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Comparing reusable to disposable products: Life cycle analysis metrics

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Abstract

This research is to produce the first quantitative evaluation, using global warming potential (GWP, kg CO_2 eq), of all published cradle-to-gate life cycle studies that compare reusable vs single-use products. We seek to determine whether there are consistent and fundamental factors that differentiate disposable and reusable products. A comparative assessment was made of the cradle-to-gate life cycle analyses of all published comparisons of reusable and single-use products from 1990 to 2016. A literature search found only 20 products in which a full life cycle analysis of cradle-to-gate (supply chain, manufacturing, reprocessing, and packaging of the reusable item) and supply chain plus manufacturing for the disposable had been published. GWP or carbon footprint was used as the environment comparison metric to which we added energy for the product manufacturing metrics. In this diverse set of products, the reusable product was consistently lower in cradle-to-gate energy use and global warming potential than the comparable single-use product. However, no apparent product characteristic appeared to govern the extent by which the reusable had a lower carbon footprint. These compelling results were compared with two other references in which disposable products were reported as better. However, when the data were reviewed with those authors, they reevaluated and found errors in calculations and corrected the results to then identify the lower reusable GWP impact compared to the respective disposable. The diversity of products studied and the consistently lower GWP impact of reusable products herein may suggest that products with reusable/disposable options could be predicted to show that the reusable is better than the single-use option.

KEYWORDS

carbon footprint, life cycle assessment, reusable/disposable garments

1 | INTRODUCTION

Our global markets are open, and there are a number of products that have been produced either as reusable systems or as a single-use alternative. Disposable and reusable products often have different characteristics of material composition, packaging, reusability, cost, and disposal. Reusable products are generally made from high-quality materials and are intended to be used for many cycles. If the comparison between disposable and reusable items is based on just one cycle only, then the single-use item may appear to be the better environmental

TABLE 1 Comparison of full cradle-to-gate life cycle information on reusable versus disposable products

References	Products with comparison of reusable vs disposable	Reusable cycles
Raugei et al.[3]	Steel drums vs disposable wood fiber drums	200
McDowell (1993)[20]	PET reusable surgical lap drape vs 50% pulp:50% spunlace PET surgical lap drape	75
McDowell (1993)[20]	PET reusable surgical gown vs 50% pulp:50% spunlace PET surgical gown	75
Parsons[4]	NiMH rechargeable battery vs NiCd alkaline battery	400
Garrido et al.[5]	Polypropylene heavy reusable cups vs polypropylene light disposable cups	10
Garrido et al.[5]	Polypropylene heavy reusable cups vs polypropylene light disposable cups	14
UniTech (2010)[23]	Nuclear plant reusable nylon coverall vs nuclear SMS PET and polypropylene coverall	100
Albrecht et al.[6]	Polypropylene/Polyethylene fruit crates vs disposable wood fruit crates	50
Albrecht et al.[6]	Polypropylene/Polyethylene fruit crates vs disposable cardboard fruit crates	50
Grimmond and Reiner[7]	sharp containers vs disposable sharps containers	12.6
MnTAP (2010)[24]	Woven PET reusable surgical gown vs polypropylene/SMS PET surgical gown	50
ETSA (2000)[21]	Woven PET/polyurethane reusable surgical gown vs nonwoven PET/wood pulp surgical gown	75
Kummerer et al.[8]	Reusable cotton 6 layer laparotomy pads vs disposable cotton 4 layer laparotomy pads	15
Copeland et al.[9]	Polypropylene to-go food container vs disposable polystyrene to-go food container	30
D'Incognito[10]	Polysulfone plastic animal cages vs disposable PET plastic animal cages	310
RMIT (2008)[22]	Woven reusable PET/cotton surgical package vs nonwoven polypropylene surgical gown	127
Vozzola et al.[11]	Woven PET reusable cleanroom coverall vs high density nonwoven polyethylene	50
Vozzola et al.[12]	Knit PET/expanded polytetrafluoroethylene reusable surgical gown vs nonwoven PET/polypropylene surgical gown	75
Eckelman et al.[13]	Silicone/polycarbonate/polypropylene laryngeal mask airways (LMA) vs disposable polyvinyl chloride/polycarbonate/polypropylene laryngeal mask airways	40
Vozzola et al.[14]	Woven PET reusable hospital isolation gown vs nonwoven polypropylene hospital isolation gown	60

choice for such products because these tend to be lighter and less durable. However, if the objective is to include the many cycles thus reducing the environmental impact, then the reusable product may be the best choice, depending on the number of cycles and the cleaning process used. Product life cycle studies can be done using the boundaries of life cycle assessment (LCA) from cradle-to-gate. These boundaries included raw material extraction, supply chains, manufacturing, packaging, reprocessing to return to service, and transportation for both reusable and disposable products.

2 | APPROACH AND OBJECTIVES

The objectives of this study were to identify all cradle-to-gate life cycle studies published in peer-reviewed journal articles in which reusable and disposable product comparisons are made and to undertake a detailed analysis of the respective environmental benefits. The details of each life cycle study can be found by readers in the original articles. We also sought to uncover any basic properties of reusables or disposables that governed the GWP differences across all products studied. We used the systematic literature review guideline for reporting life cycle assessment (LCA) data.[1,2]

Our approach is a standard comprehensive literature search followed by assembling direct comparative data on the impact of global warming potential (GWP) projections that contrast disposables to reusable products. Despite there being over 500 journal articles with key words on life cycle, reusable, and disposable, only 20 products with rigorous, consistent cradle-to-gate boundaries and reprocessing data were identified [in 13 of the articles]. These products were diverse and used to undertake our research objectives. In the following Results section, the reader would benefit from first examining the Methods section later in this paper.

3 | RESULTS AND DISCUSSION

In the 13 articles located containing all the information for the in-depth comparisons, there were 20 separate products with reusable and disposable alternatives, as shown in Table 1 to guide the reader to the references. The overall cradle-to-gate GWP comparison, was expressed on a variety of functional units, such as hospital uses per year, 1000 L of beer served, X tons of food shipped by container, etc. This resulted in a wide range of comparative results across all products, and so a common basis was selected for all comparative results of reusables vs disposables in this research. This basis was the use of one reusable product, over the defined number of cycles until the product was finished and entered the end-of-life stage, vs the comparable number of disposable (single-use) products to match the cycles of the reusable product. In all comparisons, the number of reusable cycles was given, although in some cases, multiple reuse cycles were quoted. In order to not over represent such studies, only the lowest reuse rate for that product was selected. In all cases, the reusable scenario had a lower carbon footprint than the disposable scenario across these very diverse products. In one exception, the single-use item was found to be better, but it was for a geographic area (South Australia) in which a particularly high carbon dioxide equivalent (kg CO_2 eq) was recorded per megajoule (MJ) of electricity used, related to a specific coal, and so those authors identified this as an anomaly and recalculated with more global coal characteristics. It does point out that energy sources are important when comparing reusables and disposables.

In 20 product comparisons, data from these literature sources were also available to calculate the energy as MJnre or GWP as kg CO_2 eq needed to manufacture a single reusable product and a single disposable product. For only 4 of the 20 cases there was a need to convert MJnre energy to GWP, kg CO_2 eq since it was not reported directly. This was done with an approximate conversion factor of 0.060 kg CO_2 eq/MJ natural resource energy. This is based on the need to combust fuel that then produces life cycle process energy (steam, Dowtherm heating, high temperature furnaces, transportation, etc.) that characterize the supply chain of manufacturing disposables in which electricity use is usually small. Further, cleaning of reusable products is often aqueous-based with heating by use of natural gas. In the case of textiles, industrial laundry consumes about 10-fold more MJ natural gas than electricity,[14] emphasizing the importance of fuel combustion in reprocessing Additionally electricity is generally not a large energy use in the production of products and the chemical supply chains across the cradle-to-gate, but when it is used, much of it comes from conventional coal, natural gas, fuel oil sources found in national grids. Wind, solar and nuclear are in the mix, at a modest level and so are not fully accounted. Nevertheless, this conversion factor is a reasonable number and allows a single metric for comparing these diverse life cycle studies. No other environmental parameters were consistently being reported in these diverse studies which indicates the diversity of priorities and principles of life cycle impact assessment (LCIA) metrics in the literature. It is interesting to note that not all articles stated the actual mass of these comparative products even though the mass and materials are major factors in the life cycle cradle-to-gate analysis. The product manufacturing GWP and product mass data of reusable vs disposable products are found in Table 2.

From each article, the energy (gate-to-gate) data to manufacture new products, whether reusable or disposable were extracted. The rated number of cycles for the reusables was catalogued. The life cycle results for cradle-to-gate were obtained for the reusable system and the disposable system. These data were used to make comparisons on the functional unit basis described above; that is, the metric of kg CO_2 eq ratio of the disposable product to reusable product vs various product parameters, like product mass, gate-to-gate manufacturing energy, cycles, and also the ratios of these product parameters.

It was observed that the manufacturing energy or GWP of the single reusable item was always higher than the single disposable item. This is consistent with the reusable product being more robust to allow multiple cycles of cleaning, preparation, and reuse. However, as stated above, two products did not follow this trend, and upon discussion with those authors, an error was discovered that when they corrected the error, the data now followed the trend of the other data on reusable product benefits. This suggests that in future published articles that compare reusable and disposable products, the manufacturing energy of each single-use and reusable product (gate-to-gate) should be clearly stated as data verification. Similarly, the mass of the reusable product was larger than that of the comparable disposable product (range 23:1 to 1:1), Table 2. When the mass of the disposable product was considerably lower than that of the reusable product, it was found that the benefit of the reusable product often decreased.

The relative environmental benefit of the reusable product was characterized in this study as the ratio of the cradle-to-gate global warming potential (GWP), expressed as kg CO_2 eq, of the disposable product system divided by the single reusable product system. This includes the GWP of manufacturing, cleaning or reprocessing, and preparation for the reusable item over the specified number of cycles vs the GWP for the

TABLE 2 Metrics of GWP benefit of reusable products and several life cycle variables influencing this benefit (blanks indicate data not published)

Reusable vs disposable products comparison	Ratio of full life cycle cradle-to-gate global warming potential($kgCO_2$ eq) of disposable system to number of products served by the reusables cycles cradle-to-gate ($kgCO_2$ eq) of one reusable system for specified number reuses	Specified Reusable Cycles	Ratio of global warming potential of only the product manufacturing step ($kgCO_2$ eq) of one reusable product to the manufacturing step ($kgCO_2$ eq) of one disposable product	Mass of one reusable product/mass of one disposable product
Steel drums vs disposable wood fiber drums	46	200	3.0	3.6
PET reusable surgical lap drape vs 50% pulp:50% spunlace PET surgical lap drape	31	75	1.5	5.0
PET reusable surgical gown vs 50% pulp:50% spunlace PET surgical gown	23	75		8.4
NiMH rechargeable battery vs NiCd alkaline battery	19	400		1.2
Polypropylene heavy reusable cups vs polypropylene light disposable cups	7.0	10	7.0	14.1
Polypropylene heavy reusable cups vs polypropylene light disposable cups	13	14	7.0	14.1
Nuclear plant reusable nylon coverall vs nuclear SMS PET and polypropylene coverall	10	100	1.5	1.5
Polypropylene/Polyethylene fruit crates vs disposable wood fruit crates	9.0	50	2.2	2.4
Polypropylene/Poly-ethylene fruit crates vs disposable cardboard fruit crates	8.4	50	3.8	2.2
sharp containers vs disposable sharps containers	5.0	12.6	7.8	2.8
Woven PET reusable surgical gown vs polypropylene/SMS PET surgical gown	3.3	50	9.8	2.8
Woven PET/polyurethane reusable surgical gown vs nonwoven PET/wood pulp surgical gown	3.2	75	3.5	1.8
Reusable cotton 6 layer laparotomy pads vs disposable cotton 4 layer laparotomy pads	2.8	15	2.7	1.9
Polypropylene to-go food container vs disposable	2.3	30	10.2	23.9

TABLE 2 (Continued)

Reusable vs disposable products comparison	Ratio of full life cycle cradle-to-gate global warming potential($kgCO_2$ eq) of disposable system to number of products served by the reusables cycles cradle-to-gate ($kgCO_2$ eq) of one reusable system for specified number reuses	Specified Reusable Cycles	Ratio of global warming potential of only the product manufacturing step ($kgCO_2$ eq) of one reusable product to the manufacturing step ($kgCO_2$ eq) of one disposable product	Mass of one reusable product/mass of one disposable product
polystyrene to-go food container				
Polysulfone plastic animal cages vs disposable PET plastic animal cages	2.0	310		
Woven reusable PET/cotton surgical package vs nonwoven polypropylene surgical gown	2.0	127	13.5	1.5
Woven PET reusable cleanroom coverall vs high density nonwoven polyethylene	2.0	50	4.0	1.6
Knit PET/expanded polytetrafluoroethylene reusable surgical gown vs nonwoven PET/polypropylene surgical gown	2.0	75	6.0	2.0
Silicone/polycarbonate/polypropylene laryngeal mask airways (LMA) vs disposable polyvinyl chloride/polycarbonate/polypropylene laryngeal mask airways	1.5	40	1.2	1.0
Woven PET reusable hospital isolation gown vs nonwoven polypropylene hospital isolation gown	1.2	60	13.3	3.8

number of disposable items needed for the same specified number of use cycles. This ratio is the primary metric used in this review to examine the impact of life cycle variables on the relative environmental benefit of reusables. Some of the variables were number of cycles, ratio of manufacturing energies for a single disposable product to the single reusable product, ratio of the mass of the reusable product to the mass of the disposable product, and combinations of these variables, as shown in Table 2.

The ratio of GWP of disposables to reusable is listed in Table 2 from the highest (46) to the lowest (1). This ratio allows one to see if there are patterns in the other data in Tables 1 and 2. None of the attempts at statistical linear regression of the GWP ratio of disposables to reusables vs the variables in Table 2 or combinations thereof were significant.

As we look at identifying future analysis goals, the consistent pattern of higher GWP impact of disposables products when compared to reusables is an important

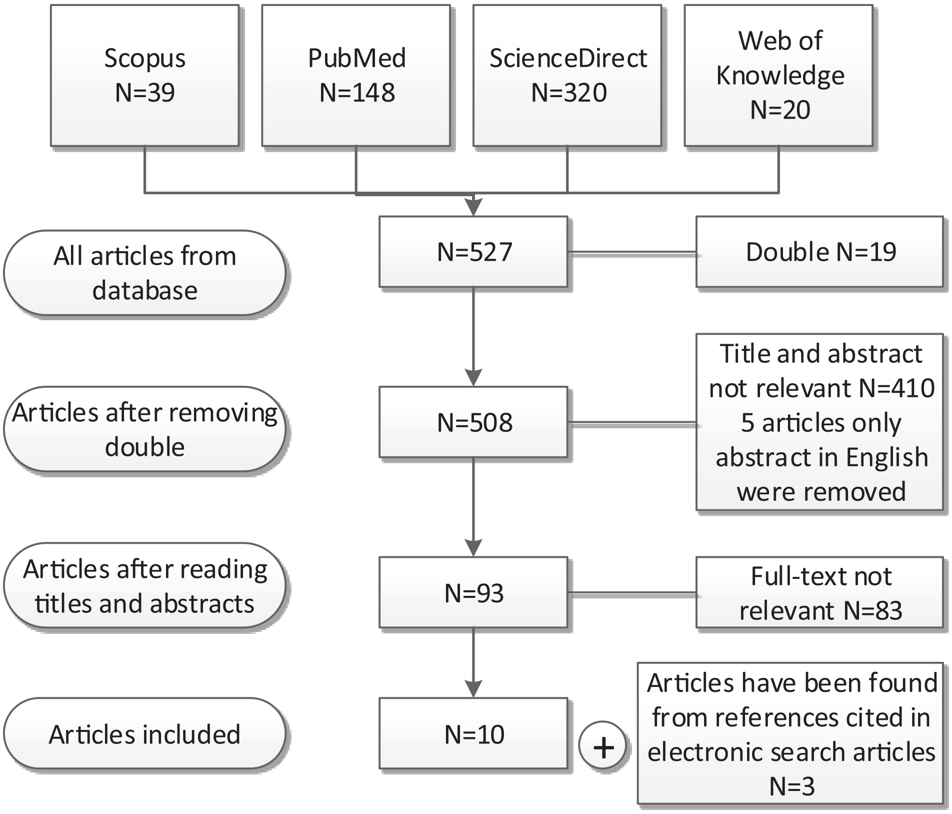

FIGURE 1 Flowchart of selected studies indicating life cycle of reusable and disposable (total in these articles was 20 products)

concept that reinforces the sustainability movement to produce reusable products. The reusables:disposables ratios of mass and single product manufacturing energy (as reflected in GWP metric of CO_2 eq) being greater than one can serve as review thresholds in future comparative articles. Future studies in which the mass of the reusable or the manufacturing energy of reusables are less than disposables, the authors should report detailed explanations of what causative factors were involved prior to journal publication.

While we were unsuccessful in finding a manufacturing or a product characteristic factor that correlated to the ratio of GWP of disposable systems to reusable products, we believe such underlying factors should exist. That is, even though the literature herein covers a wide variety of products from drum containers to food storage to medical devices and have a huge range of reusable cycles (12.6-400 cycles), some recurring characteristics probably underlie the GWP benefits of reusables. We hope to continue these deeper analyses, possibly for closer families of products to find these important product characteristics as a means to stimulate product design for environmental sustainability. Intuitively, the mass and life cycle profile of the materials in the respective products should have measurable influence on the relative GWP benefit of reusables.

4 | METHODS

The overall literature method in this study was to use peer-reviewed publications that provided information about life cycle studies on reusable vs disposable (single-use) items. Using the systematic literature review guidelines for reporting life cycle assessment (LCA) data[1] a comparative assessment of the global warming potential, kg CO_2 eq, was made of the cradle-to-gate life cycle analyses of all published comparisons of reusable and single-use products. Related journal articles were identified from electronic reference databases using combinations of key words and titles from 1990 to March 2016. The key words used in this search were "life cycle," "carbon footprint," "reusable," "disposable," "single-use," and "life cycle assessment" for any product with journal articles in the English language. The following search engines were used in this study: PubMed, Web of Knowledge, ScienceDirect, and Scopus. The total number of titles and abstracts resulting from searches for relevance was 148 from PubMed, 20 from the Web of Knowledge, 320 from ScienceDirect, and 39 from Scopus, bringing the total to 527 from all search engines. Approximately 19 articles occurred in more than one database, and these were identified and removed with the help of Endnote. From the total, 410 articles were excluded because of titles and abstracts that did not actually encompass the necessary life cycle approach and quantitative data. Of all the key words searched, "life cycle assessment" had the most output results. In addition, five articles were found with the title or the abstract in the English language but the remaining body of the articles were in different languages. These were excluded, but are in the references for use by the reader.[15-19] Of the remaining 93 articles, 83 full texts were excluded because the discussion was about cost, impact of delivery, or quality, for the comparison between the two systems of disposable and reusable, but with no information of the actual life cycle data or providing only one part of the cradle-to-gate life cycle boundary and these were not included in this study. Three more articles were found from the 10 articles references. The 13 articles yielded the data on 20 separate products. A flowchart showing the search engines used in the initial pooling of this study is shown in Figure 1.

5 | CONCLUSIONS

A variety of products with reusable and single-use options having different masses, sizes, and complexity were studied using the cradle-to-gate life cycle analyses. The life cycle of the reusables includes the manufacturing, cleaning, and preparation of the reusable item for the next cycle of use. In this first published review of all products with complete data in the peer-reviewed cradle-to-gate life cycle articles there were 20 product comparisons and it is clear that many other products with reusable and disposable options have not been studied. However, the diversity of products included herein is a heterogeneous collection (with some greater emphasis on textiles) and so these conclusions may also predict results in as yet unstudied products. The primary conclusion was that on a cradle-to-gate basis, reusables consistently have lower energy use and global warming potential metrics than the single-use alternative. The range of improvement due to reusables compared to disposables was from slightly above 1:1 to 46:1. The number of reusable cycles was from 12.6 to 400 and the range of mass differential of reusable to disposable was from about 1:1 to 24:1. A series of statistical studies were conducted and no correlations of the magnitude of the reusable to single-use life cycle GWP were found from the variables of mass, materials of construction, number of reuse cycles, or ratio of manufacturing energy of a single reusable to a single disposable. More life cycle studies of reusable and disposable products may uncover basic design and manufacturing principles that explain and could thus strengthen the use of reusable GWP benefit in sustainable product design.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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