Life Cycle Assessment

- A comparison of fossil energy use and climate impact on small scale manufacturing and large scale conventional manufacturing of textile toys

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Life Cycle Assessment - A comparison of fossil energy use and climate impact on small scale manufacturing and large scale conventional manufacturing of textile toys

Livscykelanalys - En jämförelse av användningen av fossila bränslen och klimatpåverkan mellan småskalig tillverkning och storskalig konventionell tillverkning av textilleksaker

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Abstract

This study conducts a Life Cycle Assessment to compare the environmental impacts, specifically climate impact and fossil fuel use, of textile toys produced in China and Sri Lanka. Through evaluating large-scale industrial production in China against small-scale, handcrafted production in Sri Lanka, it identifies the considerable environmental footprint of cotton production in both scenarios. The findings demonstrate that Sri Lanka's handcrafted production results in a significantly lower environmental impact, with a Global Warming Potential of nearly 15 CO_2-equivalents per kg, compared to over 21 CO_2-equivalents per kg for China's large-scale production. The study suggests that the reduced energy consumption and reliance on manual labor in Sri Lanka contribute to a lesser climate impact and decreased fossil fuel usage. These insights offer valuable guidance for APS Sweden, the project's end-user, to refine supply chain practices for enhanced sustainability. The study also highlights areas for future research, including a comprehensive "cradle-to-grave" analysis and deeper investigation into the supply chain and regional production differences, to further inform sustainable practices in the textile industry.

Executive Summary in English

This Life Cycle Assessment aims to evaluate the environmental impacts of textile toys manufactured in China and Sri Lanka, focusing on climate impact and fossil fuel use. The study employs a comparative analysis of large-scale production in China and small-scale, handcrafted production in Sri Lanka, utilizing GWP100 and fossil fuel consumption as key metrics. The LCA reveals that small-scale, handcrafted production in Sri Lanka results in a significantly lower environmental impact compared to large-scale industrial production in China. Specifically, the GWP100 of the product from Sri Lanka is nearly 15 CO_2-equivalents per kg, whereas it is over 21 CO_2-equivalents per kg for the product from China. Cotton production emerges as a significant contributor to both global warming potential and fossil fuel consumption in both manufacturing scenarios, underscoring the importance of sustainable agricultural practices. The reduced reliance on electricity and the emphasis on manual labor in Sri Lanka's production method are key factors contributing to its lower environmental footprint. The findings suggest that APS Sweden, the end user of this project, could benefit from adapting their import and handling practices to favor more sustainable production methods. Emphasizing the procurement of handcrafted textile toys from Sri Lanka could significantly reduce the environmental impact associated with their product offerings. The study recommends conducting a "cradle-to-grave" analysis to provide a more comprehensive understanding of the environmental impacts of textile toy production. Additionally, exploring the supply chain and regional differences in production practices could offer further insights into achieving sustainability in the textile industry. This LCA underscores the potential environmental benefits of selecting sustainable production methods and sources for textile toys. For APS Sweden and the broader textile industry, the study highlights the importance of integrating sustainability into supply chain practices to mitigate environmental impacts, particularly those associated with cotton production and energy consumption.

Exekutiv sammanfattning på svenska

Denna livscykelanalys syftar till att utvärdera de miljömässiga effekterna av textilleksaker tillverkade i Kina och Sri Lanka, med fokus på klimatpåverkan och användning av fossila bränslen. Studien använder en jämförande analys av storskalig produktion i Kina och småskalig, handgjord produktion i Sri Lanka, med användning av GWP100 och förbrukning av fossila bränslen som huvudsakliga mått. LCA visar att småskalig, handgjord produktion i Sri Lanka resulterar i en avsevärt lägre miljöpåverkan jämfört med storskalig industriell produktion i Kina. Specifikt är GWP100 för produkten från Sri Lanka nästan 15 CO_2-ekvivalenter per kg, medan den är över 21 CO_2-ekvivalenter per kg för produkten från Kina. Bomullsproduktion framträder som en betydande bidragsgivare till både global uppvärmningspotential och förbrukning av fossila bränslen i båda tillverkningsscenarierna, vilket understryker vikten av hållbara jordbruksmetoder. Den minskade beroendet av elektricitet och betoningen på manuellt arbete i Sri Lankas produktionsmetod är nyckelfaktorer som bidrar till dess lägre miljöavtryck. Resultaten tyder på att APS Sverige, slutanvändaren av detta projekt, skulle kunna dra nytta av att anpassa sina import- och hanteringspraxis för att prioritera mer hållbara produktionsmetoder. Att prioritera inköp av handgjorda textilleksaker från Sri Lanka skulle kunna minska den miljöpåverkan som är förknippad med deras produktutbud avsevärt. Studien rekommenderar att genomföra en "vagga-till-grav"-analys för att ge en mer omfattande förståelse för de miljömässiga effekterna av produktion av textilleksaker. Dessutom skulle utforskning av leveranskedjan och regionala skillnader i produktionspraxis kunna erbjuda ytterligare insikter för att uppnå hållbarhet inom textilindustrin. Denna LCA understryker de potentiella miljömässiga fördelarna med att välja hållbara produktionsmetoder och källor för textilleksaker. För APS Sverige och den bredare textilindustrin belyser studien vikten av att integrera hållbarhet i leveranskedjans praxis för att mildra miljöpåverkan, särskilt de som är förknippade med bomullsproduktion och energiförbrukning.

Abbreviation list

LCA - Life Cycle Assessment

APS Sweden - Anna Purna South Sweden

CO_2 - Carbon Dioxide

kWh - Kilowatt-hour

MJ - Mega Joule

GWP100 - Global Warming Potential over 100 years

IPCC - Intergovernmental Panel on Climate Change

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1 Introduction

1.1 Purpose of study

The purpose of this study is to identify and investigate the climate impacts and fossile fuel use of textile toys manufactured in China and Sri Lanka, in order to confirm and find ways to reduce their climate impact and energy use. This is achieved by conducting a Life Cycle Assessment on a specific textile toys from both countries. The product in China is produced on a large scale, whereas in Sri Lanka, it is made on a smaller scale with many of the production processes being hand made. By identifying the climate impact and energy usage from fossil fuels in the process, potential hot spots can then be pinpointed and imporvement options can be suggested.

The study is conducted at the request of APS Sweden, a Swedish company that imports textile toys from Sri Lanka to Örebro, where the products are then distributed to its buyers [6]. The reason for this LCA is to provide a basis and support for potential changes in APS Sweden's handling and import of the goods.

1.2 Background

Life Cycle Assessment is a methodology for assessing the environmental aspects and potential impacts associated with a service, process or product. This can encompass everything from the extraction and processing of raw materials, manufacturing, distribution, usage, reuse, maintenance, recycling and final disposal. By encasing the understanding of environmental consequences of human activity, it can help identifying opportunities to improve the environmental performance of products to inform decision-makers, and to reduce use and environmental emissions.[7]

Fossil fuels such as coal, natural gas and oil, have been the backbone of global energy production for decades. It has been an important factor for the development of technological, social and economic advancement. But fossil fuel come with many negative impacts on the environment. Their combustion releases CO_2, making them the primary contribution to global climate change. They also significantly contribute to local air pollution, which is linked to millions of premature deaths annually.[28]

Electricity is one of the three parts that forms the total energy production, the other two being transport and heating. Globally, coal is the predominant source of electricity, closely followed by gas. Among low-carbon sources, hydro power and nuclear are significant contributors, though wind and solar are rapidly expanding.[27]

The textile industry uses a high amount of energy in many of the stages in the production chain. Electricity and thermal energy are most common to be used. By optimizing and changing the energy sources for consumption throughout the production process, cost minimizing and a positive impact on the environment may come[2].

China is the global leader in coal electricity generation, contributing to 54% of the worldwide total. The country generates over 5300 terawatt hours of coal-fired power annually[29]. They are also one of the greatest country regarding textile production. In October 2023, China produced around 2,66 billion meters of clothing fabric, maintaining a consistent monthly production volume of nearly three billion meters over the past years. In 2022, China was responsible for approximately 43,6% of global textile exports.[24]

The textile industry is a crucial sector for Sri Lanka as well, as it accounts for about 44% of the total exports and 33% of the employments in the country. Sri Lanka has focused on adding value through product quality and manufacturing superior products rather than relying on cheap production costs. There textile market is witnessing a surge in demand for sustainable and ethically produced clothing.[3]

1.3 APS Sweden

As the world moves towards a more sustainable future, the focus shifts to low-carbon energy sources. When these alternatives becomes more accessible, a shift from fossil fuels is possible.[28] The company APS Sweden wants this LCA conducted to be able to shift their business to a more sustainable business throughout the production chain. They want the hot spots to enable knowledge in where the biggest impact is, and will use this as a benchmark for future business change towards more environmentally sustainable changes. Today APS Sweden focus their sustainability on social and environmental sustainability, but wants to advance in the environmental sustainability and cut their climate impact.

1.4 Study Goals

The study's goal is to evaluate and compare the climate impact and fossil fuel use when producing textile toys using two case studies, one in Sri Lanka, and another in China.

1.5 Objectives

- Assess and compare the climate impacts of the two products and identify related hot spots.
- Assess and compare the energy consumption of the two products and identify the related hot spot.
- Investigate and recommend potential fossil-free alternatives for a more sustainable production chain.

2 Material and Methods

2.1 Product Description

The study focuses on two products with the same material composition but sourced from different manufacturers. The materials of the both products are cotton as the outer fabric and polyester as filling inside the toy. Product 1, seen in Figure 1, is from Sri Lanka and is produced following Fair Trade practices, with many production steps being partly hand made. These include spinning, dyeing and sewing the textile toy [34]. Product 2, seen in Figure 2, originates from China, and is distributed by the company H&M [20]. The study adopts a "cradle to gate" approach, addressing a partial product life cycle due to data limitations in the use and end-of-life phases. Therefore, the system boundary encompasses material extraction, processing, production processes, energy consumption related to these stages, and transportation from the manufacturing country to Örebro, where the toys are being redistributed to its end-customer.

2.1.1 Product 1

Production country: Sri Lanka.
Weight: 0,042 kg.
Height: 25 cm.
Outer shell: 100% cotton.
Stuffing: 100% polyester.

Figure 1: Product picture for Product 1 [6].

2.1.2 Product 2

Production country: China.
Weight: 0,05 kg.
Height: 23 cm.
Outer shell: 100% cotton.
Stuffing: 100% polyester.

Figure 2: Product picture for Product 2 [20].

2.2 Flow Chart and System Boundaries

Figure 3 represents the flow chart and system boundaries of the two systems. The inputs of the system is raw material and energy as electricity and fossil fuel. The outputs are the textile toy and CO_2-equivalents. The colouring in Figure 3 indicates the specific process; shared process, process for Product 1, Product 2, or if they are out of scope. All the process steps inside the dashed line are included in the system, thus, user-phase and end-of-life phase are not considered in the study.

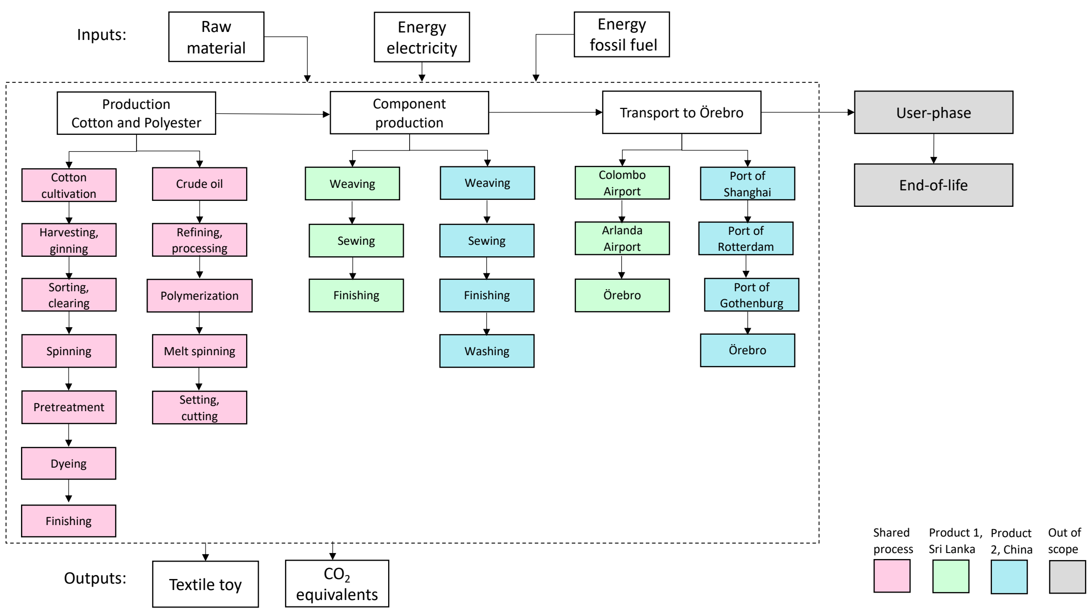

Figure 3: System boundary and process flow diagram for the production of the textile toys.

2.2.1 System Boundaries

This study's boundaries are constricted to the materials that the toys components consists of, as well as the production process to produce the toys. The transportation from the manufacturer to Örebro is in the system, but transportation from Örebro to costumer is not included. Örebro is where APS Sweden has there main office, and continuing to resell and distribute the products to there end buyer. Energy extraction of fossil fuels during production of materials, manufacturing, and transportation is also considered in the study.

2.3 Functional Unit

The functional unit of the study 1 kg textile toy arriving to Örebro, Sweden. This functional unit was used in the study by La Rosa and Grammatikos (2019). [31]

2.4 Assumptions and Limitations

Based on information from the company Selyn Textiles[34], which manufactures Product 1, 25% of the cotton fabric production is performed with electricity use. The same applies to the sewing of the textile toy. One assumption is therefor that 75% of the manufacturing process in for Product 1 are handcrafted, and the remaining is machine work that requires electricity. This only counts for Product 1. Approximately 55,5% of the electricity in Sri Lanka is made out of fossil fuels, and in majority made out of coal [5].

Furthermore, information from Selyn Textiles [34] indicated that 60% of Product 1 is made out of cotton, and 40% is made out of polyester, whitch can be seen in Table 1. The production of polyester and cotton does not include hand made production but is using electricity for production. This information was also obtained for Product 2, as it was difficult to find information about the content ratio for this product. Thus, the cotton content is 60% and the polyester content is 40% for both Product 1 and Product 2. This is shown in Table 1 and 2.

The sewing has been estimated to take one hour for one product, and it has been assumed to require 100kWh [23]. This is defined in Table 1 and Table 2.

Packaging the products is excluded for both products, as there was no available information on the packaging process for Product 2. It is uncertain whether this is done by hand or with electricity and therefor hard to determine. Product 1 is on the other hand certainly packaged by hand, but since no information could be found about Product 2, an assumption was made that Product 2 is also packaged without electricity.

To enable comparison of the climate impact and fossil fuel use between the products, they have been normalized by adding a factor. The factor has been calculated based on the weights of the different products (0,042 respectively 0,05 kg), and divided by the weight from the functional unit (1 kg). The factor for Product 1 was calculated to be 23.8, and the factor for Product 2 was calculated to 20. These factors are used in the calculations to make them comparable.

The equation for calculating the numbers of products per kg is $1/0,042 = 23,8$ for Product 1, and $1/0,05 = 20$ for Product 2.

To calculate the impact from the different processes included in the polyester production, the total impact was shared between the processes. The calculations were done based on Palacio-Mateo et al. (2021) [26]. Palacio-Mateo et al. (2021) suggest that approximately 10% of the impact will be generated from refinishing av processing of polyester, 50% is required for the polymerization, 30% from the melt spinning, and only 10% from setting and cutting. The polymerization step stands out as the most energy-consuming and therefore the one contributing the most to GWP100 and the fossil fuel use, while refinishing and processing and setting and cutting are assumed to have the lowest energy consumption and thus a lower contribution to the climate impact. The distribution of the polyester production can be seen in Table 3 and Table 4.

Data collection for specific regions like Sri Lanka and China was in some part of the inventory difficult to assess and could not be found in Ecoinvent. Due to this, Global data from Ecoinvent has been used for some parts of the productions before weighted with its factor. Global data is a measure that indicates an average value, and can therefore affect the precision of the results. [12] Thee broad perspective that it gives may not accurately reflect local manufacturing conditions, energy mix or environmental regulations. It might therefor reflect the study on its precision and lead to over- or underestimations on the climate impacts and fossil energy usage.

Transportation from production to Örebro is included in the LCA, however, the transport for the raw materials (cotton and polyester) to the factories is not considered, as the study focuses on the processes and transportation to Örebro, not from farming to factory. Because this is out of the company APS Sweden to influence. The cotton for both cases are produced in China, according to Selyn Exports [34].

2.5 Selection of Impact Categories

2.5.1 GWP100

GWP100 is is a metric defined by the Intergovernmental Panel on Climate Change, IPCC, to compare the impact of different greenhouse gases on global warming. GWP100 measures the amount of heat a gas traps in the atmosphere over a century, relative to CO_2. This comparison is essential for understanding and assessing the long-term climatic impacts of various greenhouse gases. [32] It is beneficial to use GWP100 in the study because it provides a standardized way to compare the long-term impact of different greenhouse gas emissions relative to CO_2. It helps in accurately assessing the potential climate change impacts of the products and is essential for making informed decisions and strategies for reducing greenhouse gas emissions. GWP100 is assessed in the metric grams of CO_2-equivalents, and referred in the report as CO_2-eq [30].

2.5.2 Energy use - Fossil Fuel

The use of fossil fuels is estimated to gain an understanding of the impact related to fossil fuel used through the process. The study aims to find hot spots in the process, and because high use of fossil fuels relate to high CO_2 emissions, it is an important factor to consider in the study. Fossil energy is used in the transport sector as transportation fuel, but is also used in the production of the materials and in the production of the textile toys. The energy mix in the electricity includes a lot of fossil fuel for both China and Sri Lanka. In 2021, 66% of the electricity in China originated from fossil fuels[4]. The use of coal is the by far biggest in the share with 63% of the total mix [4]. Sri Lanka had a total use of fossil fuel in there electricity of 50,5%.[5]. And the use of oil was the biggest use, with about 34%. The amount of fossil fuel is in the study is described in mega joule and is in the text referred as MJ.

3 Life Cycle Inventory (LCI)

3.1 Data collection

Table 1: Input-Output data for Product 1.

Product 1			
Input:	**Amount:**	**Unit:**	**Remarks:**
Cotton	0,6 [34]	kg	60% cotton
Polyester	0,4 [34]	kg	40% polyester
Energy - electricity	2380 [23]	kWh	Sewing 1h, 1kg product
Energy - fossil fuel	168,1 [11]	MJ	Manufacturing and transportation 1 kg product
Output:			
Textile toy	1 [31]	kg	
CO_2-eq.	15 [11]	kg	

Table 2: Input-Output data for Product 2.

Product 2			
Input:	**Amount:**	**Unit:**	**Remarks:**
Cotton	0,6 [34]	kg	60% cotton
Polyester	0,4 [34]	kg	40% polyester
Energy - electricity	2000 [23]	kWh	Sewing 1h, 1kg product
Energy - fossil fuel	206,5 [11]	MJ	Manufacturing and transportation 1 kg product
Output:			
Textile toy	1 [31]	kg	
CO_2-eq.	21 [11]	kg	

3.1.1 Inventory data collection

The inventory data was mainly collected from Ecoinvent, a comprehensive database that contains life cycle inventory data. Ecoinvent includes data on material and energy flows, covering raw material extraction and manufacturing processes. The database is carefully complied and standardized to ensure high quality, comparability and updated with the latest research findings and industry data. The Ecoinvent database, which is updated annually, presently households more than 20,000 dependable life cycle inventory datasets, incorporating both new and revised data along with technical enhancements. [11]
The dataset Global in Ecoinvent was used when specific data for China respectively Sri Lanka has not been provided in Ecoinvent. The Global dataset represent and reflect an average global condition based in international data. [12]
Via direct contact with Selyn, the company that produces Product 1, information has been gathered about which processes are hand made, and which require electricity. This affects the production stage of the process, and not the transportation part.
Data for transportation was collected at NTMCalc [33]. The data that was collected include the use of fossil fuels and also the CO_2 equivalent emissions.

4 Results and Discussion

4.1 Impact Assessment Result

Table 3 and Table 4 present the impact assessment for GWP100 and for Energy use of fossil fuels. The tables presents the GWP100 for cotton production, polyester production, the process to finish the textile toy, and the transportation.

Table 3: Global Warming Potential per Functional Unit

Cotton production kg CO_2-eq.	Product 1	Product 2
Cotton cultivation	0,78 [16]	0,78 [16]
Harvesting and ginning	3,72 [14]	3,72 [14]
Spinning	0,82 [19]	3,29 [19]
Dyeing	0,55 [13]	2,19 [13]
Weaving	1,68 [18]	6,84 [18]

Polyester production kg CO_2-eq.	Product 1	Product 2
Refinishing and processing	0,22 [17]	0,22 [17]
Polymerization	1,12 [17]	1,12 [17]
Melt spinning	0,67 [17]	0,67 [17]
Setting and cutting	0,22 [17]	0,22 [17]

Toy production kg CO_2-eq.	Product 1	Product 2
Sewing	0,2 [25]	1,2 [25]
Washing	-	0,63 [15]

Transport kg CO_2-eq.	Product 1	Product 2
Freight aircraft	4,894 [33]	-
Sea transport	-	0,111 [33]
Truck with trailer	0,017 [33]	0,125 [33]

	Product 1	Product 2
Total kg CO_2-eq.	14,98	21,12
Total per product kg CO_2-eq.(factor included)	0,63	1,06

Table 4: Energy Consumption - Fossil Fuel per Functional Unit

Cotton production MJ Energy/kg	Product 1	Product 2
Cotton cultivation	5,63 [16]	5,63 [16]
Harvesting and ginning	15,66 [14]	15,66 [14]
Spinning	6,15 [19]	24,61 [19]
Dyeing	6,30 [13]	25,19 [13]
Weaving	15,18 [18]	60,66 [18]

Polyester production MJ Energy/kg	Product 1	Product 2
Refinishing and processing	3,91 [17]	3,91 [17]
Polymerization	19,56 [17]	19,56 [17]
Melt spinning	11,74 [17]	11,74 [17]
Setting and cutting	3,91 [17]	3,91 [17]

Toy production MJ Energy/kg	Product 1	Product 2
Sewing	4,5 [25]	20,2 [25]
Washing	-	7,27 [15]

Transport MJ Energy/kg	Product 1	Product 2
Freight aircraft	70,139 [33]	-
Sea transport	-	1,423 [33]
Truck with trailer	0,213 [33]	1,534 [33]

	Product 1	Product 2
Total MJ Energy	168,10	206,50
Total per product MJ Energy/kg (factor included)	7,06	10,36

4.2 Interpretation and Analysis of Results

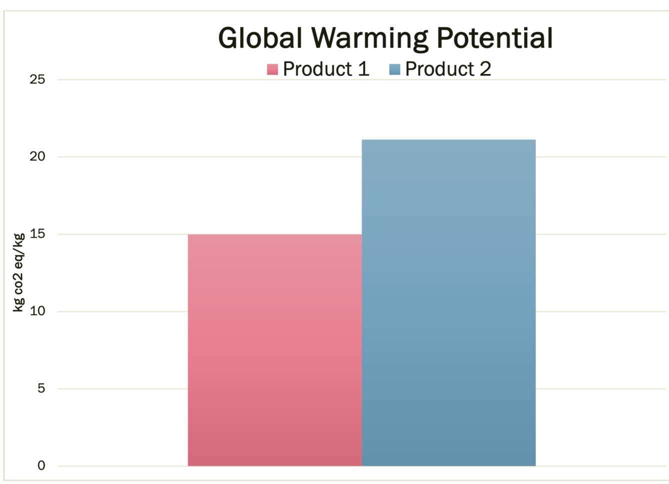

Figure 4: Total CO_2 equivalent emissions per kilo gram for Product 1 and Product 2.

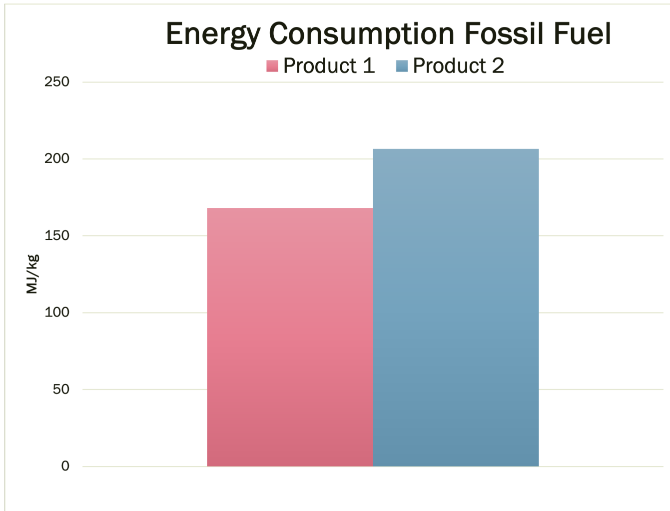

Figure 5: Total fossil fuel consumption per kilo gram for Product 1 and product 2.

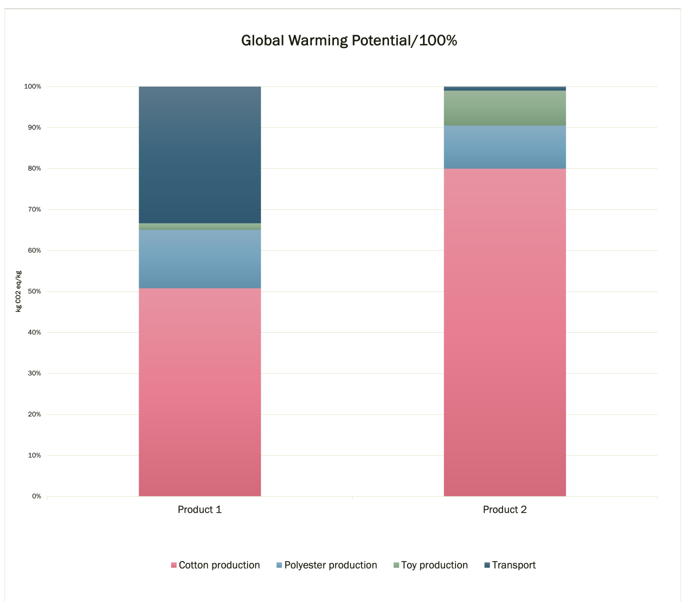

Figure 6: Global Warming Potential in kg CO_2-eq/kg product. The results are presented in percentage format in order to compare the impact of each part of the process directly.

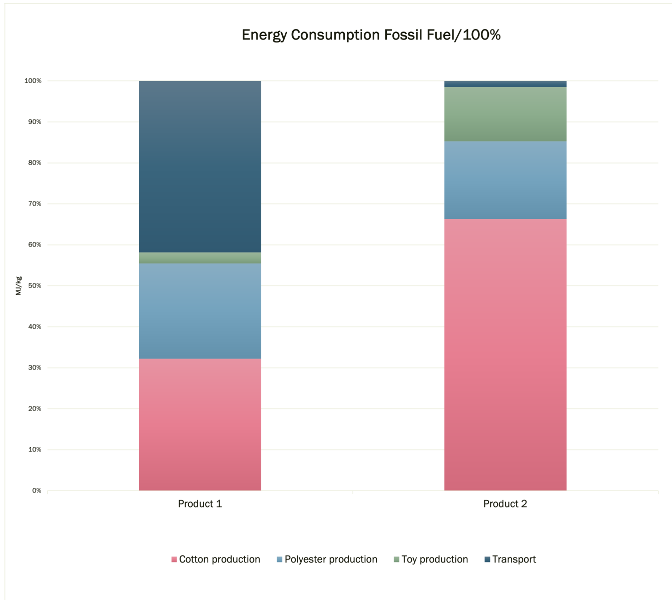

Figure 7: Energy consumption of fossil fuels in MJ/kg product. The results are presented in percentage format in order to compare the impact of each part of the process directly.

Figure 4 show the result of higher global warming potential for Product 2 than for Product 1. The impact is about $\frac{2}{5}$ higher for Product 2, indicating a larger contribution to global warming with 40%. The same pattern follows in Figure 5, where the use of fossil fuel is about 23% larger for Product 2 than for Product 1.
When examining the contribution for different production processes, its clear that the cotton production contribute a lot to the global warming potential as well as the use of fossil fuels in the process. In Figure 6, it is shown that approximately 50% of the total global warming potential in Product 1 is caused by the cotton production, and for Product 2, this stand for 80% of the total contribution, making it a huge impact on the total process. In Figure 7, about 60% of the fossil fuel use comes from the transportation for Product 1. And both polyester production and cotton production is a big contributor of fossil fuel use. In Figure 5 where the fossil fuel for Product 2 is shown, about 65% of the total fossil fuel use impact comes from the cotton production. But for Product 1, there is a bigger impact from the transport with about 60% and the cotton production stands for about 30% of the total impact. Notable is also that the polyester production contribute a lot to the fossil fuel use for Product 1.

4.3 Discussion

Figure 6 shows cotton production as the main source of emissions for both Product 1 and Product 2, indicating the energy-intensive process of cotton production. This is particularly true for Product 2, where a large portion of energy is fossil fuel-based. The heavy reliance on fossil fuels in China and Sri Lanka elevates this impact, but Product 1's handcrafted production reduces its overall effect. Changing the energy mix used in production and include more renewable sources could significantly reduce climate impacts and fossil energy usage. According to Baydar et al. (2014) [1], the climate impact from a GWP100 perspective has its largest influence in the user phase. However, the second largest impact is the cotton production, more specific the cultivation and harvesting, wet processing and yarn manufacturing. The research of the article is on a t-shirt and comparing the climate impact on an eco t-shirt and a non-eco t-shirt. When comparing the result from the article to this study, there are similarities when it comes to the biggest contributors to the GWP100 impacts. In the result of this study, harvesting and ginning has the largest impact on GWP100 for Product 1, followed by weaving, that is the biggest contributor for product 2,

and then comes spinning and cotton cultivation. However, in fossil fuel use, most of the impact comes from harvesting and ginning and weaving for Product 1, but clearly most from weaving for Product 2. This makes the hot spots clear from the production of cotton, and can be used to change the process to decrease the impact.
China is one of the world's largest cotton producers, and the energy footprint related to cotton cultivation is significant. The most demanding parts of cotton cultivation include the techniques that are used to improve the maximization of the production.[21] The adaption to mechanised cotton cultivation, such as mechanised tillage, sowing and harvesting, has lead to an increased use of fossil fuels and electricity, but has also lead to an improved efficiency and reduction of labor dependency [10]. The demanding agricultural methods required for the extensive cotton production in China present challenges to sustainability, notably in terms of energy usage. Initiatives to mitigate soil contamination, streamline agricultural management, and enhance the use of machinery target not just the enhancement of productivity but also aim to lower energy consumption and the ecological footprint associated with cotton farming. There is potential for improving energy efficiency in China's cotton production through the adoption of more sustainable farming practices, such as the development and use of more energy-efficient farming machinery. According to Feng (2022) [9] the improvement of energy efficiency in China's cotton production can be achieved through the adoption of more sustainable farming implementation. For example, a precision seeding technology can save up to 60% of the seeds, and increase the cotton yield by 5-10%. And the development of under-mulching drip irrigation has become a popular water-saving irrigation system in some part of China. These systems combine drip irrigation with plastic mulching and allows for the simultaneous application of water and fertilizer directly to the cotton root zone, maintaining appropriate moisture and soil fertility. These improvements might be hart for APS Sweden to control and correct, but to investigate in what type cotton cultivation and harvesting methods the farmers or their specific production are using, might be an opportunity to influence the producer in Sri Lanka to consider a more sustainable cotton production.
Figures 6 and Figure 7 reveal that the transport of Product 1 significantly impacts environmental factors. This is due to the aircraft freight connected to its transport from Sri Lanka to Sweden. When comparing climate impact of air freight versus ocean freight, there is a notable reduction in carbon footprint when choosing ocean transport over air transport. Air freight emits substantially more CO_2 per metric ton of freight per kilometer than ocean transport. [22]. However, the high sulfur content of bunker fuel used by ships and technological advancements that could reduce emissions makes it a more complex matter. For APS Sweden, it might be considerable to change the air freight to ocean and truck. The downside is that the freight changes the time perspective of the shipment with about an additional month to get the goods from Sri Lanka to Örebro. [8].
Despite Product 1's higher transport impact, its overall environmental footprint is smaller than for Product 2. This is partly due to the manual, handcrafted processes. This suggests a potential benefit in reducing energy consumption in the production phase. But implementing a higher amount of hand crafted processes for Product 2 may not seem very realistic, as a large scale production often is associated with high focus on efficiency and mass production. Unlike Product 1, which adheres to Fair Trade standards ensuring good working conditions, applying manual labor to Product 2 might not guarantee similar standards and could worsen working conditions. A broader approach, considering both products are made in countries with high fossil fuel usage, would be to integrate a higher amount of fossil-free energy in the process. For example, the factories could use solar panels to reduce reliance on coal and oil, or adopt to more energy-efficient technology to lower electricity use.

4.4 Future Research Directions

For future research a comprehensive "cradle-to-grave" LCA would be beneficial to understand the full life-cycle impacts of these products. This study doesn't address product durability, so examining if the partly handcrafted Product 1, offers greater sustainability because of greater quality in the making, would be insightful. This could reveal more about the differences or similarities between the two products, and include impact of washing and maintenance. This would be interesting for further research due to the author Baydar et al. (2014) [1] that argues that the largest impact on the environment as GWP100 originates from the user phase of a textile product, in this case a textile t-shirt. This makes it interesting to try to capture the user phase of the textile toys, and study the differences between these two products then the whole life-cycle is considered.

Future research could also delve deeper into the supply chain, focusing on the extraction of raw materials to better understand the upstream impacts. Another interesting avenue would be to compare Product 1 with a similar products made under similar conditions but in a different region. This comparison could reveal how variations in transport distances and energy sources affect climate impacts and consumption of fossil energy.

5 Conclusions

This LCA study provided significant insights on fossil energy use and climate impacts associated to the production of textile toys in China and Sri Lanka. Through a detailed analysis encompassing global warming potential and energy usage from fossil fuels, the study identified significant differences in the environmental footprints of large-scale production in China compared to small-scale, hand made production in Sri Lanka.

The findings reveal that the production in Sri Lanka, characterized by its handcrafted methods, results in a notably lower environmental impact compared to the industrialised, large-scale production processes in China. Specifically, the reduced electricity consumption and reliance on manual labor in Sri Lanka contribute to a lesser climate impact and decreased fossil fuel usage. The significant role of cotton production in both countries underscores the need for sustainable agricultural practices to mitigate the overall environmental footprint.

For APS Sweden, the end user of this project, these insights offer a valuable perspective on improving their supply chain towards more sustainable practices. Emphasising the importance of selecting production methods and sources that align with environmental sustainability goals can not only reduce the carbon footprint but also enhance the company's reputation for responsible manufacturing.

Future research directions suggested include a "cradle-to-grave" analysis to cover the entire life cycle of the products, further exploring the supply chain, and investigating regional differences in production practices. Such studies could provide deeper insights into achieving sustainability in the textile industry, emphasizing the need for a shift towards renewable energy sources and more efficient use of resources.

In conclusion, this LCA underscores the potential for significant environmental benefits through careful selection of manufacturing processes and sources. It highlights the importance of integrating sustainability into the core of business practices, not just for APS Sweden but for the broader textile industry aiming to mitigate its environmental impact.

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