The results show:

1. Products employing all three eco-label types are subject to increased confidence of eco-label accuracy and increased confidence.
2. Type I eco-labels are accurate to the sustainability area they represent. In the case of the chainsaw, there is proven accuracy to the Type I eco-label, but the Type II labels were deemed to be misleading. This finding is conclusive with the idea that type I eco-labeling organizations likely build a reputation on being accurate and representative.
3. Most Type II eco-labels are representative of reduced environmental impact. However, there is evidence that competitive/comparative statements align more with marketing and less with improved environmental performance.
4. Type II eco-labels can be deceptive, as shown through the chainsaw product comparison. Since the completion of this work, the eco-labeled chainsaw seemingly removed the Type I eco-labels.
5. There is evidence that suggests eco-labels, though accurate, can be used to manipulate the market place through the inclusion or exclusion of qualifying eco-labels. This is the case with recyclable eco-labeled single-use coffee pods versus non-eco-labeled (with improved environmental performance) reusable coffee pods.
6. Eco-labels are indicative of lower consumer investment costs. The results of the LCCA show that eco-labels are closely related to increased savings as a way to incentive consumers.
7. The preliminary S-LCA results are mostly inconclusive due to the novelty of implementing such an assessment. However, this assessment suggests that eco-labeled products are subject to increased social perception.

8. Through the S-LCA, we discovered that some products rely on social behaviors to meet qualifications the eco-labels attached to the product. This is the case with the complicated recycling procedure of the eco-labeled coffee pod. This discovery concluded that eco-labels might be related to a "best case use scenario"; one that may not be representative of traditional or probable use scenarios.

This study provides insight into how and why eco-labels are marketed. In some cases, the eco alternative can be used to save on use and production cost. In other cases, eco-labels are used to improve the social perception of a product, as is the case with the recyclable coffee pods. It is clear that the companies explored in this study associate eco-labels (especially Type II labels) with improved environmental sustainability and marketability. According to Cronin et al. 2011[13] We know that eco-labeling is used in marketing strategies. Sharma and Kushwaha 2019,[18] Indicate that consumers build trust according to the eco-labels used. As such, the previous literature suggests that green marketing strategies could lead to abuse of consumer trust. The results found in this paper indicate that there are malicious green marketing strategies, even in a small case study. These results justify the need for further literature that explores predatory eco-labeling practices and suggested improved complex eco-labeling regulation.

The data gathered in this study highlighted a few cases where a product was purposely compared, in its eco-labeling, to the "worst-case" conventional alternative, while ignoring potentially more sustainably alternative for comparison. For example, the coffee pod manufacturer offers a more sustainable solution than its eco-labeled alternative. The more sustainable offering is void of any eco-labels. There is a need to explore manipulative eco-labeling practices where a company may hide sustainable solutions in favor of more profitable but less sustainable alternatives.

Horne 2009[16] States that eco-labels need to reach beyond an environmental standpoint to provide social and economic impact information to consumers. However, given the current state of eco-labeling, we suggest there is further work needed to improve the classical environmental eco-labels. Future work can implement a more extensive case study to substantiate the results found in this case study for all eco-labeled products. Future studies should be inclusive of complex multi-assembly products. Complex products can be more insightful of targeted eco-labels that may not be represented of the entire system; as shown by the chainsaw. For example, a vehicle may be marketed as sustainable for using recycled materials for door paneling. However, this may be negligible in the improvement in sustainability for the system. This idea is inadvertently shown in the coffee brewer pods: there is only a small improvement of environmental impact using eco-labeled consumables.

There are likely more effective improvements that can be made to the entire system itself.

The presented methodology in this paper can serve as a precursor to the development of a standardized framework for measuring and comparing the sustainability of 'on-the-market' consumer products. In contrast to work done by Nikolaou, Tsalis, and Kazantzidis,[25,26] this framework is created with single-product comparative analysis in mind, as opposed to identifying the sustainability of firms. The proposed framework contributes to the need for a method that measures a product's triple-bottom-line sustainability using globally available LCA tools. This methodology is the starting point to encourage the widespread use of trustworthy eco-labeling by creating a foundation in LCA methods to assess product sustainability claims.

The novel comparative framework has implications beyond "green marketing." Eco-labeling, precisely type II, appears to be a marketing scheme to display a marked improvement over a product alternative. This improvement, though valuable, often goes unmeasured. Through the use of LCA design tools-based methodology, engineering designers can use this framework to identify the most sustainable alternatives on the market and what design decisions contribute to increased sustainability.

In closing, our work suggests that further improvement can be made in the form of labeling transparency, requirement, and standardized framework for measuring and comparing product sustainability. The proposed precursor framework can aid in moving eco-labeling from a marketing tool to an engineering design method for identifying the sustainability of competitive products. Furthermore, we suggest that increased regulation in complex eco-labeling can reduce the occurrence of predatory green marketing schemes. Precise requirements to meet labeling standards can lead to actionable design decisions for new products entering the market space. The results presented in this study can serve to influence new regulations on using eco-labels as a basis of comparison, and promote the adoption of eco-labeling during the design process.

Appendix

TABLE A.1
ReCiPe indicator values per product

-		MID-POINT INDICATOR												END-POINT INDICATOR		
#	Product	CO2(kg)	SO2(kg)	P(kg)	CFC-11(kg)	Oil (kg)	1,4-DB(kg)	U235(kg)	N(kg)	Fe(kg)	PM10(kg)	NMVOC(kg)	Water(m2)	Species. yr	DALY	$
1	Metal reusable bottle	1.09	3.58E-03	3.58E-03	3.98E-11	0.332	0.608472	0.0147	9.50E-04	1.06	1.62E-03	3.18E-03	0.254	8.69E-09	2.37E-06	5.41
2	Single use bottle	72.8	0.135	1.59E-03	1.03E-08	41.8	34.117	3.41	0.0322	0.239	0.0417	0.152	26.1	5.92E-07	1.37E-04	6.71E+02
3	Plastic reusable bottle	0.517	9.97E-04	9.93E-06	6.83E-11	0.268	6.02E-02	2.99E-02	2.73E-04	1.47E-03	3.14E-04	9.39E-04	3.63E-01	4.19E-09	8.47E-07	4.3
4	Conventional trash bag	1.83E-02	3.38E-05	6.51E-07	1.50E-12	1.53E-02	0.004123	8.54E-04	8.55E-06	6.07E-05	1.09E-05	3.10E-05	1.30E-02	1.52E-10	3.13E-08	0.246
5	Eco trash bag	0.0137	2.67E-05	7.06E-07	1.88E-12	8.66E-03	0.004157	7.42E-04	6.15E-06	4.99E-05	8.71E-06	2.20E-05	8.21E-03	1.15E-10	2.43E-08	1.39E-01
6	Hand dryer	412	1.2	4.17E-04	1.58E-07	121	1.53E+01	4.49E+01	0.191	36.3	0.327	0.583	164	3.27E-06	6.73E-04	1.95E+03
7	Eco hand dryer	166	0.494	3.38E-04	6.01E-08	5.01E+01	1.07E+01	1.75E+01	0.0837	3.57E+01	0.144	0.254	81.9	1.33E-06	2.78E-04	806
8	Gas chainsaw	13	0.039	2.32E-04	1.94E-09	7.27	1.94852	0.637	0.0106	1.56	0.0282	0.0297	4.95	1.04E-07	2.69E-05	117
9	Eco electric chainsaw	16.4	0.0372	2.29E-05	4.74E-09	5.24	1.46E+00	0.989	7.98E-03	1.55	0.0165	0.025	5.53	1.30E-07	2.83E-05	84.3

TABLE A.2
ReCiPe indicator values per product

-		MID-POINT INDICATOR												END-POINT INDICATOR		
#	Product	CO2(kg)	SO2(kg)	P(kg)	CFC-11(kg)	Oil(kg)	1,4-DB(kg)	U235(kg)	N(kg)	Fe(kg)	PM10(kg)	NMVOC(kg)	Water(m2)	Species. yr	DALY	$
10	Single serving pod w/brewer	258	0.376	5.34E-04	3.19E-08	70.8	6.23	26.7	0.119	2	0.117	0.318	549	2.05E-06	3.96E-04	1.40E+03
11	Single serving recyclable pod w/brewer	252	0.37	4.93E-04	3.17E-08	68.8	6.03	26.5	0.115	1.99	0.12	0.306	546	2.00E-06	3.89E-04	1.10E+03
12	Reusable pod w/brewer	238	0.355	4.72E-04	2.33E-08	63.8	5.85	26.2	0.112	2.01	0.11	0.294	539	1.89E-06	3.67E-04	1.02E+03
13	Conventional foil	4.48	0.022	1.74E-06	1.98E-07	1.37	0.66	0.373	3.83E-03	-0.548	9.05E-03	0.0132	59	3.85E-08	9.59E-06	21.9
14	Eco foil	0.648	1.59E-03	-5.27E-08	6.56E-08	0.25	0.33	0.11	4.72E-04	-0.664	1.50E-03	2.68E-03	2.29	5.43E-09	1.58E-06	3.97
15	Manual toothbrush	0.132	1.44E-04	7.06E-08	8.73E-11	0.057	2.22E-03	2.95E-03	4.42E-05	1.79E-04	4.55E-05	1.68E-04	0.077	1.05E-09	1.98E-07	0.91
16	Eco manual toothbrush	0.088	5.19E-05	1.43E-08	7.91E-11	8.85E-03	5.66E-04	1.74E-03	1.90E-05	8.28E-05	1.70E-05	5.19E-05	0.060	6.99E-10	1.28E-07	0.14

TABLE A.3
S-LCA results

#	Product	Country of Production	Social Perception	User Safety	Ease of Maintenance
1	Metal reusable bottle	China (labor laws & practices are less regulated compared to USA)	Good (+ve)	Choking hazards (6 incidents of spouts breakage reported in one year)	Easy to maintain
2	Single-use bottle	USA (labor laws are pretty strict)	Poor (−ve)	Choking hazard/warnings about cancer	Not required
3	Plastic reusable bottle	USA (labor laws are pretty strict)	Good (+ve)	Choking hazards (1 incident reported in 2013)	Easy to maintain
4	Conventional trash bag	USA (labor laws are pretty strict)	Poor (−ve)	Danger of suffocation	Not required
5	Eco trash bag	USA (labor laws are pretty strict)	Good (+ve)	Danger of suffocation	Not required
6	Hand dryer	USA (labor laws are pretty strict)	Unknown	Chances of burns	Regular maintenance required
7	Eco hand dryer	USA (labor laws are pretty strict)	Unknown	No chance of burns	Less maintenance as heating components are not involved
8	Gas chainsaw	USA (labor laws are pretty strict)	Unknown	Exhaust fumes are highly harmful. Interaction with flammable materials	High maintenance. possibly need to mix fuels every fill-up.
9	Eco electric chainsaw	USA (labor laws are pretty strict)	Unknown	Circuit malfunction and battery explosion	Less maintenance
10	Single-serving pod	USA (labor laws are pretty strict)	Poor (−ve)	Potential plastic/metal contamination	No maintenance
11	Single-serving recyclable pod	USA (labor laws are pretty strict)	Unknown	Potential metal contamination	Maintenance to retain recyclability
12	Reusable pod	USA (labor laws are pretty strict)	Good (+ve)	Potential plastic contamination/choking hazard	High maintenance
13	Conventional foil	USA (labor laws are pretty strict)	Poor (−ve)	Sharp hazard	No maintenance
14	Eco foil	USA (labor laws are pretty strict)	Poor (−ve)	Sharp hazard	No maintenance
15	Manual toothbrush	China (labor laws & Practices are less regulated compared to USA)	Unknown	Potential choking hazard	Moderate maintenance
16	Eco manual toothbrush	USA (labor laws are pretty strict)	Unknown	Potential choking hazard	Moderate maintenance

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