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Leveraging life cycle assessment to evaluate environmental impacts of green cleaning products

Kathryn G. Van Lieshout[a,]*, Cindy Bayley[a], Sarah O. Akinlabi[b], Lisa von Rabenau[c], David Dornfeld[a]

[a]*Department of Mechanical Engineering, University of California, Berkeley, CA, 94709, United States*
[b] *Department of Chemical Engineering, University of California, Berkeley, CA, 94720, United States*
[c] *Department of Mechanical and Process Engineering, Technische Universität Darmstadt, 64289 Darmstadt, Germany*

* Corresponding author. *E-mail address:* kvanlieshout@berkeley.edu

Abstract

The green cleaning industry continues to pursue products that reduce or eliminate impacts on human health and the environment; however, these impacts over the life cycle are not well understood. This study assessed environmental impacts of four green cleaning products from Method Products, PBC (all-purpose cleaner, hand wash, dish soap) and Ecover (dish soap). A life cycle assessment from cradle-to-grave was performed using ReCiPe and IPCC GWP methodologies. Results correlated greatest impact contributors to ingredient composition and identified the need to improve data quality. Based on the findings, a prioritized list of actions for green cleaning companies was developed.

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Keywords: life cycle assessment; cleaning products; ecological footprint; global warming potential; environmental impact

1. Introduction

Among a complex and ever-changing chemical market, the need to understand the impact cleaning products have on our health and environment has become increasingly vital. Global production of chemicals is expected to grow at a rate of 3% each year, significantly faster than the population growth rate. Meanwhile, production, price, and performance drive the U.S. chemical market rather than human health and the environment [1]. To this end, green chemistry aims to design “chemical products and processes [that] reduce or eliminate the use and generation of hazardous substances” [2].

The green cleaning industry has grown through demand by consumers for environmentally-friendly products while maintaining product effectiveness, as well as through pressure by industry regulations. With over 85% of our lives being spent indoors in the United States [3], it is important to address the health hazards of cleaning products. Many cleaning product companies have begun pursuing greener chemicals as they foresee not only social and environmental benefits but economic benefits as well. According to a 2011 report by Pike Research [4], transitioning from petroleum-based chemicals to green chemicals has the potential to save industry $65.5 billion by 2020. Additionally, new regulations soon to be enforced by the European Union require that cleaning products display their Product Environmental Footprint (PEF) on packaging labels [5].

2. Background

Many attempts have been made to understand the health and environmental hazards of green cleaning products, but very few have examined products over their entire life cycle. Current practices frequently focus on human toxicity impacts from using the formulations. To accomplish this, chemicals are often screened by third party companies and resources such as McDonough Braungart Design Chemistry (MDBC), the Pharos Project, or Green Screen. However these do not encompass the full extent of impacts over products’ life cycles. Other evaluation methods include Cradle to Cradle, a

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certificate program that rates products in terms of material, energy, water, and social factors [6]. On occasion, companies have developed their own frameworks, such as Ecover's Diamond Model, by which they evaluate all of their products across the entire life cycle [7]. While all these methods aim to quantify environmental impacts, they are limited by having a narrow scope or by not being standardized. Life cycle assessment (LCA) can help fill these gaps to better understand comprehensive environmental impacts of cleaning products.

Previous LCAs of chemical products have been sparse and inconsistent in their methodologies, and few have focused on cleaning products. When examining LCA trends in pharmaceutical and chemical industries, Jiménez-González and Overcash [8] indicated that life cycle inventory (LCI) data is not available for most chemicals. Possibly as a result, many groups have formulated their own methodologies for LCA of chemical products. Yu et al. [9] developed an analytic hierarchy process that resulted in a single score environmental metric, while Saouter et al. [10] used risk quotients (a function of consumption, removal, sewage flow, and dilution).

There are a few existing studies that use LCA to evaluate the environmental impacts of cleaning products. An existing comparative LCA study by Kapur et al. [11] demonstrated that general purpose cleaning products compliant to the Green Seal Standard for Cleaning Products for Industrial and Institutional Use, GS-37, had substantially lower environmental impacts than conventional cleaning products in the market. Kuta et al. [12] performed a LCI of two hard surface cleaning products from Procter & Gamble (P&G) in order to "develop baseline information on the relative contribution of various ingredients, processes, and consumer use and disposal to total resource use and emissions." The authors of this paper argue that "the true value of LCI is the realization that a change in one portion of a product's life cycle will have some effect (either positive or negative) in other areas of the product's life cycle. By applying this 'life cycle thinking' to the product design process, true improvement opportunities can be identified" [12]. Saouter and van Hoof [13] used SimaPro to construct a LCI database for examining P&G laundry detergents. With this database and CML92 methodology, they performed a life cycle impact assessment (LCIA) from cradle-to-grave of a hypothetical laundry detergent used in Belgium excluding transportation. This study maintains that "LCIA is the appropriate tool to help determine to what extent a particular product, process or ingredient's emissions may be associated with a particular impact category" [13].

Compared to conventional cleaning products, green cleaning products already have reduced health and environmental impacts, yet the impacts over the life cycle remain to be understood. The purpose of this investigation is to evaluate life cycle environmental impacts of several green cleaning products in order to identify opportunities for improvement within product formulations and across product life cycles. Method Products, PBC can in turn use these guidelines to further reduce environmental and health impacts. This study demonstrates how through a comprehensive analysis, a prioritized list of actions for green cleaning companies can be developed in order to augment their current methods of creating environmentally-friendly products.

3. Methodology

Environmental impacts were determined by means of a life cycle assessment (LCA), following ISO 14040 guidelines through the process of: goal and scope definition, inventory analysis, impact assessment, and interpretation [14]. Products were analyzed from cradle-to-grave, which is defined as considering the impacts from raw material extraction through production and use to disposal. Fig. 1 delineates the specific phases of the life cycle that were included in this analysis. System Boundary 1 considers the ingredients within each product formulation and System Boundary 2 assesses impacts based on life cycle stages (product formulation, use, transportation, and end-of-life). It is important to note that packaging was excluded from the analysis, as both companies have already performed detailed LCAs on their packaging.

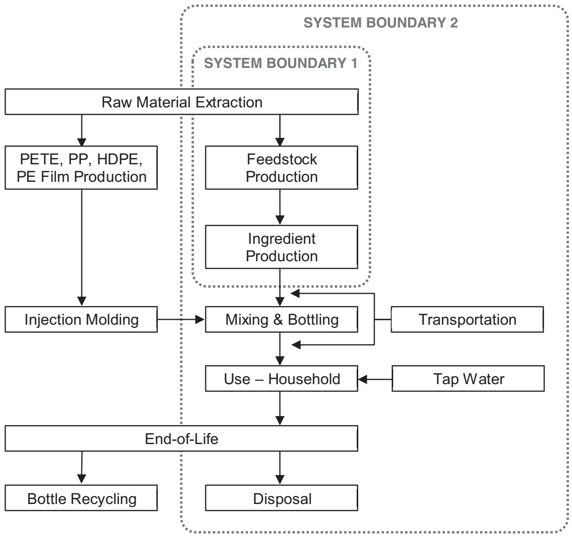

Fig. 1. Simplified system boundary diagram for evaluated products.

The analysis was conducted using LCA software SimaPro 8 [15] with the ecoinvent v3 database [16]. Analysis methodologies included IPCC GWP 100a [17] and ReCiPe Endpoint H [18] to determine global warming potential (GWP) and categorical environmental impacts, respectively. The 18 impact categories included in ReCiPe are: climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, ionizing radiation, agricultural land occupation, urban land occupation, natural land transformation, water depletion, metal depletion, and fossil depletion. European E/A normalization factors in ReCiPe were applied to impact categories to achieve a single score evaluation represented as "millipoints."

The selected methodologies provide comprehensive representations of environmental impacts and communicable results. The ReCiPe methodology offers a "harmonized" set of modeling principles and the middle-ground, hierarchist (H) perspective represents "the most common policy principles with regards to time-frame and other issues" [19]. Similarly, global warming potential as determined by the Intergovernmental Panel on Climate Change (IPCC) over a 100 year timeframe – "the default for the Kyoto protocol and for carbon footprint studies" [20] – provides a metric that is communicable and trusted among companies.

4. Case Study

Method Products, PBC, a U.S. based company founded in 2001, specializes in high quality and environmentally-friendly cleaning products made from naturally derived ingredients. Method prides itself in utilizing recycled and, in most cases, recyclable materials for its product packaging [21]. Ecover, a Belgium based company, also specializes in green cleaning products and maintains that it uses environmentally-friendly plant-based ingredients in its product formulations [22]. In 2012, both companies merged to form the world's largest green cleaning product company [23].

Four products from Method and Ecover were evaluated in this study: Method all-purpose cleaner (MAPC), Method dish soap (MDS), Method hand wash (MHW), and Ecover dish soap (EDS). These products were selected as they are representative of the companies' product lines. Given the differing applications of these products, a functional unit of "1 kilogram of product" was selected. Product formulation, use, and end-of-life phases were included, as well as transportation in-between life cycle phases.

4.1. Product Formulation

In performing this analysis, Method provided the quantities and ingredients for the product formulations of the four products evaluated. The formulas were provided in March 2014. Dyes and fragrances (which make up less than 0.01% of the products) were not included because their formulations are considered proprietary information.

Of the 19 unique chemical ingredients present across all four products, only six ingredients were directly present in the SimaPro database. For those not directly available, proxy chemicals were developed based on the chemical formulation, molecular weights, and common manufacturing methods. We gathered information on reactants and processes used in making ingredients through library research and consulting with chemists. When exact matches of these reactants were not in the database, we carefully sectioned the molecular structure of the absent chemical into parts so that the parts closely matched what was available in SimaPro. The molecular weights of these parts were used to determine their mass contribution to the absent chemical.

Sensitivity analyses were performed when multiple options for a proxy chemical were available. For example, sodium lauryl sulfate (SLS), a commonly used surfactant, was represented as 60% fatty alcohol sulfate and 40% sodium carbonate. Eight proxies were developed for SLS representing four different feedstock varieties (coconut oil, palm oil, palm kernel oil, and petrochemical). If all proxy choices produced comparable environmental impacts, an average case was selected, but if impacts varied significantly, both the high and low cases were modeled. Similarly, cocamidopropyl betaine (CAPB) was mapped to 73% esterquat from coconut and palm kernel oil and 27% chloroacetic acid based on the chemical formulation and molecular weights. To identify opportunities for improvements within product formulas, several feedstock options were evaluated; for example, fatty alcohol sulfate from coconut, palm kernel, and palm fruit were compared.

4.2. Use

Water consumption during the use phase of dish soap and hand wash were estimated based on average consumer data. Approximate soap doses for washing hands and dishes were measured based on the bottles' controlled dispensing mechanisms. With water consumption averages for washing hands and dishes from the U.S. Geological Survey (USGS) [24] and estimated dosage amounts, the total mass of water consumed per kilogram of product was estimated as 1200 kg and 5200 kg of water for hand wash and dish soap, respectively. It was assumed that no water is consumed while using Method's all-purpose cleaner.

4.3. Transportation

Considering transportation, Method provided information about its supply chain and the locations of main suppliers and distributors. This analysis assumed transportation methods and distances for an average case in Method's and Ecover's supply chain, which included transport from suppliers to a bottling factory, bottling factory to regional distributor, and regional distributor to user (Table 1). Method uses a renewable biodiesel fuel blend for approximately a third of its shipments and estimates that these trucks produce 20% less carbon and air pollutants than conventional trucks [25]. Since biodiesel transportation was not in the database and literature is sparse, sensitivity analyses were performed around this transportation segment. Nanaki and Koroneos [26] found biodiesel transportation to have 60% reduced environmental impacts compared to diesel transportation in Greece, but this was for cars, not trucks, and other studies have not verified this claim. For a sensitivity analysis, we assumed impacts from biodiesel trucking are equal to 60%, 30%, and 0% of the impacts from diesel trucking.

Table 1. Summary of average transportation methods and distances.

Transportation Segment	Method	Distance (km)
Suppliers to factory	Diesel truck	1200
Factory to regional distributor	Freight train	3400
Regional distributor to user	Biodiesel truck	800

4.4. End-of-Life

When cleaning products have reached their end-of-life, they can exit households through various streams, including wastewater, municipal solid waste, and evaporation. Since residential wastewater treatment was not directly available in SimaPro's waste scenarios, we assumed that all products are disposed of entirely as non-durable (soft) goods in the United States. This waste scenario includes the landfill and recycling of products that are used up entirely after a single use, such as with cleaning products [15], and is based on average rates from the Environmental Protection Agency's 2006 Facts and Figures [27]. It is important to note that the impacts from this disposal scenario encompass the total municipal waste stream in the United States, and therefore there is no differentiation between green cleaning products and other non-durable goods, such as cosmetics, conventional cleaning products, and clothing. Packaging disposal was excluded from this analysis.

5. Results

Products were analyzed from cradle-to-gate (System Boundary 1) and from cradle-to-grave (System Boundary 2). System Boundary 1 analysis indicated that impacts generally correlate with ingredient concentration in product formulas; sodium lauryl sulfate (SLS) contributes most of the environmental impacts in all products except Method all-purpose cleaner, which does not contain SLS, while lauryl glucoside and decyl glucoside contribute 64% of the impacts in Method all-purpose cleaner (Fig. 2). These ingredients are also present in high quantities in the formulation, which increases their likelihood of dominating environmental impacts. Within SLS formulation, the majority of the impacts are attributed to the fatty alcohol sulfate feedstock. For SLS, fatty alcohol sulfate from coconut oil, palm oil, palm kernel oil, and petrochemical sources were tested, and no significant impact reductions were discovered across feedstock types.

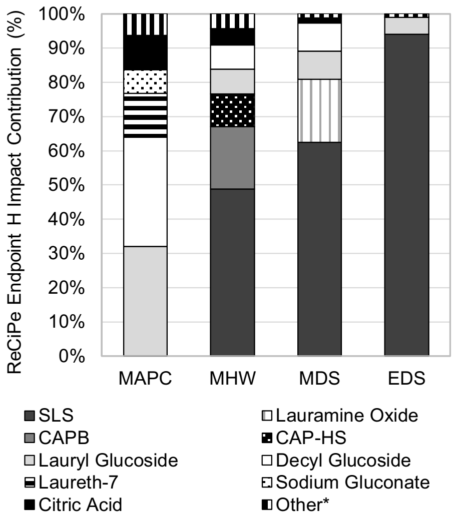

Fig. 2. ReCiPe Endpoint H impacts by ingredient (System Boundary 1). Other* includes ingredients that contribute less than 5% to product impacts. MAPC = Method all-purpose cleaner, MHW = Method hand wash, MDS = Method dish soap, EDS = Ecover dish soap, SLS = sodium lauryl sulfate, CAPB = cocamidopropyl betaine, CAP-HS = cocamidopropyl hydroxysultaine.

Environmental impacts with respect to life cycle stage were quantified with ReCiPe Endpoint H (Fig. 3). For Method all-purpose cleaner, 49% of the impacts come from disposal at end-of-life. For Method hand wash, 46% and 28% of the impacts come from the product formulation and water during use, respectively. For Method dish soap and Ecover dish soap, 48% and 42% of the impacts come from water during use, respectively.

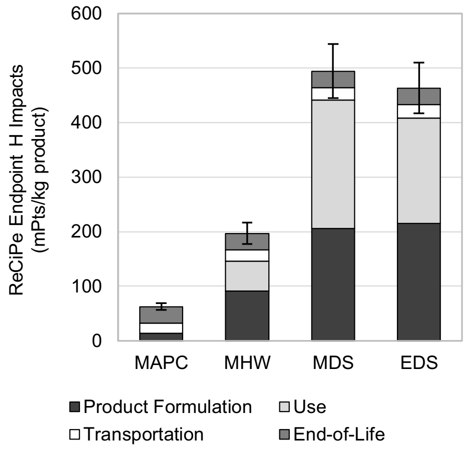

Fig. 3. ReCiPe Endpoint H impacts by life cycle stage (System Boundary 2). MAPC = Method all-purpose cleaner, MHW = Method hand wash, MDS = Method dish soap, EDS = Ecover dish soap.

In addition to examining impacts across life cycle stages, impacts were also broken down by impact category. After applying European E/A weighting factors, the top five impact categories were identified: climate change human health, fossil depletion, climate change ecosystems, natural land transformation, and human toxicity (Fig. 4). Global warming potential as determined by IPCC 100-year methodology was also evaluated for all products in System Boundary 2. This assessment indicated that Method all-purpose cleaner, Method hand wash, Method dish soap, and Ecover dish soap have GWP of 0.85, 1.9, 4.5, and 4.2 kg CO2-eq, respectively.

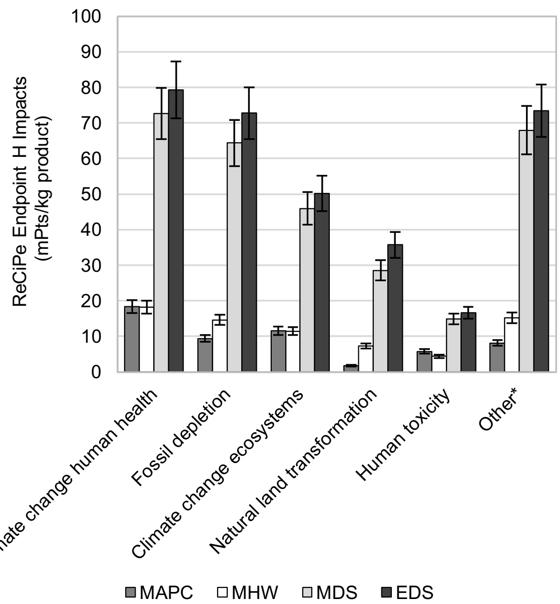

Fig. 4. ReCiPe Endpoint H impacts by impact category (System Boundary 2). Other* includes impact categories that contribute less than 10% to overall impacts. MAPC = Method all-purpose cleaner, MHW = Method hand wash, MDS = Method dish soap, EDS = Ecover dish soap.

6. Discussion

In this study, a cradle-to-grave life cycle assessment of four green cleaning products from Method Products, PBC and Ecover was performed. Results indicated that both dish soaps have higher impact potential per kilogram of product than the all-purpose cleaner and hand wash; however, comparisons across product types are limited because the intended functions vary significantly. For these products, the top three dominant impact categories were identified as climate change human health, fossil depletion, and climate change ecosystems. Further investigation into product formulations revealed that the fatty alcohol sulfate in sodium lauryl sulfate contributes most significantly to environmental impacts, indicating a need to focus on this ingredient.

Improvements can and should be made within product formulas, but the greatest potential for reducing environmental impact lies downstream from manufacturing. For all-purpose cleaner, this analysis indicated that most impacts come from disposal, and impacts from transportation are double the impacts from the product itself. For hand wash, it is important to focus on water consumption as well as the product formulation. For dish soap, a 50% decrease in water consumed during use could reduce overall impacts by approximately 20%. With these considerations, green cleaning product companies and users can direct their efforts towards solutions with the greatest potential for improvement.

Possible comparisons to literature are limited due to the absence of published data, but this LCA study generally reinforces previous evaluations. Taking a surface level perspective, results can be compared to certificate program evaluations such as Cradle to Cradle, but this comparison is limited due to the lesser scope and resolution of certificate ratings. For example, Method all-purpose cleaner, Method hand wash, and Method dish soap received Cradle to Cradle ratings of Gold, Silver, and Silver, respectively [28], which agree with trends found here. Van Hoof et al. [29] used SimaPro 7.3.3 to conduct a cradle-to-grave LCA case study on a hand dishwashing product developed by P&G, and they also identified climate change and fossil depletion as the most relevant indicators. Saouter and van Hoof [13] found that from a life cycle perspective, the product use phase is significant for environmental impacts of laundry detergents, and impacts are also variable due to consumer habits. More specifically, the energy used to heat the water led to most of the emissions generated [13]. Future work for this study could include adjusting the system boundary to include the impacts from energy consumed to heat water. Finally, Koehler and Wildbolz [30] conducted LCAs of nine home-care and personal-hygiene products and also confirmed the influence of consumer behavior on environmental performance. These studies and the one presented in this paper demonstrate how LCA can be used to rank life cycle phases according to their contributions to certain emissions or impact categories.

Uncertainty for this analysis was assumed to be ±10% for all total impact scores, as can be seen through the error bars in Fig. 3 and Fig. 4. Data used in LCA can have uncertainty for many reasons, including the acquisition method, independence of data suppliers, representativeness, temporal correlation, geographical correlation, and further technological correlation [31]. Uncertainty for this analysis resulted primarily due to geographical correlation (global and national data was used) and further technological correlation (data was from processes and materials under study, but not from Method and Ecover specifically). As a result, data quality for green cleaning products in general was strong, but it was poor for evaluating Method Products, PBC and Ecover specifically. In order to effectively leverage LCA for evaluating cleaning products from specific companies, great strides need to be made in improving chemical inventory data.

Several limitations to this assessment should be considered. First, proxy chemicals were developed for ingredients not included in the database, which may cause impacts to be falsely represented. While the ecoinvent v3 database largely expanded its chemical inventory from its predecessor, the present chemicals significantly underrepresent the complexity and size of the chemical industry. Through sensitivity analyses, it was determined that several proxy options did not alter results significantly; however, inventory that better encompasses the industry would improve the validity of results and encourage further analyses. Second, the average inventory present in the ecoinvent database do not well represent companies' specific supply chains, particularly when it comes to green chemicals. Method Products, PBC aims to source their ingredients from sustainably managed practices, which presumably have reduced impact potential compared to industry averages. Third, water consumption values are highly dependent on user habits and faucet technology. Compared to old faucets, newer faucets in the United States use approximately 50-75% less water per minute [24]. However, the effect new faucet technology has on usage patterns is not well understood. Fourth, end-of-life was determined to be a non-negligible part of the overall impact, yet its representation as disposal of non-durable (soft) goods is inexact. This general waste scenario does include cleaning products in its description, but future work should refine the modeled waste scenario to more specifically represent wastewater treatment. Finally, only products from Method Products, PBC and Ecover were studied, and results may not generalize to other green cleaning products and companies due to variations in product formulations and function.

These results can be used to focus attention when using or designing green cleaning products. For consumers, how products are used and how much water is consumed during use play a significant role that should not be ignored. For green cleaning companies, it is important to recognize impacts after products leave their factory gate in addition to continue improving their product formulations. From this analysis, a prioritized list of actions for green cleaning companies to reduce their environmental impacts was developed:

1. Focus on non-water ingredients present in high quantities in the formulation, such as SLS
2. Encourage reduced water consumption during product use
3. Investigate feedstocks and suppliers with strong land-management and environmental practices

7. Conclusion

The results of this LCA contribute to an understanding of the environmental impacts of green cleaning products. This analysis quantified environmental impacts of average green cleaning products, but an adequate assessment for company-specific impacts was not possible due to limitations in data. SLS was identified as an opportunity for reformulation in hand wash and dish soap given its high percentage in the formula and therefore significant contribution to the products' environmental impacts. Taking a life cycle perspective of the products, it was determined that the impacts due to water consumption during use and disposal at end-of-life contribute significantly to the environmental impacts of dish soap and all-purpose cleaner, respectively. For hand wash, the environmental impacts from water consumption and product formulation are comparable. The results of this work can be used to identify opportunities for choosing alternatives in product formulation that can reduce environmental impact. Future work includes comparing these findings to traditional, non-green cleaning products in order to better understand the advantage that these green cleaning products present, as well as assessing impacts specific to product supply chains to account for market variations.

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