A Playful Life Cycle Assessment of the Environmental Impact of Children's Toys

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ABSTRACT

Toys aid in children's progression through developmental stages, yet toy production has an environmental impact. This study is the first comparative life cycle assessment of three children's toys. A life cycle assessment quantifies the impact of an item in comparable impact categories (i.e. global warming potential in kg CO2 equivalents). In this study, we use open LCA to compare toy impact from production to use. The results indicate that the plastic polybutylene carried the highest impact in terms of global warming potential for our predominantly plastic toy. The addition of a battery to the plush dog increased the toy's eutrophication potential by a factor of 2.398. These results indicate some of the materials that consumers may want to avoid or minimize when purchasing toys.

INTRODUCTION

Toys are an important component to life as a child (Healey, 2019). Toys allow children to exercise their imaginations, as well as develop their fine and gross motor skills (Abdulaeva, 2011). Toys also serve as a medium to foster interpersonal skills such as sharing and problem solving between and among children (Nagahama, 2011). As technology becomes more prevalent in society, parents and caregivers must make decisions surrounding what toys they expose their children to. The American Academy of Pediatrics argues that there is a large discrepancy between the developmental skills that a child acquires through technological play versus traditional non-electronic play (Healey, 2019). For example, children are exposed to more adult words and conversational tools during play with traditional toys or reading books than with electronic toys (Healey, 2019). Imaginative play with non-electronic toys also boosts children's spatial relations and mathematical learning (Healey, 2019). Due to the benefits of non-electronic toys and their prevalence in the marketplace, this study focuses on different types of non-electronic

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Research Completed in Winter 2019

play toys. While toys provide many benefits to child development, their manufacturing and distribution create impacts on the environment. This paper explores these environmental impacts through a comparative life cycle assessment.

This paper studied a subset of non-technological toys to compare the toys' environmental impacts. The toys' life cycles (extraction – manufacturing – transportation – use – disposal) provide insight into the product's sustainability by quantifying environmental impacts. Since children progress through developmental stages quickly, their preference for toys evolves as well. With this evolution, the old toys are often passed down, donated, or discarded. This rapid turnover may mean that parents and those who buy toys for children may be interested in minimizing the impact of low longevity toys.

There is little existing research on the environmental impact of toy creation. Life cycle assessments are a commonly used method for determining and comparing the impact of different products. We will use the life cycle assessment methodology in this study. This study is unique because it focuses on widely used consumer goods and fills a niche that has not been explored: children's toys. This study's subject toys include: plush dog with no battery, plush dog with a battery, and Marble Frenzy™ (Figure 1). There has been one published study on the Life Cycle of a Teddy Bear (Muñoz, 2009). The teddy bear life cycle project was used as a reference in our study, but we chose to complete a comparative life cycle as opposed to a one subject study. Up until now, standards of measure for ranking toy quality are often based on: price, utility, and safety (Good Housekeeping, 2018). This study will serve as a reference for consumers so that they can make informed decisions to reduce the impact of their toy purchases.

METHODS

Study objectives

The goal of this study was to determine the environmental impact of three common toys. Each toy material has a corresponding impact. For example, 90.27 grams of fleece has a global warming potential of 0.25 kg CO_2 eq, but a eutrophication potential of 2.8×10^{-4}. These results are important for comparing two or more toys and their environmental impacts. Consumers can use this comparative study when they are interested in minimizing their impacts from toy purchases. Additionally, this comparison will add to the limited information on impact of toys and provide interested consumers information on improving their toy purchasing (Muñoz, 2008).

Functional unit

A functional unit is defined as, "Specification of the unit size of a product or system, on the bases of which subsequent environmental scores are calculated" (UNEP_II). Functional unit normally includes the service provided, along with the duration and quality of service provision. For each of our toys, the functional unit was one toy (quantity) providing a minimum of two hours of entertainment (service, quality, and duration) for a child aged 4-10.

Overview

This study delved into the environmental impacts of a sample of children's toys. We compared three toys: a small plush dog (4 inches by 4 inches by 12 inches), a plush dog with battery pack for tail wagging (4 inches by 4 inches by 12 inches), and the children's game Marble Frenzy™ (Figure 1). We used life cycle assessment methodology to visually compare the impacts of each product throughout its lifetime in common units of global warming potential (CO_2 equivalents) and eutrophication potential (kg N eq). See Results section for definitions of global warming potential and eutrophication potential accompanied by charts with the corresponding toy impacts. We also reported total impacts for acidification, ecotoxicity, human health-carcinogens, human health- non-carcinogens, ozone depletion, photochemical ozone formation, resource depletion of fossil fuels, and respiratory effects (OpenLCA). These categories are broken down into the individual materials that make up the toys and the material's percentages of each total impact category.

The software OpenLCA version 1.7.0 was used to compute results. OpenLCA software is designed to quantify the environmental impacts of thousands of products through their supply chains. OpenLCA has the ability to quantify the impacts but needs the product information from outside databases. Life cycle inventory databases contain information about the resources utilized, country of origin, inputs and outputs of product manufacturing, and in some cases disposal methods and impacts (OpenLCA nexus). The databases utilized were: Ecoinvent, Gabi Textiles, and Gabi Professional. Ecoinvent is the world's largest transparent database for life cycle inventories (Ecoinvent). Ecoinvent version 3.0 contains 30,495 processes of resources and their individual environmental impacts. Many of the product evaluations correspond to building materials due to the high demand for life cycle assessment data for construction projects. This study used the available data to quantify impacts of our three subject toys. Gabi Databases are similar in structure to Ecoinvent but hold more specified information (i.e. GabiPlastics focuses on many kinds of plastic).

Figure 1: Research subjects from left to right: plush dog (White) with no battery- representative of a stuffed toy with no mechanical parts and no electricity or energy necessary. Plush dog (Brown) with battery pack for tail wagging- representative of stuffed toys with batteries that need to be recharged which means they are more energy intensive and carry a greater impact. Marble Frenzy ™ representative of plastic toys and other sets that are assembled by the child.

System Boundaries

System boundaries detail what impacts will be attributed to the product and which will not. In many LCA studies, the impact from building the machinery used to make the product is contained outside the system boundary. This categorization is rationalized because the machines create so many products, that the environmental impact of each machine for any one toy would be negligible. Some studies choose to bound their system to when a product was extracted to the end of life stage of disposal. LCA databases often specify the boundaries of each product system so that researchers can maintain consistent boundaries. Since this project utilized multiple databases, (Ecoinvent, GabiProfessional, GabiTextiles and GabiPlastics), we defined our system boundaries to be consistent across all subjects (See Figures 2, 3, and 4). This project's system boundaries are confined to the materials that each toy component consisted of, as well as the production method to create the toy part (polyester fiberfill for stuffing, polybutylene for Marble Frenzy ™ etc.). The energy use of extraction, as well as the transportation from country of extraction to China (for toy manufacture), is not included. The transportation from the Chicago Distribution Site to the consumer home has been explored by other authors (Klimas & Shaffer, 2019) and varies due to methods of transportation. For these reasons, we do not include final toy transportation following purchase. The system is bounded geographically by the country where the toys were manufactured and the route they took to their final destination. Toys generally travel from production facilities in China to distribution sites around the world. For this study, the transportation impact ends in Chicago. Chicago is located in the middle of the United States and is a large hub for finished material distribution.

Transportation

China is the most predominant country for manufacturing toys (Avramenko, 2017). This study selected a large manufacturing city called Guangzhou in the Guangdong region of southern China as the starting point for toy manufacturing based on a communication from a toy company (Heidi Peckover from Happy Worker Toys, personal communication). From this hub, toys travel to the nearest port. This port is called the Guangzhou South China Oceangate Container Terminal. The port is located 17.413 miles from the manufacturing center in Guangzhou (Google Maps).

Using the standard dimensions for shipping containers, 624 in x 99 in x 110.25 in, the number of toys transported was calculated by dividing the area inside the container by the toy size (including packaging). This number, for example 19,584 stuffed dogs/shipping container, was used to divide the total transportation impact into the impact allocated to transporting each individual toy.

Through this methodology, the transportation results are indicative of the individual toy and not the entire shipping container. The unit of measure for transportation efforts is tkm- Tonne Kilometre (tons x km travelled). This unit is calculated by multiplying the tlc- total load carried (tons) by the distance travelled (km) (Timur, 2016). The next section of the toy's journey was via boat freight from Guangzhou South China Oceangate Container Terminal port to the Port of Los Angeles, CA. This oceanic travel covers 101,505 tkm (8.7 tons x 11,658.6 km) (SEA-DISTANCES.ORG, 2018). In order to bring the toys to Chicago, Illinois, the shipping container moves from the boat onto a second fifty-three-inch wedge truck. This cross-country travel from LA to Chicago takes 24,440.1032 tkm (8.7 tons x 2,807.1 km) (Google Maps). These distances are used to quantify the impact of driving a truck with the weight of the shipping container and toys (U.S. National Renewable Energy Lab). The category, transport freight sea transoceanic ship, in OpenLCA from the Ecoinvent database was used to calculate impacts using the sea distance traveled. The results can be used to quantify the total transportation impacts for each toy by land (NREL) and sea (OpenLCA).

System Boundaries

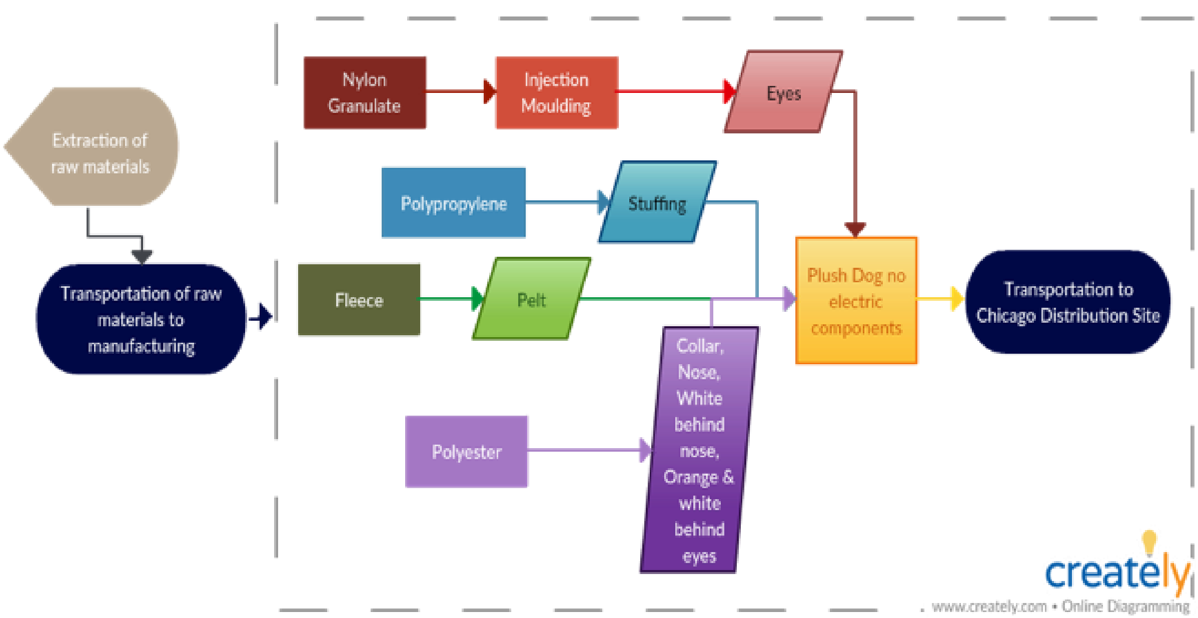

Figure 2: System boundaries for plush dog with no electric components.

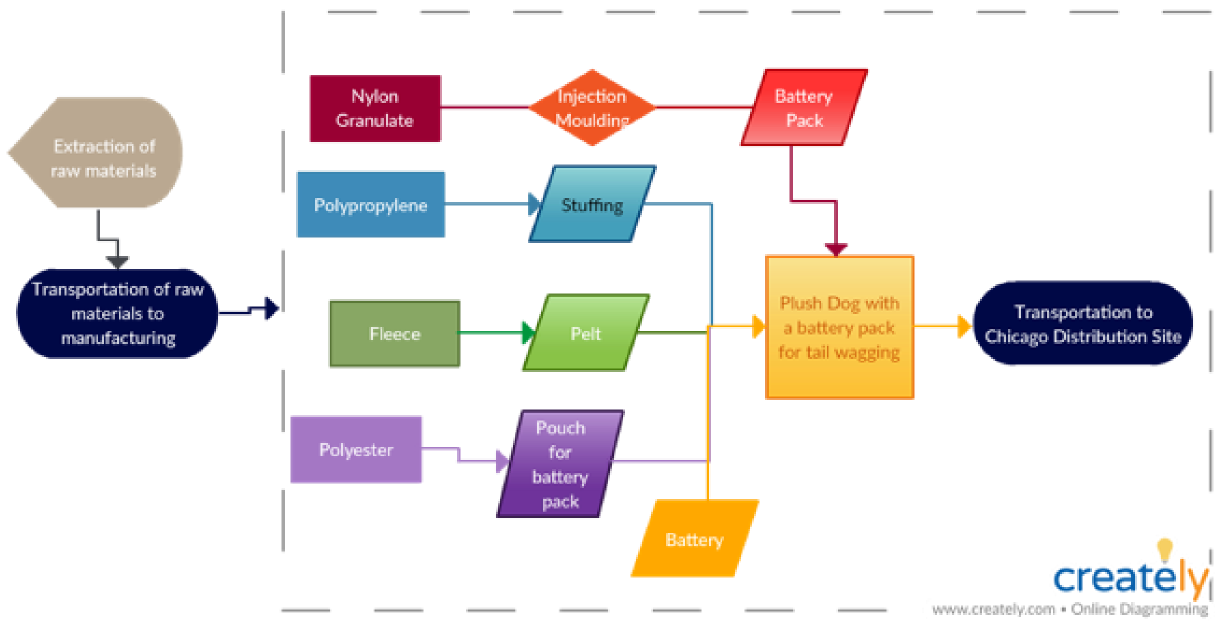

Figure 3: System boundaries for plush dog with battery pack.

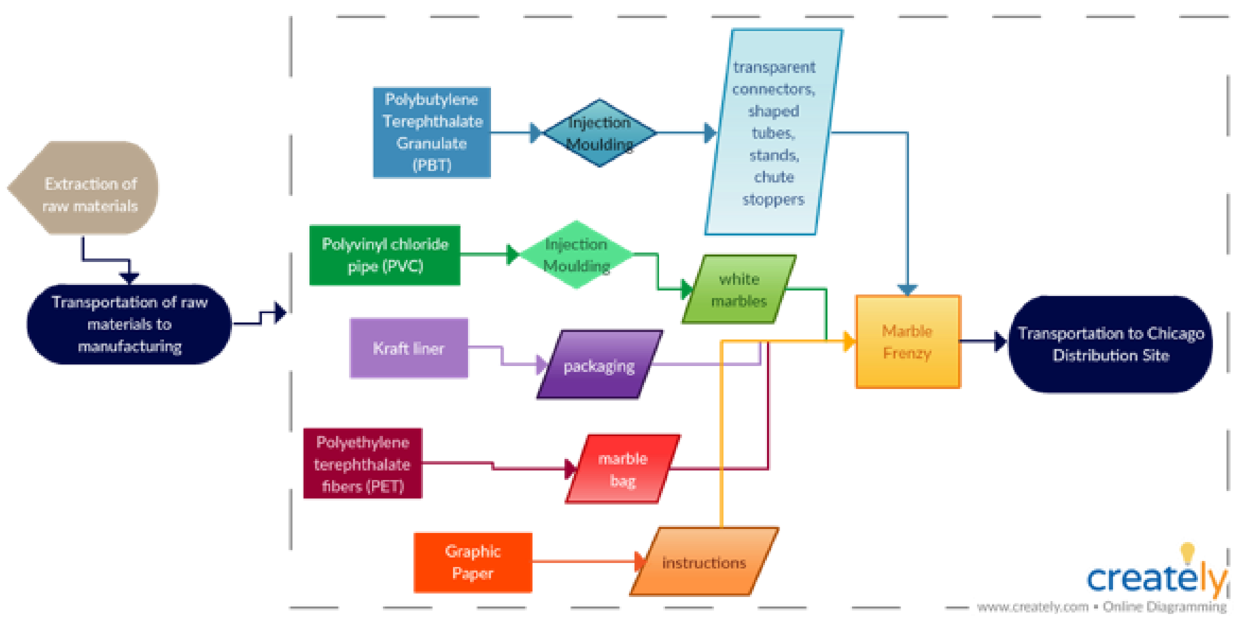

Figure 4: System boundaries for Marble Frenzy ™.

RESULTS

Global Warming Potential

According to the EPA, "GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases" (EPA, 2017). For example, methane has 3.7 times the global warming potential per mole than carbon dioxide (Lashof, 1). This 3.7 factor translates to methane containing 25x the global warming potential per molecule of CO_2 (TRACI). The differing potencies of greenhouse gases makes them difficult to compare without common units. Converting all of the different units into one common unit is the way to directly compare impacts. The unit to compare impacts in terms of Global Warming Potential is kg CO2 eq.

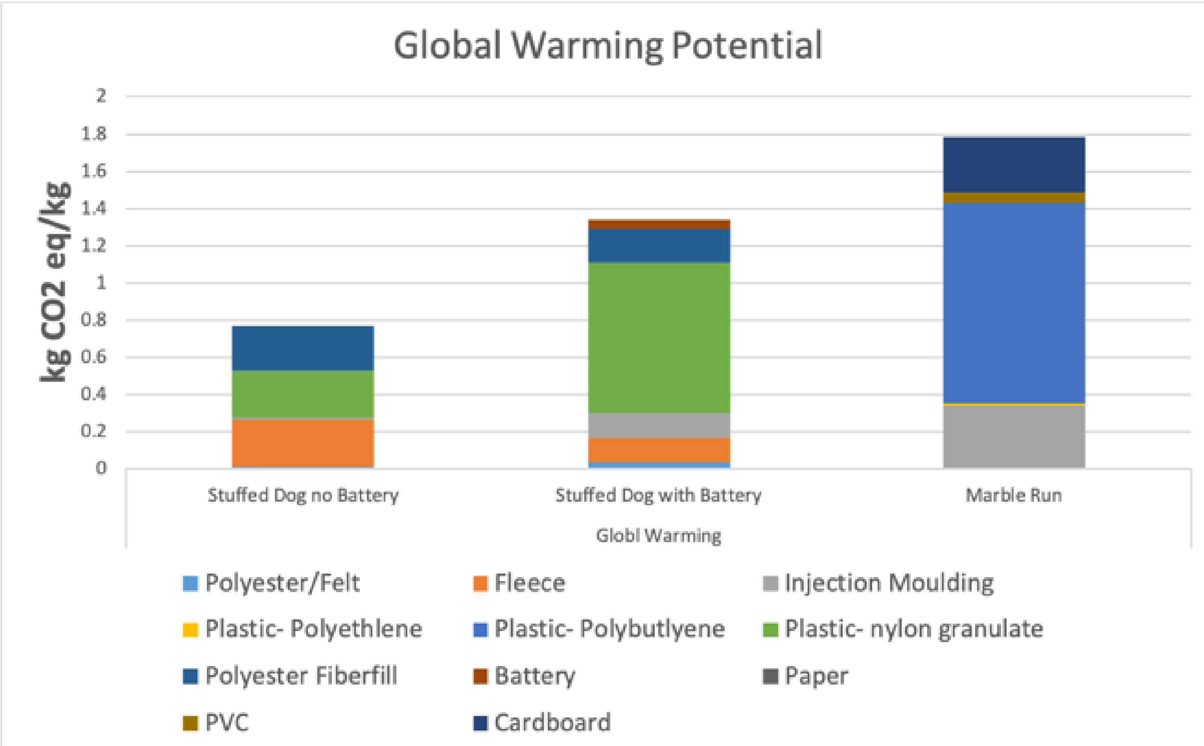

Figure 1. Global Warming Potential in kg CO2 eq/kg substance for all three subject toys separated by raw materials. See Table 6 for exact category measurements.

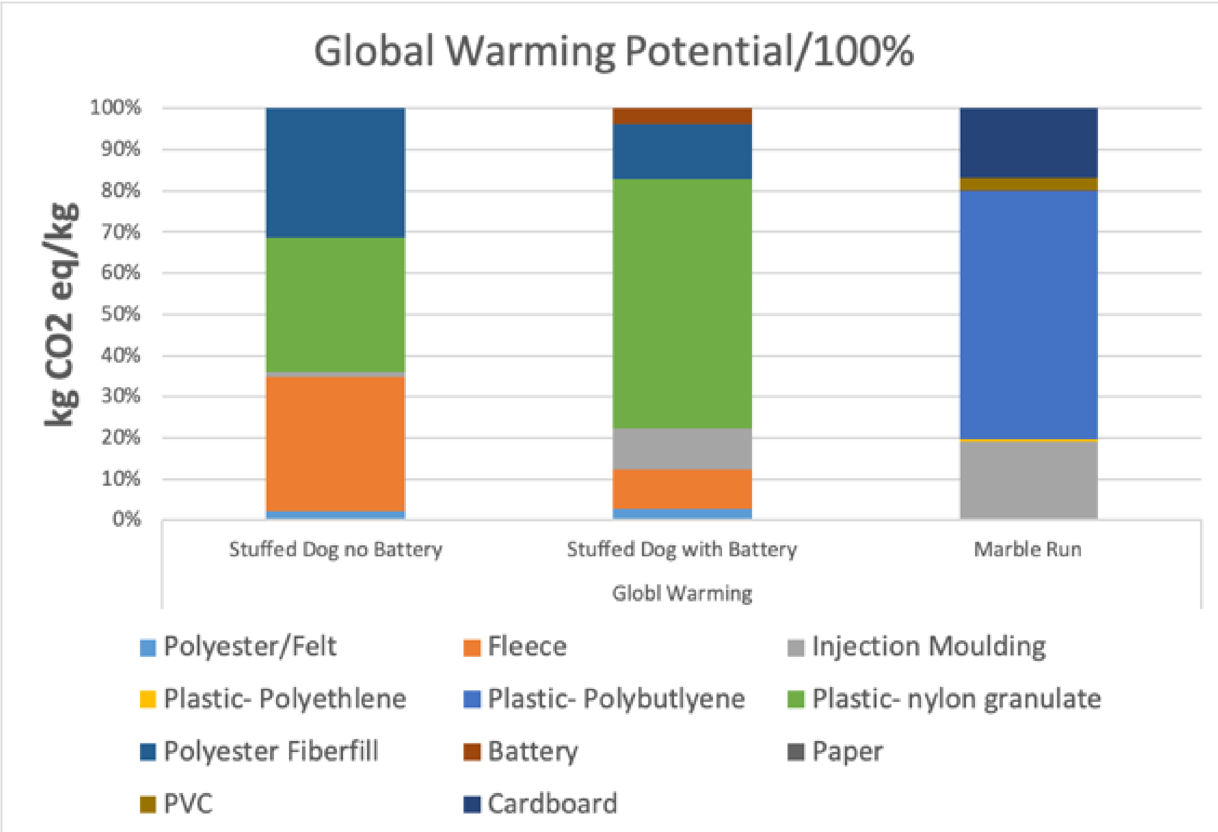

Figure 2. Global Warming Potential in kg CO2 eq/kg substance for all three subject toys separated by raw materials. See Table 6 for exact measurements. The results are presented in percentage format in order to directly compare the impact of each material as a fraction of the whole toy impact.

When examining the two graphs above, one must keep in mind the weight of each material and how that weight affects the results. Polyester/Felt may have a high global warming potential, but due to its small weight in both of the toys, the impact remains low. For example, the no battery plush dog's Polyester/Felt GWP per unit weight was 1.496% of the toy's overall impact compared to the Fleece which made up 56.752% of the toy's overall GWP impact. The categories such as Plastic and Polyester Fiberfill have higher total impacts because they were two of the higher mass materials found in the stuffed dogs. Figure 1 and 2 show the differences in Global Warming Potential between the plush dog with no battery, the plush dog with battery, and Marble Frenzy. Figure 1 presents the data with the raw numbers. This is useful in comparing the weights (kg) of each material category. The plush dog with a battery has a much larger impact from the higher amount of plastic in the dog's battery pack casing. The space that the battery pack uses in the plush dog with a battery is compensated with more Polyester Fiberfill in the plush dog with no battery. Figure 2 presents the resource data as a percentage of total impact. This chart helps analyze which materials had the greatest impact and how the total impact percentages compare for each material. The plastic category in the plush dog with a battery has the greatest percent impact. Both dogs have a low Global Warming Potential attributed to their Polyester or felt pieces due to the small weight of those particular pieces.

Eutrophication

Eutrophication occurs when a fertilizer or other non-natural substance with a high level of phosphorus is introduced to a body of water. According to the EPA, "Sources of phosphorus include runoff from undisturbed agricultural and urban lands; waste from water craft; industrial and domestic wastes;

biological sources; and precipitation. The most important single source is municipal sewage" (EPA, accessed 2019). The increased phosphorus concentrations stimulate excess algal growth, which in turn consume dissolved oxygen, negatively affecting the pre-existing aquatic life. The units in OpenLCA for eutrophication are kg N eq.

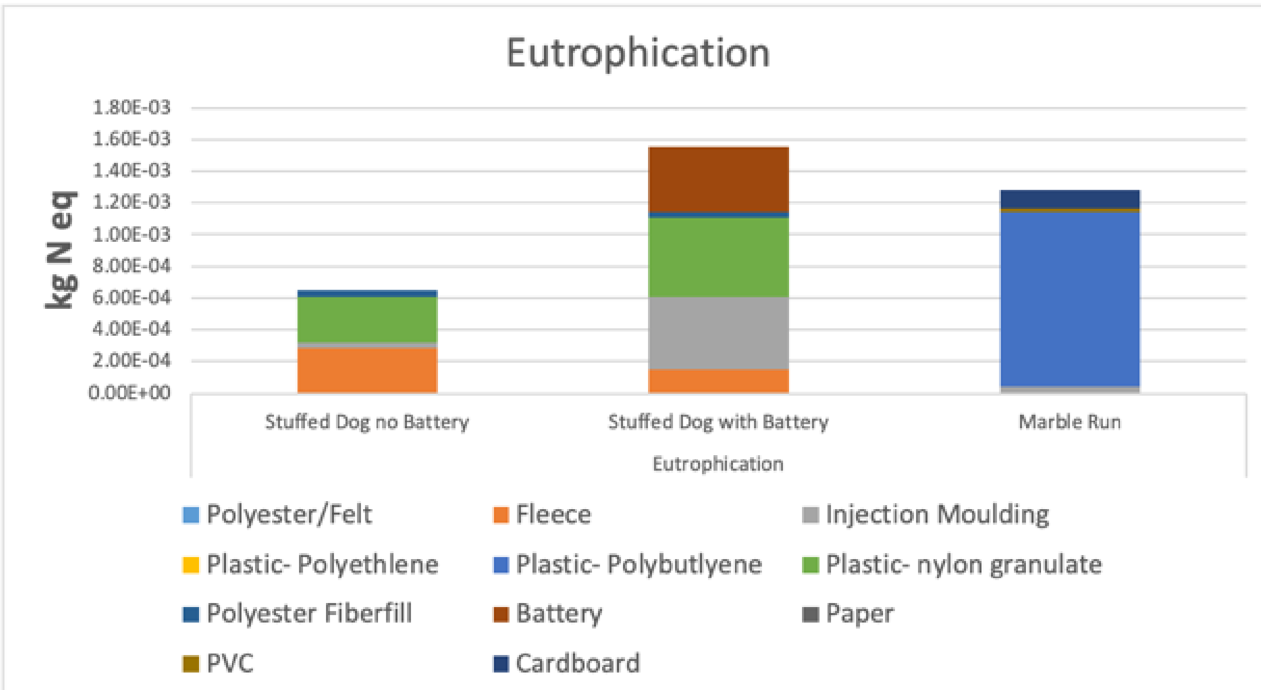

Figure 3. Eutrophication in kg N eq/kg substance for all three subject toys separated by raw materials. See Table 7 for exact measurements.

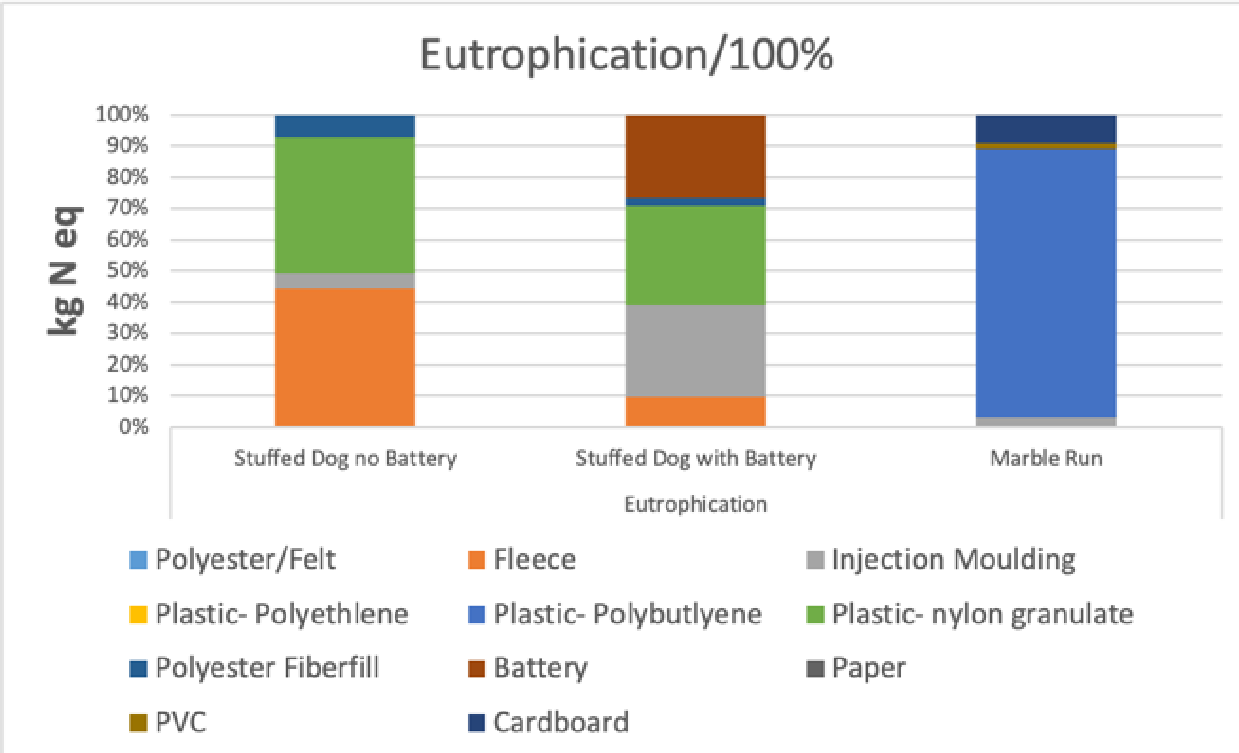

Figure 4. Eutrophication in kg N eq/kg substance for all three subject toys separated by raw materials. See Table 7 for exact measurements. The results are presented in percentage format in order to directly compare the impact of each material as a fraction of the whole toy impact.

Figure 3 and Figure 4 show the results for the eutrophication impact category for the plush dog with no battery and the plush dog with battery. Figure 3 shows the results in terms of raw data. Figure 3 shows the weights of each material and how each material's weight translates to its proportional contribution to eutrophication potential. The battery makes a noticeable difference in Figure 3 and raises the total Eutrophication potential from 6.4×10^{-4} kg N eq/kg substance to 1.5×10^{-3} kg N eq/kg substance. The battery raised the eutrophication potential of the dog with the battery pack by a factor of 2.42. This means that the battery more than doubled the eutrophication potential for the plush dog with a battery pack in comparison to the plush dog with no electric components. Figure 4 shows the Eutrophication impacts broken down by category in terms of percentage of eutrophication potential. This is useful in determining which material had the largest impact by percent for each toy. The plush dog with no battery has the most eutrophication potential due to its use of plastic and fleece. The plastic in the plush dog with a battery was also high, as well as the battery itself.

DISCUSSION

This study is the first comparative toy life cycle assessment. Our methods are focused around the environmental impacts of each toy, as opposed to focusing on the toy safety and price as factors of comparison (Good Housekeeping, 2018).

While not surprising, we found that the addition of a battery to a stuffed toy increased the impact, but only by a factor of 2.4 for Eutrophication and by a factor of 1.737 for Global Warming Potential. If the battery were replaced, each replacement adds an additional 0.04887 kg CO2 equivalents and 0.0004175 kg N equivalents for GWP and eutrophication, respectively.

Marble Frenzy ™ had the highest Global Warming Potential out of the three toys due to its plastic (Polybutylene) components. This leads to the conclusion that the plastic components resulted in the highest impact material overall, at least in terms of GWP. For parents interested in more environmentally thoughtful consumption, minimizing plastic may be a good starting point based on our findings (Kumar, same issue).

Opportunities for further research

To extend the study, researchers could look into the countries where the resources were extracted, the methods of extraction, and the transit that the resources underwent on their way to the manufacturing plant. Another interesting addition would be to study how different methods of material extraction, such as bioplastics affect the toy's overall environmental impacts (Kumar, unpublished data). These impacts could be extended to categories that provide data on human health and wellbeing of those who work in the toy manufacturing industry. Also, while we didn't investigate this, further research might want to investigate whether wood toys and/or "eco-friendly toys" are lower impact options.

ACKNOWLEDGEMENTS

Thank you to DePaul University's Environmental Science and Studies Department as well as DePaul's Undergraduate Summer Research Program for funding this project.

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