DePaul Discoveries

Volume 8 | Issue 1 Article 7

2019

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

Madeline R. Robertson
DePaul University, mrobertson182015@gmail.com

Christie Klimas
cklimas@depaul.edu

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

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.

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

Madeline Robertson[*]

Department of Environmental Science and Studies

Christie Klimas, PhD; Faculty Advisor

Department of Environmental Science and Studies

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 & Mendelsohn, 2019). Toys allow children to exercise their imaginations, as well as develop their fine and gross motor skills (Abdulaeva & Smirnova, 2011). Toys also serve as a medium to foster interpersonal skills such as sharing and problem solving between and among children (Nagahama & Takai, 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 & Mendelsohn, 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 & Mendelsohn, 2019). Imaginative play with non-electronic toys also boosts children's spatial relations and mathematical learning (Healey & Mendelsohn, 2019). Due to the benefits of non-technological toys and their prevalence in the marketplace, this study focuses on 3 different types of non-electronic play toys. While toys provide many benefits to child development, their

[*] mrobertson182015@gmail.com

Research Completed in Winter 2019

manufacturing, distribution, and use 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 as well as the hots spots (where the impacts are concentrated) for 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, Gazulla, Bala, & Puig, 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 environmental 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, and a eutrophication potential of 2.8×10^{-4}. Summing the impacts of all the materials that compose a toy can illustrate the production impact for each toy. 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 et al., 2009).

Functional unit

A functional unit is defined as, "Specification of the unit size of a product or system, on the basis of which subsequent environmental scores are calculated" (Clarke, Heijungs, Huppes, Dutilh, Haes, & Berg, 1996). The functional unit 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

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_2equivalents) 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, eutrophication, global warming, human health-carcinogens, human health- non-carcinogens, ozone depletion, photochemical ozone formation, resource depletion of fossil fuels, and respiratory effects (OpenLCA nexus, 2019). 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 by converting inputs (i.e. materials like fleece) into impact categories using standard conversion factors. For example, releasing one unit of methane is the equivalent of releasing 25 units of CO_2. Information on the inputs associated with production of materials can be found in life cycle inventory databases. These databases, with detailed information on the inputs associated with fleece and glass production, among others, are imported into OpenLCA. The databases also contain information about the resources utilized, country of origin, inputs and outputs of product manufacturing, and in some cases disposal methods and impacts. The databases utilized were: Ecoinvent, Gabi Textiles, and Gabi Professional. Ecoinvent is the world's largest transparent database for life cycle inventories (Gmbh, 2019). Ecoinvent version 3.0 contains 30,495 processes (products or materials). 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.

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 will be included in the LCA and what will not. In many LCA studies, the impact from building the machinery used to make the product is 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. We defined our system boundaries to be consistent across all subjects (See Figures 2, 3, and 4): the materials that each toy 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. 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, we assumed toys were shipped to Chicago for retail. Chicago is located in the middle of the United States and is a hub for finished material distribution.

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 ™.

Material Impacts

A toy's impact is the sum of its parts impacts. To break down the impacts, we broke down the toys. This methodology included disassembling the toys and grouping like materials. Once materials were grouped, we weighed each material type. With these measurements, we were able to match the materials with their product systems in the OpenLCA software. Product systems are individual datasets within the larger database (i.e. Ecoinvent) that contain specific impact information per material. For example, the stuffing within the plush dogs was matched with the product system "Polypropylene (PP) - fabric, production mix, at plant, technology mix, PP." We inputted the stuffing weight into the polypropylene product system and ran the calculation to compute impacts. This methodology was repeated with each material found in all three toys. The material break downs are found in the Appendix in Table 1, Table 2, and Table 3. Table 4 shows a condensed format for toy subject 3: Marble Frenzy™ due to its injection molding manufacturing process. Table 5 details the battery impacts from the plush dog with a battery. The battery component was based on a previous comparative LCA study on batteries (Dolci, Tua, Grosso, & Rigamonti, 2016). Table 6 contains the Global Warming Potential data for all three subject toys. Table 7 contains the Eutrophication data for all three subject toys. Table 6 and 7 are useful in directly comparing impacts among the subject toys.

Transportation

China is a predominant country for manufacturing toys (Workman, 2019). 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 and 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.

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). 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). 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 Laboratory 2017). 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).

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 (EPA, 2017). This 3.7 factor translates to methane containing 25x the global warming potential per molecule of CO_2 (EPA, 2017). 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 CO_2 eq.

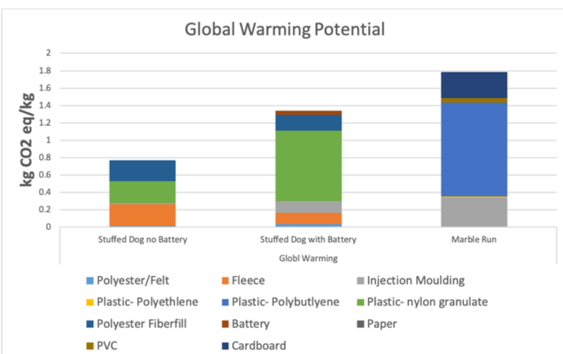

Figure 5. Global Warming Potential in kg CO_2 eq/kg substance for all three subject toys separated by raw materials. See Table 6 for exact category measurements.

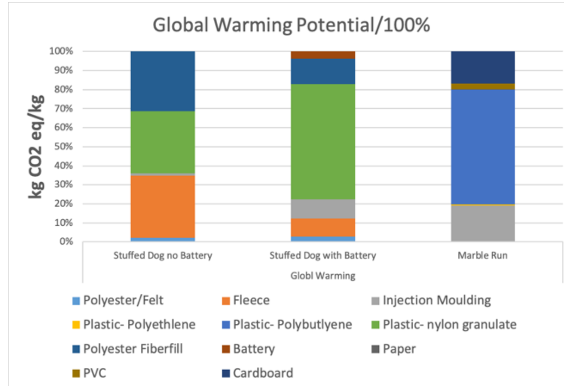

Figure 6. Global Warming Potential in kg CO_2 eq/kg substance for all three subject toys separated by raw materials. See Table 6 for exact measurements. The results are presented in percentage format in order to directly compare the impact of each material as a fraction of the whole toy impact.

When examining the two graphs above, one must keep in mind the weight of each material and how that weight affects the results. The fleece, while making up 0.9 grams of the weight of the toy, has a similar GWP to nylon granulate, which makes up only 0.006 grams of the weight of the toy. This means that overall impact is more affected by the addition of a plastic than the addition of a fiber.

Polyester/Felt may have a high global warming potential, but due to its small weight in both of the toys, the impact remains low. In the plush dog with no battery, the GWP from fleece weighing 0.09 kg has a comparable impact to the nylon granulate weighing 0.006 kg. A 1.0 kg amount of nylon granulate has the GWP of 9.3 kg CO_2 eq. Nylon granulate has 3.3x the GWP of fleece. Figure 5 and 6 show the differences in Global Warming Potential between the plush dog with no battery, the plush dog with battery, and Marble Frenzy. Figure 5 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 6 presents the data in a percentage format. 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. One kg of polyester has the global warming potential of 7.1 kg CO_2 eq. One kg of fleece has the global warming potential of 2.8 kg CO_2 eq. This direct comparison shows that polyester has 2.5x the Global Warming Potential compared to fleece. A higher amount of polyester would increase the toy's overall impact 2.5x faster than a higher amount of fleece. This is important when deciding between toys with soft components such as plush toys.

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. Also, the most important single source is municipal sewage" (EPA, 1972). The increased phosphorus level creates a high level of algae which consume the oxygen, negatively affecting the pre-existing aquatic life. The units in OpenLCA for eutrophication are kg N eq.

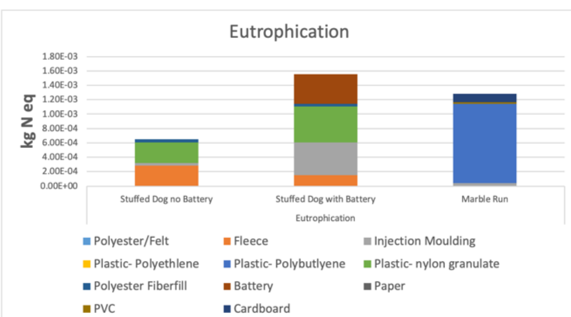

Figure 7. Eutrophication in kg N eq/kg substance for all three subject toys separated by raw materials. See Table 7 for exact measurements.

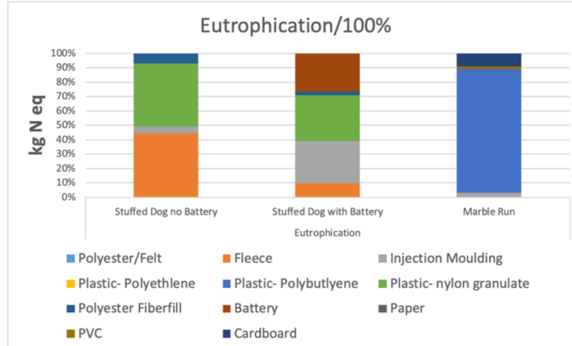

Figure 8. Eutrophication in kg N eq/kg substance for all three subject toys separated by raw materials. See Table 7 for exact measurements. The results are presented in percentage format in order to directly compare the impact of each material as a fraction of the whole toy impact.

Figure 7 and Figure 8 show the results for the eutrophication impact category for the plush dog with no battery and the plush dog with battery. Figure 7 shows the results in terms of raw data. Figure 7 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 7 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 8 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 plush dog with no battery contained 0.09 kg of fleece and 0.006 kg nylon granulate. A 1.0 kg mass of fleece has the eutrophication potential of 3.1×10^{-3} kg N eq. A 1.0 kg mass of nylon granulate has the eutrophication potential of 5.7×10^{-3} kg N eq. Nylon granulate has a 1.8x higher eutrophication potential than fleece. The plastic in the plush dog with a battery was also high, as well as the battery itself. The battery, while only weighing 0.02 kg, has a eutrophication potential of 4.1×10^{-4} kg N eq.

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 1.7 for Global Warming Potential. If the battery were replaced, each replacement adds an additional 4.8×10^{-2} kg CO2 equivalents and 4.2×10^{-4} 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. Toys with no rechargeable or disposable batteries are also more environmentally friendly (Figure 5 and Figure 7). Parents can also extend the life cycle of their children's toys by passing them down to sibling, family members, or neighbors. The longer the toy is in use, the smaller its environmental impact becomes. A significant takeaway from this study is that our decisions as consumers hold environmental weight. We have the power to minimize our impacts by choosing products with lower environmental impacts. When choosing which toy to buy, consider a few factors: how long will the child use this toy (longevity reduces impact), does the toy have parts that will need to be replaced (batteries), is the toy predominately plastic (high impact and breakable)? Instilling environmental stewardship in children can begin with the toys they play with (Louv, 2005).

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.

REFRENCES

Abdulaeva, E. A., Smirnova, E. O., (2011). The role of dynamic toys in child's development. *Psychological Science & Education*, *2*, 30–38.

Clarke, R., Heijungs, R.., Huppes, G., Dutilh, C., Haes, H., Berg, N., (1996). Life cycle assessment: What it is and how to do it. UNEP, Industry and Environment.

Dolci, G., Tua, C., Grosso, M., Rigamonti, L., (2016). Life cycle assessment of consumption choices: A comparison between disposable and rechargeable household batteries. *The International Journal of Life Cycle Assessment*, *21* (12).

EPA. (1972). The Role of Phosphorus in Eutrophication. Ecological Research Series, National Environmental Research Center Office of Research and Monitoring, U.S. Environmental Protection Agency (EPA).

EPA. (2017). Greenhouse Gas Emissions: Understanding Global Warming Potentials. U.S. Environmental Protection Agency (EPA).

Fleet DNA Project Data. (2017). National Renewable Energy Laboratory. U.S. Department of Energy.

GmbH, BlueMouse. “The Ecoinvent Database.” *Ecoinvent Version 3*, 2019, www.ecoinvent.org/database/database.html.

Good Housekeeping. (2018). Good housekeeping best toy awards 2018. *Good Housekeeping*, *267 (5)*, 139-143.

Healey, A., Mendelsohn, A., (2019). Selecting appropriate toys for young children in the digital era. *Pediatrics*, *143* (1), 1–10.

Klimas, Christie A., and Benjamin Shaffer. "Exploring the impact of holiday gifts: An economic and environmental comparison of DVDs and books received as gifts." *Sustainable Production and Consumption* 19 (2019): 11-24.

Louv, R., (2005). Last child in the woods: Saving our children from nature-deficit disorder. Chapel Hill, NC: Algonquin Books of Chapel Hill**.**

Muñoz, I.; Gazulla, C., Bala, A., Puig, R., (2009). LCA an ecodesign in the toy industry: Case study of a teddy bear incorporating electric and electronic components. *The International Journal of Life Cycle Assessment*, *14* (1), 64-72.

Nagahama, N., Takai, N., (2011). Development of self-regulation in young children competing for toys. Japanese *Journal of Developmental Psychology*, *22* (3), 251–260.

“OpenLCA Nexus: The Source for LCA Data Sets.” *OpenLCA Nexus: The Source for LCA Data Sets*, 2019, nexus.openlca.org/.

Sea Distances. (2019). Retrieved from: https://sea-distances.org/.

Workman, Daniel. “Top Toys Exporters.” *World's Richest Countries*, 2019, www.worldsrichestcountries.com/top_toys_and_games_exporters.html.

APPENDIX

Toy Part	Weight (kg)	Database	Label in OpenLCA
Collar, Nose, White behind nose, Orange & white behind eyes	0.00238	GabiTextiles	Polyester (PET) fabric, production mix, at plant, technology mix, PET
Pelt	0.09027	Ecoinvent	fleece production, polyethylene | fleece, polyethylene | cut-off, U
Eyes	0.00628	Ecoinvent	Nylon Granulate
Eyes	0.00628	Ecoinvent	injection moulding | injection moulding | cut-off, U
Stuffing	0.05385	GabiTextiles	Polypropylene (PP) - fabric, production mix, at plant, technology mix, PP

Table 1: The components, weights, and corresponding labels in databases for the stuffed dog with no battery components. The weights are given in kg as they are inputted in OpenLCA. If replicated, this table can be used to create graphs analyzing the impacts of each raw material.

Toy Part	Weight (kg)	Database	Label in OpenLCA
Pouch for battery pack	0.00494	GabiTextiles	Polyester (PET) fabric, production mix, at plant, technology mix, PET
Pelt	0.04619	Ecoinvent	fleece production, polyethylene | fleece, polyethylene | cut-off, U
Battery pack	0.08753	Ecoinvent	Nylon Granulate
Battery pack	0.08753	Ecoinvent	injection moulding | injection moulding | cut-off, U
Stuffing	0.03996	GabiTextiles	Polypropylene (PP) - fabric, production mix, at plant, technology mix, PP
Battery	0.0233	Ecoinvent	See Table 5

Table 2: The components, weights, and corresponding labels in databases for the stuffed dog with battery components for tail wagging. The weights are given in kg as they are inputted in OpenLCA. If replicated, this table can be used to create graphs analyzing the impacts of each raw material.

Toy Part	Weight (kg)	Database	Label in OpenLCA
Transparent connectors	0.0366	GabiPlastics	Polybutylene Terephthalate Granulate (PBT) Mix, consumption mix, to consumer, technology mix, PBT granulate
Injection moulding	0.0366	GabiProfessional	Plastic injection moulding part (unspecific), single route, at plant
White marbles	0.0165	GabiPlastics	Polyvinylchloride pipe (PVC), production mix, at producer, technology mix
Injection moulding	0.0165	GabiProfessional	Plastic injection moulding part (unspecific), single route, at plant
Shaped tubes	0.08055	GabiPlastics	Polybutylene Terephthalate Granulate (PBT) Mix, consumption mix, to consumer, technology mix, PBT granulate
Injection moulding	0.08055	GabiProfessional	Plastic injection moulding part (unspecific), single route, at plant
Stands	0.02828	GabiPlastics	Polybutylene Terephthalate Granulate (PBT) Mix, consumption mix, to consumer, technology mix, PBT granulate
Injection moulding	0.02828	GabiProfessional	Plastic injection moulding part (unspecific), single route, at plant
Chute stoppers	0.01608	GabiPlastics	Polybutylene Terephthalate Granulate (PBT) Mix, consumption mix, to consumer, technology mix, PBT granulate
Injection moulding	0.01608	GabiProfessional	Plastic injection moulding part (unspecific), single route, at plant
Packaging	0.1249	GabiProfessional	Kraftliner (2012), production mix, at plant, technology mix, by-products tall oil, turpentine, thermal energy sold/used externally, 0.32 kg waste paper input per kg Kraftliner
Marble bag	0.00211	GabiPlastics	Polyethylene terephthalate fibres (PET), production mix, at plant, technology mix, PET fibres
Instructions	0.00183	GabiProfessional	Graphic Paper, production mix, at plant, technology mix, 79% primary fibre, 21% recycled fibre

Table 3: The components, weights, and corresponding labels in databases for the toy Marble Frenzy. The weights are given in kg as they are inputted in OpenLCA. If replicated, this table can be used to create graphs analyzing the impacts of each raw material in addition to the injection moulding process for toy creation.

Toy Part	Material	Weight (kg)
Transparent connectors, Shaped tubes, Stands, Chute stoppers	Plastic (Polybutylene Terephthalate Granulate)	0.16151
Transparent connectors, Shaped tubes, Stands, Chute stoppers	Injection moulding (process)	0.17801
Marbles	PVC	0.0165
Packaging	Cardboard	0.1249
Marble bag	Plastic	0.00211
Instructions	Paper	0.00183

Table 4: Marble Frenzy ™ toy parts separated by material type. In this way, the data can be inputted into OpenLCA to create graphs to compare material impacts.

Battery Component	Material	Database	Label in OpenLCA
Cathode	Electrolytic manganese dioxide	Ecoinvent	manganese dioxide production | manganese dioxide | cut-off, U
Cathode	Graphite	Ecoinvent	graphite production, battery grade | graphite, battery grade | cut-off, U
Anode	Powdered zinc	Ecoinvent	zinc oxide production | zinc oxide | cut-off, U
Anode	Zinc oxide	Ecoinvent	zinc oxide production | zinc oxide | cut-off, U
Anode	Gelling agent (starch)	Ecoinvent	maize starch production | maize starch | cut-off, U
Electrode Separator	Cellulose	Ecoinvent	carboxymethyl cellulose production, powder | carboxymethyl cellulose, powder | cut-off, U
Electrolyte	Potassium hydroxide solution (35%wt)	Ecoinvent	potassium hydroxide production | potassium hydroxide | cut-off, U
Anode current collector	Brass	Ecoinvent	brass production | brass | cut-off, U
Can + Plastic coat	Nickel-plated steel	Ecoinvent	market for scrap steel | scrap steel | cut-off, U
Can + Plastic coat	Polyvinyl chloride	Ecoinvent	polyvinylchloride production, emulsion polymerisation | polyvinylchloride, emulsion polymerised | cut-off, U
Plastic cap	Nylon		nylon 6 production | nylon 6 | cut-off, U

Table 5: The components, weights, and corresponding labels in databases for the battery. The weights are given in kg as they are inputted in OpenLCA. If replicated, this table can be used to create graphs analyzing the impacts of each raw material. Based off (Dolci 2016).

Material	Plush Dog no battery	Plush Dog with battery	Marble Frenzy ™
Polyester/Felt	0.0168	0.0349	N/A
Fleece	0.2514	0.1286	N/A
Injection Moulding	0.0097	0.1363	0.3423
Plastic- Polyethylene	N/A	N/A	0.0104
Plastic- Polybutylene	N/A	N/A	1.078
Plastic- Nylon Granulate	0.2514	0.8130	N/A
Polyester Fiberfill	0.2429	0.1803	N/A
Battery	N/A	0.0488	N/A
Paper	N/A	N/A	0.0034
PVC	N/A	N/A	0.0533
Cardboard	N/A	N/A	0.2997

Table 6: Global Warming Potential results for each toy. Units are kg CO2 eq/kg substance.

Material	Plush Dog no battery	Plush Dog with battery	Marble Frenzy ™
Polyester/Felt	2.759	5.727 E-06	N/A
Fleece	0.0002	0.0001	N/A
Injection Moulding	0.00003	0.0004	3.963 E-05
Plastic- Polyethylene	N/A	N/A	1.310 E-06
Plastic- Polybutylene	N/A	N/A	0.0010
Plastic- Nylon Granulate	0.0002	0.0004	N/A
Polyester Fiberfill	0.00004	3.373 E-05	N/A
Battery	N/A	0.0004	N/A
Paper	N/A	N/A	4.870 E-06
PVC	N/A	N/A	1.988 E-05
Cardboard	N/A	N/A	0.0001

Table 7: Eutrophication potential for each toy. Units are in kg N eq/kg substance