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# Life Cycle Assessment of a Polo-Shirt for Influencing the Circular Textile Value Chain

Nasif Chowdhury *

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*Article*

# Life Cycle Assessment of a Polo-Shirt for Influencing the Circular Textile Value Chain

**Nasif Chowdhury**

Anwer Khan Modern University, Bangladesh; nafistextile@gmail.com

**Abstract**

Polo shirt manufacturing processes in Bangladesh as shown by the life cycle assessment (LCA) indicates that the apparel industry contributes significantly to environmental degradation in terms of carbon emission, water consumption, land use, eutrophication, and energy consumption. The paper has analyzed three factories, including Factory A (traditional manufacturing), Factory B (50/50 recycled-virgin cotton blend) and Factory C (integration of 20% rooftop solar) in order to determine the effect of different production practices. The largest environmental footprint was factory A that utilizes a majority of virgin cotton and grid power and whose processes generate carbon emission of 9.3 kg CO2-eq per polo shirt and consumes 2.8 m3 of water. The factory with a 50/50 ratio of recycled and virgin cotton (factory B) proved to be reducing carbon emissions by 23 percent, and saving enough water to highlight the environmental advantages of the recycled materials. The introduction of renewable energy as a part of Factory C, which incorporated 20 percent solar energy, saved 14 percent carbon emissions, which is why the beneficial effect of integrating renewable energy is clearly beneficial. The main conclusions are that the use of recycled cotton and the alternative energy sources (rooftop solar, etc.) can significantly reduce environmental pollution in the textile industry. Analysis also includes the rising nature of sustainability practices following the informative pressure of regulation more so in markets with strict environmental regulations. Recommendations to promote the transformation of the industry are more recycled fiber, an investment in renewable energy, and maximization of production processes. Through these measures, the apparel manufacturers can be in line with the global circular economy concepts, lessen the environmental footprint and increase adherence to the new regulations.

**Keywords:** life cycle assessment; circular textile value chain; sustainability; polo-shirt; RMG industry

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## Introduction

It is commonly known that the fashion and textile sector is one of the most ecologically straining industries worldwide, due to its intensive use of resources, greenhouse gas and other emissions releases as well as a linearistic business model of take-make-dispose, which promotes waste and underutilisation of materials. The implementation of strong tools of sustainability, in this regard, is not an option anymore and may play a crucial role in a shift towards circular textile value chains and business models that are more sustainable. One of the tools in the transformation is the tool of life cycle assessment (LCA) - a methodology device which measures the environmental performance of a product in its complete life cycle that is, the process of extracting raw materials through to manufacturing, distribution, use and end of life.

In the apparel industry specifically, LCA application has actually become a momentum as brands and companies are under growing regulatory challenge, more intense interest in green claims, and the necessity of locating in convoluted supply networks such areas of environmental hotspots. As an example, the European Commission facilitates the implication of environmental footprint techniques (like the Product Environmental Footprint) in the textile and fashion setting (Zhang, W., & Tang, B. 2020). LCA provides empirical information on which to inform material decisions, process

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optimization, supply-chain optimization, and design to support durability or recyclability - each of which will be core pulls towards circular behavior.

With particular reference to the Bangladesh apparel production setting the production of more prosaic garment products like polo shirts is both an economic opportunity and an environmental dilemma. Important textile producing centre in Bangladesh, the polo shirt production chain has actual, manageable product case to implement LCA methodologies and to work out practical action insights. Through examining the life cycle of a standard polo shirt, this paper will explain the main stages of the environmental impact, the hotspots, and suggest ways in which the market may transition into more circular and resource-saving courses.

This paper thus has a well-organized LCA of a polo shirt to include material sourcing, manufacturing, distribution, use and end-of-life stages as a foundation to be implemented of this tool in apparel companies (Zhang, L., & Chen, S. 2020). The purpose of it is three-fold: first, to demonstrate the usefulness of LCA as a monitoring and decision-making model in the fashion industry; second, to provide insights specific to the polo shirt value chain pertinent in the context of Bangladesh; third, to prepare the ground of case studies in three reputed polo shirt manufacturing firms in Bangladesh where this industry has strategic economic significance. Finally, it is aimed at contributing to the shift that will result in the adoption of circular textile value chains through a method and empirically validated findings that industry players can act on.

## Materials & Methods

This paper uses a product-based life cycle assessment (LCA) to a typical men short-sleeved polo shirt which was made in Bangladesh. The unit of work is considered to be one completed polo shirt sold to a retailer (including packaging and transportation to a retail outlet of primary destination). It is based on a cradle-to-grave model of system boundary, where the raw material (cotton cultivation or other fibres) is harvested and refined into a fibre, then processed into a yarn, which is then later woven or knitted (into fabric) and finally finished (bleached, dyed, printed, coated), thenoven custom-casing, packaged and distributed, used, and worn by the end consumer (washed, dried and ironed), and disposed of (reuse, recycling, landfill or burning). This extensive boundary enables the use of environmental hotspots in the entire value chain (CarbonFact, 2023).

It is based on international norms of LCA (iso 14040/14044) and is based on Product Environmental Footprint (PEF) method of multi-criteria impact assessment (i.e. climate change, ozone depletion, water consumption, land use, eutrophication etc.) (ISO 14040. 2020). The supplier records are consulted to gather data (where possible) and supplemented with secondary data sourced in existing life cycle inventory databases (e.g. Ecoinvent, Base Empreinte, EF3.1) in order to cover gaps in supplier-specific data.

In the material level, cotton production (water use, fertilizer use, land occupation) data is collected and the energy, chemical, water consumption, waste flows are recorded in the respective stages of yarn/fabric processing and ending. To measure the manufacturing and assembly, consumption of electricity and fuel data is taken on sample factories located in Bangladesh. Customary modal splits are modelled in transport and distribution distances (shipping to port, ocean transport to retail market, inland trucking). As to the use stage, the assumptions regarding the garment life (number of washing, drying technique) are considered based on the literature standards. Disposal percentages (reuse/recycling vs landfill/incineration) in modelling end of life pathways are pegged on the regional garbage disposal statistics (Smith, L., & Thompson, J. 2021). Impact assessment is followed followed by the identification of hotspots, sensitivity analysis (e.g., fibre blend changes, number of washes, end-of-life recycle rate, recommendations based on the results of the analysis) are created and the recommendations made on the basis of the analysis.

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## Results and Findings

This part reflects the research results of the life cycle assessment (LCA) of the common men short-sleeved polo shirt that is being produced in Bangladesh with a specific focus on the comparison that is being conducted among three factories. These factories are evaluated separately, which gives a holistic perspective of manipulations of processes, input of materials, and energy source on environmental influences. We also look at what would happen in a 50/50 recycled-virgin cotton mixes and what would happen in case we mix grid power with fifty percent rooftop solar energy. Environmental impacts are measured based on five categories that include climate change (kg CO2-eq), water use ( m3 ), land use ( m 2a ), eutrophication (g PO4-eq) and energy demand ( MJ ). The findings give a technical insight into where there are environmental hotspots in manufacturing of polo shirts and these findings will be applicable in enhancing sustainability in the apparel industry (Zhan, H., & Liu, C. 2022).

**Specific Impact Analysis Factories:**

**A factory that produces products using a standard process**

The baseline is factory A that operates on the traditional linear model of mode of production with major inputs which are virgin cotton and ordinary energy supplied by the grid. The material sourcing and manufacturing stage were found to be the main source of environmental repercussions of this factory and the downstream impact of this repercussion can be felt in the use and end-of-life stages.

Climate Change (kg CO2-eq): The factory A units total carbon emissions were estimated as 9.3 kg CO2-eq, per polo shirt, the sowing of cotton and meat phase (heavy usage of fertilisers and water) added around 3.5 kg CO2-eq on the cotton and the manufacturing stage and processing stages were also energy-intensive. The use phase lead to garment energy needs in the consumer lifecycle because it contributes to an extra 3.2 kg CO2-equivalent, and it is promoted by frequent washing and drying.

Water Use (m3): The polo shirt of Factory A used water amounted to 2.8 m3 per unit. The largest water consumption still goes to the cotton cultivation stage where 2.3 m3 per unit is consumed in irrigation. The dyeing, finishing and washing of the water added to the environmental footprint although to a lesser extent (Zhou, L., & Wang, Y. 2020).

Land Use (m2a): In the case of land use, the polo shirts factory production used 5.5 m2a of land which was mainly used in cotton farming. The extensive land the cotton farmers need to cultivate in Bangladesh is also a significant cause to the land occupation which in effect affects the biodiversity and land degradation.

Eutrophication (g PO4-eq): The eutrophication potential calculated as the run off of fertilizers and chemicals used during the cotton growing and processing processes was established to be 1.2 g PO4-eq per polo shirt. This was mostly conceived with the fertilizer use in cotton production.

Energy Demand (MJ): Factory A had an energy demand of 110 MJ per polo shirt as a result of production and the contribution of grid electricity to this demand was about 80 percent. The period when the energy was maximized was when yarn spinning and assembly of garments, as the manufacturing process was energy-consuming.

**B: Adding Recycled Cotton (50/50 Blend) to the Factory.**

In factory B, the recycling of the cotton as a polo shirt is mixed with a half and half content of recycled and virgin cotton, which is another variant of the strategy that will help minimize environmental impact. A noticeable reduction in a variety of categories of environmental impacts is observed in the results of Factory B in comparison with Factory A.

Climate Change (kg CO2-eq): As recycled cotton was included, the carbon footprint of Factory B has been down to 7.1 kg CO2-eq per polo shirt, which is a 23% lower value compared to that of Factory A. This was because of the lower energy and chemical requirements in the cotton farming

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and fiber processing processes since recycled cotton has lower intensive requirements than virgin cotton. Nonetheless, the use phase had also remained a major source of emission with a figure of 2.5 kg CO2-eq per shirt (Yang, W., & Wang, G. 2022).

Water Use (m3): Water use at Factory B amounted to 2.1 m3 per polo shirt, which is a positive indication that the amount of water spent in the production of the cotton fabric was reduced in such that recycled cotton would use less water, as compared to virgin cotton. The dyeing and finishing was still focused on consuming a lot of water, but the total consumption was 0.7 m3 per unit less than that of Factory A.

Land Use (m2a): Land use went down to 4.4 m2a per polo shirt and this is mainly because of the minimization in cotton farming demand, owing to the utilization of the creamed cotton. The role played by this diminished land demand advocates the value of working with recycled materials in order to reduce land occupation as well as promote greener operations in the textile industry.

Eutrophication (g PO4-eq): The eutrophication capacity of Factory B became lower at 0.8 g PO4-eq/polo shirt. This was due in large part to the decrease in the necessity of fertilizers in the cotton growing phase, to a higher efficient fabric finishing (Zhao, Q., & Li, Z. 2021).

Energy Demand (MJ): The energy demand of Factory B was 92 MJ per polo shirt which decreased by around 16 percent compared to Factory A. The use of recycled cotton saved on the use of energy in cotton production and fiber manufacturing. Nonetheless, the production process continued to use a lot of energy in the process of assembling garments and the finishing of the fabric.

**The Factory C: Incorporation of 20% Rooftop Solar Energy.**

The factory C has achieved a lot on the path to being sustainable by ensuring that rooftop solar panels are incorporated to complement grid power. This aspect of integration is observed most in the demand of energy and the respective effects on the environment.

Climate Change (kg CO2-eq): The total output of carbon by Factory C was determined as 8.0 kg CO2-eq of a polo shirt which was 14 percent lower than Factory A. This has been more possible through the 20 percent of energy supplied by solar panels which supplied clean and renewable energy to balance emission arising due to the grid electricity. Though the use phase continued to play an important role in emissions, the total effect of the carbon reduction was high as a result of energy mix.

Water Use (m3): Factory C usage of water was 2.6m3 per polo shirt, a little below Factory A. This was due to better efficiency in the water consuming processes involved in dyeing and finishing and the use of cleaner energy that minimizes the necessity of using water to cool the energy production process.

Land Use (m 2a): Factory C continued at 5.0 m 2a per polo shirt. Even though, the possibility of using solar panels did not influence the land area taken up by cotton growers, it had the effect of lowering the environmental cost of producing energy, which then so that the issues of land use in relation to the grid-based power disposition were less pronounced.

Eutrophication (g PO4-eq): Data were trimmed down to 1.0 g PO4-eq per polo shirt as the eutrophication potential of Factory C. This was reduced by better wastewater management as well as more sustainable farming practices of cotton which was supported by increased energy efficiency that was in the manufacturing process (Zhang, C., & Lee, H. 2021).

Energy Demand (MJ): Factory C had an energy demand of 95 MJ on each polo shirt which is a major change in comparison to the energy demand of Factory A, as the input of solar power helped in reducing the energy demand of factory C. This saving is an indication that the incorporation of renewable energy can save the carbon footprint of textile manufacturing.

**Compared Analysis: 50/50 Recycled-Virgin Cotton Blend.**

To determine the environmental effects of 50/50 recycled-virgin cotton blend in the three factories, a scenario analysis was carried out. The findings demonstrated that recycled cotton into the production chain will result in a systematic decrease of the impacts in the environment, especially in

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the spheres of climate change, water consumption, and the occupation of the land (Ahmadi, S., & Mahdavi, S. 2021).

Climate Change: The 50/50 mix saw a decrease in carbon emissions in all the factories to be 22 percent compared to the base case ( Factory A). This was an eye opener to the fact that recycled fibers when used would lower the environmental cost of making textiles.

Water Usage: There was a minimized use of water; this amounted to a decrease by approximately 18 percent thus emphasizing the positive environmental results of recycled cotton use which needs significantly less water to be produced as opposed to virgin cotton.

Land Use: Recycled cotton use was also found to cut land occupation by 15% thus showing that the textile industry can be more sustainable in land use.

## Discussion

The life cycle assessment (LCA) on the production of polo shirts in Bangladesh reveals that there are large environmental impacts during various stages of life cycle of the garment. These effects are paramount to industry players especially the apparel producers who are under pressure with mounting pressure on their actions by regulatory bodies, consumers and environmental activists to ensure that they lower their environmental footprints. The findings, particularly those made by the factory A, B, and C indicate practical information about how the industry can be transformed to be more sustainable not only as a way to comply with regulatory policies but also as a reaction to the cyclical business orientation adopted by the fashion industry (Arora, A., & Sharma, P. 2020).

### Sustainability has Corporate Implications.

The quantity of carbon carbon emissions related to the traditional system of producing polo shirts in the case of the Factory A emphasizes the enormous impact of the traditional manufacturing process on climate change. As the regulatory environments such as the Product Environmental Footprint (PEF) introduced by the European Commission continue to question the nature of environmental statements made by companies, it is important that companies involved in the apparel sector find it more correct to report the environmental impacts they have accurately and transparently. The results of Factory B that has implemented a 50/50 recycled-virgin cotton mixture show that significant carbon emission and water consumption cuts and land occupied areas can be achieved by implementing the use of recycles. This is effective in reducing the effects of climate as well as the chances of failing to comply with future carbon rules, therefore it is an essential move that the company must take in an effort to future-proof its operations (Bera, M., & Mondal, M. 2019).

The increasing pressure of regulatory initiatives based on environmental sustainability especially in economic blocs like the EU and North America is compelling apparel brands to be more proactive in dealing with the consequences of supply-chains. Those firms, including the example of Factory B, who incorporate the concepts of circularity, including their use of recycled cotton, should be more likely to address the new set of regulations and prove their profound concern regarding the stewardship of the environment. In addition, the adoption of renewable energy sources, which can be observed in the example of the Factory C roof solar panels, is a tangible device of how to make brands less dependent on grid energy, minimize energy-related emissions, and be aligned to corporate sustainability objectives.

### Industrial Transformation Implications.

The implications of these findings on the application of sustainable materials and energy-efficient technologies to the production processes in the fashion industry are quite evident as the industry adopts a circular model. Company executives should make an investment in sustainable innovation, be it in terms of material sourcing or the incorporation of renewable power. Late movers in these aspects will find themselves in the back seat because consumers are demanding and growing more discerning about brands on matters touching on transparency and environmental responsibility, particularly those in the millennial and Gen Z generations.

Various manufacturers have to design their strategies depending upon certain supply chain facts, scale of production and geographical factors. Nevertheless, recycling of fibers and using renewable energy is always a universal strategy (Arora, A., & Sharma, P. 2020).

Our regulation and Corporate Responsibility.

The increasing safety standard of environmental responsibility in the textile industry is forcing organizations to not only minimize emissions, but also redesign their supply chains to avoid waste and resource usage. With sustainability policies being intensified by governments all over the world, including extended producer responsibility (EPR) policies and product take-back programs, organizations that do not implement the process of going circular can be punished or face market restriction. The results of the present research point to the competitive edge of the active adoption of the concept of circularity as the companies that embed sustainable practices into their business models will be in a better position to fulfill the requirements of the regulation process and will receive positive feedback within the environment of more environmentally-conscious buyers.

The business repercussions of the move towards sustainability in the making of polo shirts are far afield. To reduce societal effects of climate change and to ensure the adoption of new regulations, the fashion sector will need to make the concept of being circular and sustainable be the primary part of their business model. Findings of this paper can serve as a guide to corporate behavior, as they have shown that transitioning to circular textile value chains is not merely an obligation dictated by environmental considerations but is also business-wise required (Aljohani, R., & Ibrahim, M. 2022).

## Recommendations

Resting on the findings and discussion on the life cycle assessment (LCA), several strategic suggestions can be made regarding how corporate choices can be made and create a circular change in the production of polo shirts within the Bangladesh apparel industry. These are recommendations aimed at material sourcing, transition to energy, process optimization and policy alignment that are essential in ensuring that industrial practices are related to global sustainability objectives.

Strategies Material Circularity and Fiber.

A 50/50 recycled-virgin cotton combination introduction showed a decrease in carbon emissions, water usage and land utilization by 20-25 percent over the customary production of virgin cotton. The companies dealing with apparel ought to gradually adopt the percentage of recycled fibres and in the next five years they should have a specific target of at least 70 percent of recycled content. This may be facilitated by collaborating with textile recycling companies as well as investing in closed-circuit systems. Recycling post-consumer textiles into the feedstock and implementing the take-back programs should help increase material recovery and minimize reliance on virgin materials, which will be part of both cost-efficiency and regulatory compliance amid the upcoming EU circularity requirements (Lim, Y., & Lee, S. 2022).

RE should be encouraged and supported by the government.

Renewable Energy Transition

The hybrid energy model (grid + 20% rooftop solar) in factory C demonstrates that the number of volume CO2 emissions and total energy demand decreased significantly. The companies ought to thus put a priority on installing rooftopic solar panels or power purchase agreements (PPAs) of renewable power. There is a gradual goal of reaching 50 percent of renewable energy use by 2030, which would considerably reduce operation emissions and enhance the resistance to the intermittent costs and dependence on fossil fuels (Deniz, S., & Ertan, M. 2022).

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Efficiency and Cleaner Production of processes.

The low-liquor ratio dyeing, enzyme-based processing, and recycling of the wastewater are efficient dyeing and finishing technologies that could reduce the use of water, including eutrophication potential. The use of lean ways of manufacturing and real time energy monitoring tablets should be used to streamline the use of energy within the production lines.

Corporate Strategy, Policy, and Regulation.

Bangladeshi manufacturers need to make the institution of LCA-based reporting schemes to meet global trends like the EU Product Environmental Footprint (PEF) scheme and the Extended Producer Responsibility (EPR) scheme. The integration of sustainability metrics in the procurement and supplier selection criteria will enhance the maintenance of compliance and transparency.

Taken altogether, such measures will not only optimize the environmental performance but also make the polo shirt manufacturers leading in the global shift toward the circles and low-carbon textile value chains (Choi, H., & Lee, H. 2021).

## Conclusion

This LCA shows that more sustainable aspects in the manufacturing of the polo shirts, including recycled cotton use, incorporation of renewable power sources, etc., can greatly decrease the environmental impacts of the production of textiles. The analysis of the three factories also demonstrates the significance of focusing not only on material selection but also on the sources of energy and optimization of the processes to decrease the impact of the fashion industry on the environment. The addition of 50/50 recycled-virgin cotton mixture and the development of solar energy on the roof are the essential interventions which will help to shift to more circular textile value chain in Bangladesh and other parts of the world.

The results of this research present some practical implications; this is that, it aims to offer suggestions that will guide the apparel firms that want to minimize their environmental footprint and join in the rising trend of circularity in the fashion industry. By focusing on the hotspots in the value chain and taking specific measures allowing to mitigate the issue, manufacturers will be able to catalyze essential environmental performance, which will lead to an even more sustainable and resource-efficient future.

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