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To Rent or Not to Rent: A Question of Circular Prams from a Life Cycle Perspective

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**Abstract**

Product-as-a-service business models have been strongly promoted to support a transition to a circular economy. Prams for babies are an ideal product for this type of business model since they are widely used, are mature products, have established design cycles, and are very durable. A cradle-to-grave life cycle assessment was conducted to compare the environmental impacts of the pram rental business model and the traditional pram ownership business model to serve all children born in Singapore over a period of 5 years. The results revealed that the total environmental impacts of the rental business model were lower than the ownership business model by 29–46%, depending on the impact category. However, the impacts of the pram rental business model were shown to be higher than the ownership business model if rental prams undergo heavy cleaning more than 10 times per year. It is generally recommended that pram users rent a pram if the alternative choice is to own a pram, use it for only 3 years, and then dispose of it. This study provides policy recommendations focused on partnerships between government agencies and pram rental companies to facilitate greater collection, refurbishment, and recirculation of used prams in the market.

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### 1. Introduction

Product/service-systems have been widely promoted as a pathway for businesses to transition to a circular economy (Kjaer et al., 2018). In a product/service-system, products provide a service to customers and are treated as assets by the service providers as opposed to products being treated as consumables. This type of business model incentivizes companies to extend the life of a product through product take-back programs and maintenance so long as it can continue providing a valuable service. Many successful business examples exist such as car sharing services (BlueSG, 2020; Zipcar, 2020), on-demand driver services (Grab, 2020; Lyft, 2020; Uber, 2020), pay-per-copy models for selling office equipment (Xerox, 2020), and lighting as a service (Philips, 2013). These product/service-systems have allowed companies to continue accumulating revenue while reducing resource requirements and wastes generated.

One product that is suitable for product/service-systems is prams for babies (also known as strollers or carriages). This is because prams are mature products that are widely used, have established design cycles, and are very durable meaning that they can be used for many years and have a high recovery value at their end of life (Mont et al., 2006). Despite the durability of prams, typical pram users often discard them because the textile has become worn or outdated, while the chassis and other parts are in good working condition. Several businesses have been established that allow customers to rent prams and other baby equipment as a service. Providing the service of prams offers environmental benefits such as reductions in material requirements and waste. These benefits have often been advertised, but such benefits have not yet been quantified holistically in comparison to the traditional pram ownership business model.

Life cycle assessment (LCA) is a tool used to holistically measure the environmental impacts of a product or service across its entire life and can help identify environmental burden shifts. Several LCA studies have been conducted for different product/service-systems (Becr et al., 2019; Bonilla-Alce et al., 2020; Chun and Lee, 2017; Ding et al., 2019; Kaddoura et al., 2019). These studies have shown...
that product/service-systems are able to provide the same level of service with fewer products compared to the traditional ownership model. However, resources are required during maintenance depending on the type of product. To date, LCA studies have not been conducted for the case of prams as a service in comparison to the traditional business model of owning a pram. Such a study can unveil potential environmental trade-offs between life cycle stages and impact categories in the different pram business models. The results of an LCA can help address environmental questions posed by pram users and companies such as:

1. Pram users: Is it environmentally better to own or rent a pram? If I choose to own a pram, what options are there to reduce my environmental impacts?
2. Pram manufacturers and distributors: How can my business reduce the environmental impacts of prams sold?
3. Pram rental companies: What actions should my company take to ensure that the pram rental service has lower environmental impacts compared to the traditional pram ownership business model?

Therefore, the objective of this study is to compare the life cycle environmental impacts of the pram rental business model and the traditional pram ownership business model. The results of the study can be used to provide recommendations to both pram users and pram businesses about how to reduce their environmental impacts. Although the study is conducted in the Singapore context, the findings can be applied in other countries where prams are widely used by parents. Finally, this study adds to the literature further insight regarding how consumer preferences during the use stage can determine whether a product/service-system has a better environmental performance than the traditional product ownership business model from a life cycle perspective.

2. Literature review

LCAs of product/service-systems were conducted as far back as 20 years ago when Bennett and Graedel (2000) compared the environmental impacts of an air conditioner as a service versus a traditional residential air conditioning unit. Since then, many other types of product/service-systems have been evaluated through LCA. Kjaer et al. (2018, 2016) analyzed the different types of LCAs of product/service-systems that have been conducted. The analysis aimed to identify the challenges of using LCA to evaluate product/service-systems to support in the development of guidelines for conducting such assessments. The guidelines developed by Kjaer et al. (2018) state that the scope of LCA studies of product/service-systems can be classified into 3 different categories which are product/service-system optimization, comparison, and consequences. Among the LCA studies conducted since 2000 that had a comparative scope, the product/service-systems evaluated included air conditioning units (Bennett and Graedel, 2000), core plugs for rollers at paper mills (Lindahl et al., 2014), cleaning and drying of buildings (Lindahl et al., 2014), soil compactors (Lindahl et al., 2014), photocopiers (Kerr and Ryan, 2001; Khumboon et al., 2009), power tools and gardening equipment (Mont, 2004), water purifiers (Chun and Lee, 2017), and car sharing (Ding et al., 2019; Nurhadi et al., 2017). In a majority of the studies, the product/service-systems proved to have lower life cycle environmental impacts compared to the traditional business model scenario. This was due to the product-as-a-service business model being able to extend the useful life of a product and enable shared use of a product among multiple users. Some LCA studies of product/service-system identified environmental tradeoffs between the different business models. In a comparison of rental and ownership business models for water purifiers in South Korean homes, Chun and Lee (2017) revealed that the rental scenario had lower climate change impacts, but higher abiotic resource depletion impacts due to higher material requirements during the product maintenance stage. Similarly, an LCA study about car sharing in Beijing (Ding et al., 2019) showed that the environmental benefits of car sharing in comparison to the car ownership business model are dependent on the number of passengers in a car per trip and the dispatch distance. These two studies show how the use and maintenance stages can strongly influence the life cycle environmental performance of a product/service-system. The life cycle environmental performance of prams may similarly encounter the same case. What makes prams unique compared to other products is that the number of times a pram is sent for cleaning and maintenance is not necessarily dependent on a technical requirement, but instead can be strongly subjective to a customer’s personal preferences. For example, a pram may only need to be cleaned once every 2 or 3 months, but the customer may choose to have it cleaned at least 1-2 times per month due to hygienic concerns. This study therefore aims to compare the environmental performance of the pram ownership and rental business models from a life cycle perspective and analyze how the number of cleaning cycles per year for each business model can affect the total environmental impacts.

3. Methods

3.1. Goal and scope definition

The goal of this LCA is to compare the life cycle environmental impacts of the pram rental business model versus the pram ownership business model in Singapore. The intended audience of this study includes pram users, pram manufacturers and distributors, and pram rental service providers. The results of this study can be used to inform the intended audience about pathways to reduce their environmental impacts and help determine under which conditions should pram users and companies shift from an ownership to a rental business model. Finally, the results of this study can help in further understanding the environmental benefits and trade-offs of product/service-systems in a circular economy.

3.2. Functional unit and system boundaries

The functional unit of this LCA is the service provision of prams for 600,000 child-years in Singapore. The service the pram provides allows each child to travel twice a day every day for a total of 6 km each day. This functional unit was calculated based on the number of children born in Singapore each year, the number of years each child requires the service of a pram, and the temporal boundary of the functional unit. This study assumes that 40,000 children are born each year based on national birth statistics (Singapore Department of Statistics, 2020). Each child is assumed to use a pram for the first 3 years of life. The total number of child-years for all children born in Singapore in 1 year is therefore 120,000 child-years. This study examines the service of prams required by all children born within a period of 5 years. The annual number of births is assumed to be the same at 40,000 during the 5-year period. Therefore, the total amount of function is 600,000 child-years; the functional unit of this study. The prams in all scenarios are assumed to have a lifetime of 6 child-years. This assumption was made based on interviews with pram rental company staff in Singapore and literature related to the lifetime of prams (Mont et al., 2006). In this LCA, it is assumed that each pram is designed to be large enough to hold a child between the ages of 1 and 3 years. However, prams can be disposed before all the child-years are used if the pram owner (first user) decides to not pass the pram onto another user when it is no longer needed.
The system boundaries of this LCA are cradle-to-grave which include the stages of raw material extraction, manufacturing, use, repair and maintenance, and disposal of the pram as shown in Fig. 1. All intermediate transportation is also included.

All prams are assumed to be manufactured in China and are imported to Singapore by a container ship.

3.3. Scenarios analyzed

This LCA analyzes 4 scenarios that can be categorized into 2 groups of business models; ownership and rental. In the ownership business model, 3 different scenarios are analyzed. In all the ownership scenarios, it is assumed that each child only requires a single pram throughout its first 3 years of life. This assumption was made based on a sample survey of pram users in Singapore that revealed that about two-thirds of the respondents use a pram for 3 or more years before they buy a new one. The ownership 1 scenario assumes that all parents dispose of the prams when the child no longer needs it. Ownership 2 assumes that 50% of prams manufactured are passed onto a second user after the first 3 years of use and the second user uses the pram for the remaining 3 years of life. Ownership 3 assumes that all prams manufactured are passed onto a second user after the first 3 years of life and the pram’s remaining 3 years of life are used. The purpose of ownership scenarios 2 and 3 is to analyze the potential reductions in environmental impacts by passing prams onto second users. In the ownership scenarios, light cleaning is done periodically.

In the rental scenario, the business model in operation is that the prams are provided as a service measured in child-years. In this business model, customers can rent a pram either one-time or on a subscription basis. All 6 child-years of a pram are used before the rental company disposes it. Therefore, fewer prams are required to be manufactured to provide the service required by the functional unit. In the rental scenario, heavy cleaning is done periodically by the pram rental company which involves technical maintenance and high-quality cleaning. The heavy cleaning ensures that the pram is in good condition and is hygienically clean to meet the satisfaction of customers. Furthermore, the heavy cleaning ensures that the rental prams can be used for all 6 child-years by multiple customers. Regardless of whether the customers choose to do a one-time rental or on a subscription-based service for all 3 years, the study assumes that the same number of heavy cleaning cycles will be done each year.

3.4. Reference flows and allocation

The reference flow in this LCA is the number of prams that must be manufactured to fulfill the required service (child-years) in the defined functional unit. In all scenarios, each pram is able to provide 6 child-years of service before it is disposed. However, prams may be disposed before all 6 child-years are used in certain scenarios. In scenario ownership 1, the service of the pram is met by manufacturing one pram per child. The parents of the child own and use the pram for 3 years and then dispose it at a time between years 4 and 6. Since 40,000 children are born annually and the study analyzes the children born within a period of 5 years, 200,000 prams must be manufactured in the ownership business model to meet the study’s functional unit. In scenario ownership 2, it is assumed that 50% of all prams manufactured are passed onto a second user when 3 child-years are used while the remaining 50% of prams are disposed. Therefore, only 150,000 prams need to be manufactured because 50,000 children will be able to use a second-hand pram that still has 3 child-years remaining. In scenario ownership 3, it is assumed that 100% of prams manufactured are passed onto a second user when 3 child-years are used. Therefore, only 100,000 prams need to be manufactured because 100,000 children will be able to use a second-hand pram that still has 3 child-years remaining.

In the pram rental scenario, the functional unit is met through a fleet of prams owned by multiple pram rental companies in Singapore. None of the parents own the prams they use. The prams are used interchangeably between all the children each year. Rental prams are used on the basis of child-years and are only disposed when all 6 child-years have been used. To determine the number of prams that manufactured and disposed in the rental scenarios, the functional unit of 600,000 child-years was divided by 6 child-years of a pram, resulting in a requirement of 100,000 prams. In the rental scenario, it is also assumed that when rental prams are not used by customers, they are put into storage. The usable life (child-years) of prams does not decrease when in storage because prams are durable products and are well-maintained at the shop. Table 1 summarizes the 4 scenarios, their reference flows, and end-of-life treatment of the prams.

The number of cleaning cycles required in all scenarios was computed based on the number of times a parent or the pram rental company cleans a pram each year. Allocation was not required for the impacts of cleaning cycles.
3.5. Life cycle stages

3.5.1. Pram manufacturing

In this study, all prams are assumed to be manufactured in China because prams are currently not manufactured in Singapore. Each pram has a total mass of 16.2 kg and is made of steel (3.22 kg), acrylonitrile butadiene styrene (ABS) plastic (4.61 kg), nylon (0.61 kg), cotton (0.38 kg), and vulcanized rubber (0.5 kg). Electricity is directly consumed during different pram manufacturing processes, which are summarized in Table 2. The electricity consumption rates for the different processes were obtained from a study by Ciceri et al., 2010.

As previously mentioned, all prams are assumed to be manufactured in China and are sent to Singapore on a container ship. A distance of 100 km was assumed for land transport between the pram factories and the port of Canton. The sea route from the port of Canton to the port of Singapore was estimated to be 2,858 km (Ports.com, 2020).

3.5.2. Pram use, cleaning and maintenance

It is assumed that the use of the prams by children and the number of cleaning cycles per year is the same whether the parents own or rent the pram from a company. Only the processes for cleaning and maintaining the pram are different in the ownership and rental scenarios. In the ownership scenarios, light cleaning is done once every 3 months. Therefore, for every child-year, the pram in the ownership scenario undergoes 4 cycles of light cleaning. For each light cleaning cycle, 2 liters of tap water and 3 mL of a cleaning agent are used to wash any stains.

In the pram rental scenario, the pram rental company does heavy cleaning once every 3 months (4 times per year). Heavy cleaning must be done to ensure that the pram is sanitary and is in good-as-new condition for any user and will last for 6 years. During the time a rental pram sits in storage, it does not undergo heavy cleaning. The pram rental company provides the service of picking up the pram from the customer using a small commercial van. Through interviews with a pram rental company in Singapore, the longest pick-up distance from the customer to the shop was 40 km and the shortest was 3 km. This study takes the average of those two distances and assumes a one-way pick-up distance of 21.5 km. One heavy cleaning cycle therefore requires a van to transport a pram 43 km. Several processes are involved in heavy cleaning a rental pram. Cleaning starts with removing the detachable fabric parts from the chassis of the pram such as cushions and covers. The detachable parts are put into a bucket of water with a cleaning agent, some baking soda, and fabric softener. Once the detachable fabric parts are cleaned, a water extractor is used to remove water soaked inside. The detachable fabric parts are dried in a foldable electric clothes dryer. The pram chassis and other remaining parts are cleaned by using a steamer. Several wet wipes are used to clean the metal and plastic components of the pram chassis. Finally, the pram chassis is dried in an open area using a large fan. In this study, it is assumed that rental prams are sent back to the rental company every 3 months to have them cleaned and maintained. For rental prams, an assumption was made that parts such as wheels or tires and the cloth for the seats do not wear out or get otherwise damaged during the 6-year lifetime, and thus need not be replaced. This is because based on interviews with pram rental company staff, the heavy cleaning cycle that is done periodically helps keeps the pram parts in good working condition.

3.5.3. End-of-life

In both the pram ownership and rental scenarios, the prams are disposed at a waste-to-energy incineration plant in Singapore (National Environment Agency of Singapore, 2020). At the waste-to-energy incineration plant, the waste is reduced to ash which is about 10% of its original volume and any electricity that is generated is fed back into Singapore’s electricity grid. Any ferrous scrap metals in the ash, such as steel, are recovered and recycled. The remaining ash is sent to a transfer station for shipping to a sanitary landfill on Semakau Island (National Environment Agency, 2020).

3.6. Data sources

The life cycle inventory (LCI) data for this study came from both primary and secondary sources. LCI data for cradle-to-gate pram manufacturing came from a study conducted by Carnegie Mellon University (2008). Inventory data for the heavy cleaning process was obtained from interviews with 3 staff members at a single pram rental company in Singapore. The LCI data for the heavy cleaning process cannot be presented in this paper because of the confidentiality of the dataset. Production of wet wipes was represented with LCI data from studies conducted by the European Commission (Paspadzhiev et al., 2018) and (Faught et al., 2014). LCI data from the Ecoinvent v3.6 database (Ecoinvent 2020) were used to represent the background system processes. The Ecoinvent datasets used are shown in Table 3.

3.7. Environmental impact categories

This LCA used the ReCiPe2016 midpoint method (Huijbregts et al., 2017) with a hierarchist perspective to characterize 15 different impact categories. The impact categories were climate change, fossil depletion, freshwater ecotoxicity, freshwater

Table 1
Reference flows and end-of-life-treatment for all scenarios.

| Scenario name | Number of prams manufactured | End-of-life treatment |
|---------------|-------------------------------|-----------------------|
| Ownership 1   | 200,000                       | All prams are disposed after one child has used |
| Ownership 2   | 150,000                       | 50% of all prams manufactured are passed onto a second user |
| Ownership 3   | 100,000                       | 100% of all prams manufactured are passed onto a second user |
| Rental        | 100,000                       | Prams are only disposed when all 6 child-years have been used |

Table 2
Direct electricity consumption to produce one pram.

| Process          | Materials         | Rate (MJ/kg) | Mass (kg) | Total energy (MJ) |
|------------------|-------------------|--------------|-----------|-------------------|
| Machining        | Steel and plastic | 6.4          | 8.12      | 52                |
| Grinding         | Steel             | 8.8          | 3.32      | 29                |
| Forging          | Steel             | 16.3         | 3.32      | 54                |
| Finish machining | Steel             | 24           | 3.32      | 80                |
| Total            |                   |              |           | 215               |
eutrophication, human toxicity, ionising radiation, marine eco-
toxicity, marine eutrophication, metal depletion, ozone depletion, particulate matter formation, photochemical oxidant formation, terrestrial acidification, terrestrial ecotoxicity, and water depletion.

4. Results

In this paper, the LCA results are presented for only 9 out of the 15 impact categories considered within the scope of the study. The results for climate change, fossil depletion, metal depletion, and water depletion are presented because these impact categories have been prioritized in Singapore’s zero waste masterplan (Ministry of Sustainability and the Environment, 2019). The results for freshwater eutrophication, human toxicity, marine eutrophication, particulate matter formation, terrestrial acidification, and terrestrial ecotoxicity follow the same trends as the results in the 4 aforementioned impact categories. These results are provided in the online Supplementary Information. The results for the impact categories of freshwater ecotoxicity, ionising radiation, marine ecotoxicity, ozone depletion, and photochemical oxidant formation are presented because they follow slightly different trends compared to the results for climate change, fossil depletion, metal depletion, and water depletion.

The environmental impacts of each process in the pram life cycle for all 15 impact categories are summarized in Table 4. These processes include pram manufacturing, shipping a pram from China to Singapore, a light and heavy cleaning cycle, a roundtrip transport of a pram to the rental company for heavy cleaning, and pram disposal.

Certain processes had the highest contributions to the impacts of pram production in different categories as shown in Fig. 2(a). The processes of ABS plastic production and electricity for manufacturing had the highest contributions in the categories of climate change and fossil depletion. Steel production had the highest contribution to metal depletion, freshwater ecotoxicity, marine ecotoxicity, and photochemical oxidant formation while cotton textile production had the highest contribution to water depletion, marine eutrophication, and terrestrial ecotoxicity. The impacts of disposal in fossil depletion and metal depletion have negative values in Table 4 because electricity is generated during incineration and

| Impact category | Cradle to gate production of one pram | Shipping one pram from China to Singapore | One light cleaning cycle | One heavy cleaning cycle | One round trip to pick up pram for heavy cleaning | Disposal of one pram |
|-----------------|--------------------------------------|-----------------------------------------|------------------------|-------------------------|-------------------------------------------------|----------------------|
| Climate change (kg CO₂-Eq) | 78.3 | 0.43 | 7.6 × 10⁻¹ | 0.63 | 0.79 | 2.6 |
| Fossil depletion (kg oil-Eq) | 32.9 | 0.14 | 3.9 × 10⁻¹ | 0.22 | 0.28 | -0.52 |
| Metal depletion (kg Fe-Eq) | 7.7 | 1.2 × 10⁻² | 5.8 × 10⁻⁴ | 4.1 × 10⁻³ | 8.1 × 10⁻² | -0.15 |
| Water depletion (m³) | 3.3 | 5.1 × 10⁻⁴ | 2.8 × 10⁻⁴ | 8.9 × 10⁻³ | 1.6 × 10⁻² | 4.6 × 10⁻³ |
| Freshwater ecotoxicity (kg 1,4-DCB-Eq) | 2.4 | 3.5 × 10⁻⁵ | 2.3 × 10⁻⁴ | 9.3 × 10⁻² | 4.8 × 10⁻² | 2.8 |
| Freshwater eutrophication (kg P-Eq) | 5.2 × 10⁻² | 3.3 × 10⁻⁵ | 4.2 × 10⁻⁵ | 5.1 × 10⁻³ | 1.8 × 10⁻⁴ | -1.8 × 10⁻³ |
| Human toxicity (kg 1,4-dcb-eq) | 36.8 | 6.5 × 10⁻⁵ | 2.9 × 10⁻⁴ | 4.4 × 10⁻³ | 2.7 × 10⁻¹ | 1.9 |
| Ionizing radiation (kg u235-eq) | 2.7 | 2.4 × 10⁻² | 3.3 × 10⁻⁴ | 4.8 × 10⁻² | 5.0 × 10⁻² | -0.31 |
| Marine ecotoxicity (kg 1,4-DB-Eq) | 2.3 | 3.7 × 10⁻³ | 2.0 × 10⁻⁴ | 9.5 × 10⁻² | 4.2 × 10⁻² | 2.7 |
| Marine eutrophication (kg N-Eq) | 0.1 | 2.4 × 10⁻⁴ | 4.3 × 10⁻⁵ | 5.6 × 10⁻⁴ | 1.7 × 10⁻⁴ | -4.7 × 10⁻⁴ |
| Ozone depletion (kg CFC-11-Eq) | 2.5 × 10⁻⁶ | 7.0 × 10⁻⁸ | 5.5 × 10⁻⁶ | 4.6 × 10⁻⁸ | 1.3 × 10⁻⁷ | -7.6 × 10⁻⁸ |
| Particulate matter formation (kg PM10-Eq) | 0.28 | 2.5 × 10⁻⁵ | 1.8 × 10⁻⁵ | 2.1 × 10⁻⁵ | 1.8 × 10⁻⁵ | -1.0 × 10⁻⁴ |
| Terrestrial acidification (kg NMVOC-Eq) | 0.21 | 6.7 × 10⁻⁵ | 2.8 × 10⁻⁵ | 7.5 × 10⁻⁴ | 4.8 × 10⁻³ | -5.7 × 10⁻³ |
| Terrestrial ecotoxicity (kg 1,4-DCB-Eq) | 0.14 | 8.9 × 10⁻⁵ | 1.3 × 10⁻⁴ | 2.1 × 10⁻³ | 1.1 × 10⁻⁴ | 4.5 × 10⁻⁴ |
is returned to the grid and any metal scrap recovered is recycled into new materials.

The LCA results of the ownership and rental scenarios per the functional unit of 600,000 child-years are illustrated in Fig. 3. Overall, in 14 out of 15 impact categories, the rental scenario had lower total environmental impacts compared to the business-as-usual scenario (ownership 1) where everyone owns a pram and disposes it when no longer needed. Ozone depletion was the only category where renting prams had a higher impact than all the ownership scenarios due to the transportation requirements of the heavy cleaning and maintenance process.

The scenario with the lowest impacts in all categories was ownership 3. This is because all prams manufactured were given a second life where the remaining child-years of the prams are fully used by others after the first child and only light cleaning was done. Therefore, the impacts of owning prams can be reduced by 25–50% when parents pass the used prams onto others when no longer needed.

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Fig. 2. Contribution analysis of (a) pram manufacturing and (b) heavy cleaning.
Fig. 3. Life cycle environmental impacts of pram ownership versus rental per functional unit.
Although the rental scenarios had lower impacts in pram production compared to the ownership scenarios, the heavy cleaning and maintenance impacts in the rental scenarios were higher. As shown in Fig. 3, the total impacts of the rental scenario in the categories of climate change, fossil depletion, metal depletion, and water depletion were greater than ownership 3 (100% 2nd life), but lower than ownership 2 (50% 2nd life). This same trend was observed in the impact categories of freshwater eutrophication, human toxicity, marine eutrophication, particulate matter formation, terrestrial acidification, and terrestrial ecotoxicity, which are presented in the graphs in the online Supplementary Information. This difference in impacts is noticeable in the categories of freshwater ecotoxicity, ionising radiation, marine ecotoxicity, and photochemical oxidant formation where the heavy cleaning and transport processes caused the total impacts of the rental scenarios to be higher than those of scenario ownership 2 (50% 2nd life). As previously mentioned, the transport requirements in the heavy cleaning stage caused ozone depletion of the rental scenario to be greater than the business-as-usual scenario (ownership 1). The rental scenarios had noticeable impacts from transport because the prams had to regularly be sent back to the shop by van for cleaning and maintenance, unlike the ownership scenarios where prams were cleaned at home. The impacts of heavy cleaning of rental prams were higher because electricity was consumed and heavy cleaning had greater material requirements compared to light cleaning. Electricity use, mainly from the drying process, had the highest contribution to the impacts of heavy cleaning in the categories of climate change, fossil depletion, metal depletion, freshwater eutrophication, human toxicity, ionising radiation, particulate matter formation, photochemical oxidant formation, and terrestrial acidification as shown in Fig. 2(b). Reducing the use of electricity-based processes would help lower the impacts of the heavy cleaning cycle. In the impacts to water depletion however, the use of wet wipes for heavy cleaning had the greatest contribution. This was

![Graph](image-url)

**Fig. 4.** LCA results with varying number of cleaning cycles per year.
unexpected as it was initially predicted that direct water use for washing would have a higher contribution. Instead, it was the production of the fibers for the wet wipes that had high water requirements.

The LCA results showed that the heavy cleaning and maintenance stage affected whether renting prams had a better environmental performance compared to the ownership scenarios. To analyze this, the life cycle environmental impacts in the categories of climate change, fossil depletion, metal depletion, and water depletion were projected over the number of times prams are cleaned each year, which are shown in Fig. 4(a) – (d).

For the dashed lines representing scenarios ownership 1, 2, and 3, although the total impacts appear to be constant in the graph, they are actually increasing at a very small rate as the number of light cleaning cycles per year increase. The impacts for the ownership scenarios are increasing at a rate that is barely noticeable in the graphs because the light cleaning cycles in the ownership scenarios had a very low contribution to the total impacts even when the number of light cleaning cycles per year increase. In the 4 impact categories presented in Fig. 4, the business-as-usual scenario (ownership 1) always starts off with higher impacts compared to the rental scenarios. The impacts of the rental scenario had a more noticeable change when the number of heavy cleaning cycles per year increase. At around 10 heavy cleaning cycles per year (once every 5 weeks), the rental scenario starts to have higher impacts to climate change than scenario ownership 1. In fossil depletion, around 11 heavy cleaning cycles per year (nearly once a month) is when the impacts of the rental scenario are higher than scenario ownership 1. For metal depletion, rental prams can go through heavy cleaning about 15 times per year (a little more than once a month) before they have impacts higher than scenario ownership 1. In water depletion, rental prams can be cleaned twice a month and the impacts would still be lower than scenario ownership 1. Rental pram companies would have to reduce the amount of clean-
ing cycles to 4–5 times a year (once every 3 months) to have a better environmental performance, compared to scenario ownership 2 where 50% of the prams are passed onto other users.

5. Discussion

5.1. Individuals: Renting versus owning a pram

Choosing the rental option can reduce the life cycle environmental impacts of prams under certain conditions. Users should rent prams if the alternative option is to own a pram and use it for only 3 years before it is sent for disposal. This was proven in the results where ownership 1 had greater impacts compared to the rental scenarios. When sending rental prams for heavy cleaning at the shop, it is recommended that users do this no more than once every 5 weeks (10 times per year). This ensures that the impacts of the rental prams do not exceed those of the business-as-usual case. If possible, sending the pram for heavy cleaning no more than once every 3 months (4 times per year) would further reduce the impacts of rental prams and ensure that the impacts do not exceed a case where half of all prams in the fleet are passed onto other children.

There will inevitably be users who choose to buy their own pram because they prefer to have full ownership, may have a stigma regarding the quality and reliability of second-hand products, or other reasons. If this is the case, pram owners can reduce their impacts by passing their prams onto another parent or a company that can refurbish it for use as a rental pram. The LCA results showed that the scenario where all ownership prams are passed onto other users that fully utilize the remaining useful life, would have the lowest impacts. Such a scenario however is unreal- istic because not every pram owner will be able to find a second-hand user. Pram owners may not know someone else who will accept the used prams. Also, pram owners may find it very tedious or time-consuming to bring the pram to a shop or person who will accept it. Parents with an interest in second-hand prams may be found in community-based networks at nursery schools, shared recreation facilities, or health service centers for children. However, these community-based networks are usually informal and do not necessarily provide a guaranteed demand for second-hand prams. As a result, pram owners may find it more convenient to dispose their prams after 3 years instead of securing a second-hand user. Therefore, if pram owners cannot guarantee that the pram they plan to purchase will be fully used for 6 years either by the original owner or multiple users, they should rent a pram to have a lower environmental impact.

5.2. Pram companies

Pram rental companies play an important role in reducing the environmental impacts of this product. They provide a guarantee that prams are fully utilized before they are disposed. Pram rental companies should have a fleet of prams that is greater than the number of customers they need to serve. From a business management perspective, this must be done to ensure there is a back-up supply of prams in case there are additional customers or some prams in the fleet must be temporarily taken out of circulation due to performance issues and need to be repaired or replaced. Having a fleet of rental prams that is larger than the demand does not increase the life cycle environmental impacts compared to the ownership model when providing the same level of service (child-years). This is only possible if after the rental prams have provided the required level of service, the remaining useful life of the rental prams are fully utilized by other customers in the future. It is only when rental prams are disposed earlier before the end of their useful life that the case of rental prams could have impacts greater than or equal to users who own prams and dispose them after 3 years.

Pram rental companies may face some challenges in pursing pathways to reduce their environmental impacts. The LCA results showed that heavy cleaning of rental prams can cause the impacts of rental prams to be greater than those of ownership prams. The direct way to address this would be to reduce the number of cleaning cycles done each year. This is ideal from an environmental standpoint, but may be impractical from a customer service standpoint. Unlike the prams owned by customers, pram rental companies have to ensure quality control of prams since there are multiple users. The heavy cleaning cycles are done to ensure that the rental prams are in good condition and can continuously serve multiple customers. Furthermore, based on interviews with pram rental company staff, the prams must be hygienically clean so that users of rental prams are not concerned about the spread of germs between different rental pram users. Another challenge that goes beyond the scope of this study because it applies to a different target customer group is that pram rental companies may operate their business with many short-term rentals. For example, there may be tourists visiting a city who rent a pram for a few days or weeks. If short-term rentals are in high demand, more heavy cleaning would be required because rental prams are returned and redistributed more frequently, which limits the ability of pram rental companies to reduce the number of cleaning cycles. Pram rental companies could consider doing different types of cleaning for certain conditions. Light cleaning where only water, cleaning agents, and open air drying is required could be done for rental prams that are returned in good condition. Heavy cleaning could be done for prams that are returned stained or damaged. However, doing light cleaning of rental prams in some cases, as opposed to heavy cleaning every time, could affect customer trust and the rental company’s reputation due to concerns about cleanliness.

5.3. Areas of uncertainty

The results of this LCA study are based on specific assumptions and scenarios tested. Therefore, there are several uncertainties that could affect the LCA results. One assumption made in the ownership scenarios was that each child uses a single pram for the first 3 years of life. This assumption was made based on a sample survey of pram customers in Singapore that revealed that a majority of the customers use only one pram per child. It is possible for a child to use more than one pram during its first 3 years of life. For example, a child could use a small pram during the first 6 months of life and then switch to a larger pram in the subsequent years. The choice of the number of prams to purchase per child is dependent on the choice of the parents which can vary in different contexts related to personal preferences, economic status, and cultural norms in different countries regarding the use of prams. Data regarding these preferences were not available in Singapore. However, it is expected that the life cycle environmental impacts of the ownership scenarios would increase if a child uses more than one pram and the prams are not from a second-hand source.

Another assumption made was that each pram has a usable life of 6 child-years in both the ownership and rental scenarios. It is possible that certain prams could have usable lifetimes that are longer than 6 child-years if the pram was designed with highly durable materials. With higher usable lifetimes, the number of prams required to be manufactured would decrease to provide the same amount of service defined by the functional unit. The usable lifetime of rental prams could also be lower than 6 child-years if they are mistreated through poor handling, which would increase the number of prams needed to be manufactured to provide the same level of service. This study assumed that the usable life of
rental prams would not degrade based on interviews with pram rental company staff members.

Finally, the heavy cleaning cycle modeled in this study was based on a process done by a specific company in Singapore. The amount of water, cleaning agents, and electricity required could vary depending on process carried out by other pram rental companies. It is possible for the inputs of the heavy cleaning cycle to increase in the short-term due to increased sanitary and hygienic concerns among customers that has been brought about by the recent coronavirus pandemic (Wired, 2020). The frequency of cleaning heavy cleaning cycles could also increase, which has already been examined in the analysis of varying the number of heavy cleaning cycles done each year for the rental prams.

Overall, the comparative LCA results will likely remain valid even if the conditions mentioned above were to change, although the absolute values of the impacts may change.

5.4. Implications for similar products

The existing LCA case studies of product/service-systems that were discussed in the literature review section have shown that it is often the case that the product-as-a-service business model has lower life cycle environmental impacts compared to the product ownership model. A few studies have shown environmental trade-offs between the two business models due to activities that occur during the use stage (Chun and Lee, 2017; Ding et al., 2019). The results for the rental prams in this LCA study showed a similar trend where the number of heavy cleaning cycles done each year affected the environmental performance of rental prams in comparison to the ownership business model. The rental business model of prams could be applied to other consumer products that have a long usable life, a single function, require few or no replaceable parts, and are used regularly for an expected period of time (e.g. several months or years). Products such as household tools (e.g. screwdrivers, hammers, ladders) and non-electrical exercise equipment could apply the rental business model and could have LCA results similar to those of rental prams in comparison to the traditional ownership business model. Other household products that can be provided on a rental basis are toaster ovens, blenders, and vacuum cleaners. However, the usable life of these products can easily be reduced due to a wide range of uses by different types of consumers. As a result, the product may need to be replaced more frequently to continue providing the rental service. Furthermore, the maintenance and repair process could be more frequent or require resources other than labor such as electricity, water, chemicals, and materials. Thus, products that are mature, highly durable, and have few to no replaceable parts are more likely to experience environmental benefits similar to those of prams when moving from an ownership business model to a product-as-a-service business model.

5.5. Policy recommendations

Policies at the national and regional levels have been initiated in recent years to promote activities that support a circular economy. Examples are the Circular Economy Action Plan that has been adopted in Europe (European Commission, 2020) and the Resource Sustainability Act that was passed in Singapore (Ministry of the Environment and Water Resources, 2019). Both policies have included electronics, packaging, and food as target waste streams. Such policies would benefit from identifying specific product groups that have high potential for circularity such as prams. This study looked at the potential for reducing the environmental impacts of prams for the entire country of Singapore. For these reductions to be achieved, policy intervention is needed from local government agencies. The main objectives of policies and programs should be to ensure that the life of prams is extended for as long as technically possible. A government agency could form partnerships with different pram rental companies. Through these partnerships, the government agency could help identify sources of used prams and connect their owners with pram rental companies. The pram rental companies would be responsible for working with the government to refurbish prams back to a good-as-new condition. This same government agency could be given the authority to certify second-hand prams. The government’s certification of refurbished prams could improve customer confidence in the quality of second-hand prams. Healthcare agencies and reputable parenting organizations could play a role in facilitating the circularity of prams. For example, hospitals could include rental pram options as a part of their childbirth service packages for mothers. Parenting organizations could promote the use of second-hand prams among new parents and become a channel for pram rental companies to access new customers. This stakeholder-based approach for designing policies and programs to promote circularity could be replicated for other product types similar to prams that have high potential for refurbishment and reuse.

6. Conclusions

This study aimed to answer the question of whether it is better for the environment to own or rent prams. A cradle-to-grave LCA was conducted to compare the life cycle environmental impacts of renting and owning a pram for all children born in Singapore within a period of 5 years. The results indicate that the life cycle environmental impacts of renting prams are 29–46% lower, depending on the impact category, than the current practice of purchasing a pram and disposing it after the first use. Parents who choose to own and use a pram for 3 years can reduce their environmental impacts by 50% if they are able to find another person to use the pram for the remaining 3 years. It is recommended that parents rent a pram if the alternative choice is to own a pram and dispose of it after only 3 years of use. The results of the LCA indicated that the number of heavy cleaning cycles done each year for rental prams affect whether they have higher or lower impacts compared to prams that are owned. Thus, it is essential that pram rental companies try to minimize the amount of heavy cleaning cycles to no more than once every 5 weeks to ensure that the life cycle environmental impacts of rental prams do not exceed those of the traditional ownership business model where the pram’s useful life is not extended to other users. Although this LCA was done in the context of Singapore, the findings can be applied to other countries that frequently use prams.

Around the world, prams are products that are widely used, durable, and have simple maintenance processes which give them high potential for circularity. Policy intervention is needed to guarantee that used prams are recovered, refurbished, and redistributed to users who demand them. Partnerships can be established between government agencies, community groups, and pram rental companies to develop programs that facilitate the use of second-hand prams so that they are used as long as possible before they are disposed. This study demonstrates how LCA can be used to evaluate circular product systems and target opportunities for improvement that can be addressed through technical solutions and policies and programs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
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Supplementary materials

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