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Life Cycle Assessment of Flame-Resistant Textiles Used in the Production of Occupational Safety Clothing: A Focus on the Personal Protective Equipment Industry

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Abstract

Flame-resistant textiles are crucial for workers' safety in various industries, but their production and disposal can have environmental consequences. This study conducts a comparative life cycle assessment (LCA) of three commonly used flame-resistant fibers in the personal protective equipment (PPE) industry: flame-resistant cotton, modacrylic, and meta-aramid. Using the LCA methodology that encompasses all life cycle stages of raw material extraction, production, transportation, and end-of-life stages, this research aims to identify the most sustainable fiber option. This study does a comparative analysis of the environmental profiles of each fiber type across selected impact categories to achieve its intended results. Additionally, an aspect of social life cycle assessment is conducted to evaluate the social hotspots during garment production with regards to fair labor practices. The findings will contribute to informed decision-making that balances worker safety with environmental responsibility, promoting environmental protection and social responsibility within the industry.

Research Question

What are the environmental impacts along the life cycle of flame-resistant textiles, from the extraction of raw materials, to the fibre, fabric and garment production stages, to the transportation and the disposal of the textile at their end of life?

What are the social impacts associated with the garment production stage in terms of worker welfare?

Introduction

Personal Protective Equipment (PPE) is considered to be the last line of defense in the hierarchy of controls for occupational hazards and is a mandatory requirement from organizations such as provincial Occupational Health and Safety groups. Employers must ensure that employees are protected from any form of workplace hazards by providing adequate PPE. Specifically, according to section 1910.269 App E - Protection from Flames and Electric Arcs of Federal OSHA (Occupational Safety & Health Administration) Standard; it is the responsibility of the employer to identify risks and hazards in the workplace and provide appropriate apparel and equipment for the protection of their workers. To this end, employers are required to protect employees who are exposed to thermal hazards by providing flame-resistant (FR) clothing (such as FR coveralls) for them (OSHA 2012). Employees working in areas where there is exposure to hazards from electric arc flash, flash fire, sparks/hot work operations and flammable chemicals must be provided with FR clothing (Lee 2022). Given the wide and mandatory use of FR PPE in the energy sector, an important question raised is: - while ensuring the safety of the personnel, is consideration being given to the environmental impacts created through the production, transportation, use and final disposal of these large quantities of garments that are produced to meet employer/employee needs?

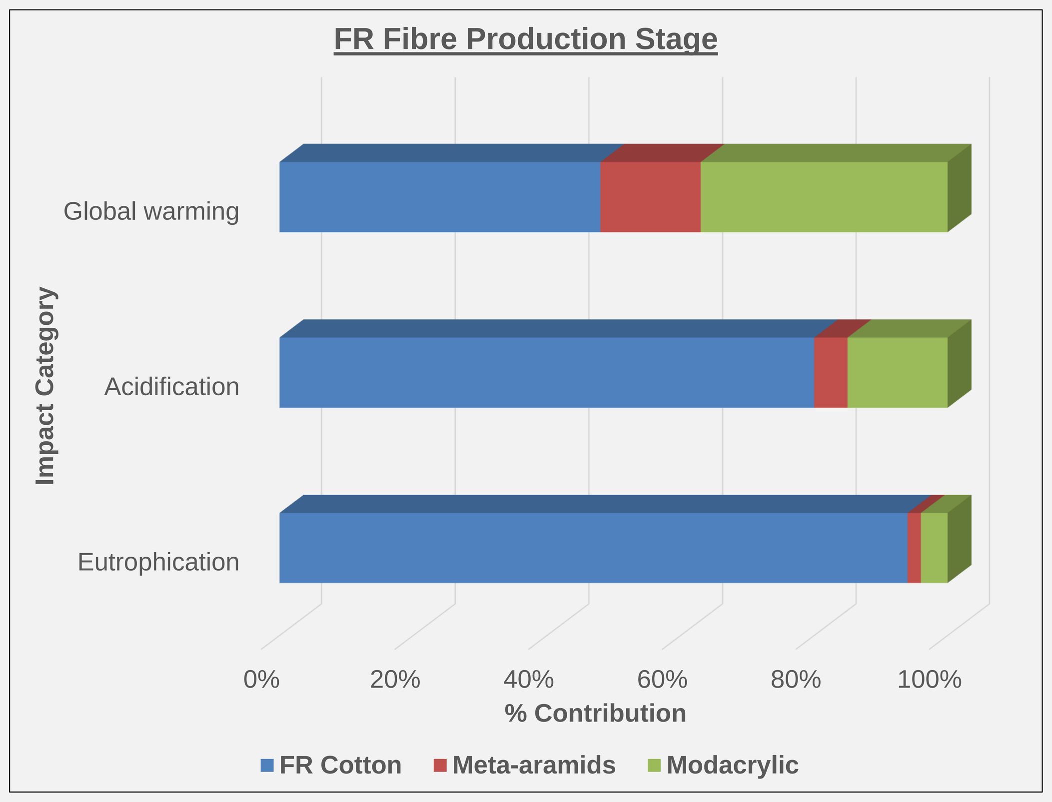
Methods

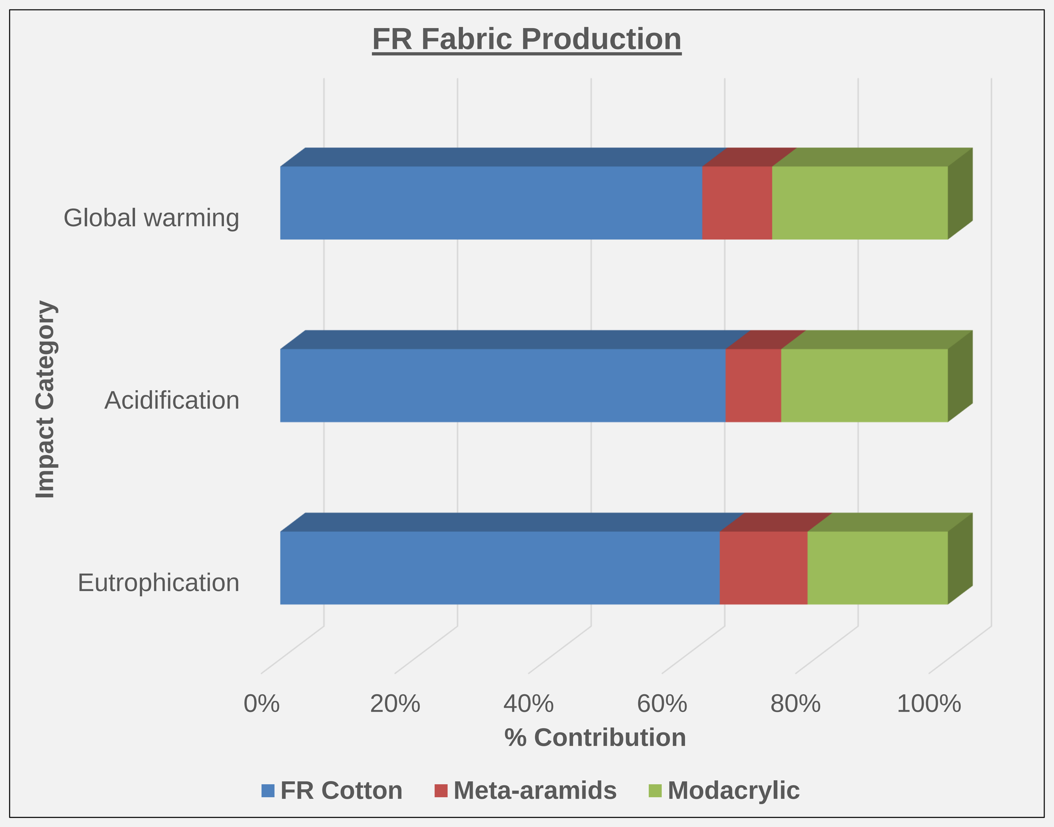
This study used a combination of quantitative and qualitative data to analyse the environmental and social impacts. Data was sourced from existing and publicly available literature to get the inputs and the OpenLCA software was used to conduct the analysis and obtain quantitative results. Impact assessment methods used include TRACI 2.1 method to determine the environmental impact results, Fuel LCA Model to determine the carbon intensity of the fuels used for the transportation of finished garments to the end users in Canada and the PSILCA impact assessment method to determine the social impact results.

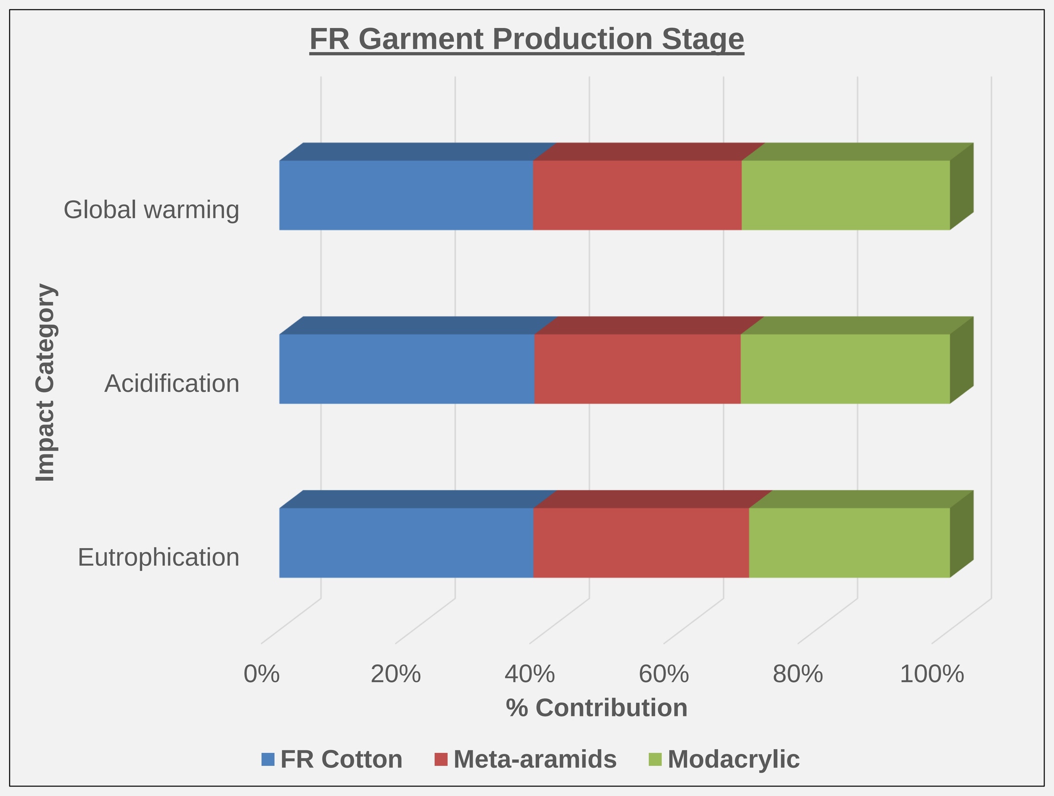
This study used the LCA tool to conduct a comparative analysis for three FR fibre types: FR Cotton, Meta-aramid and Modacrylic fibres.

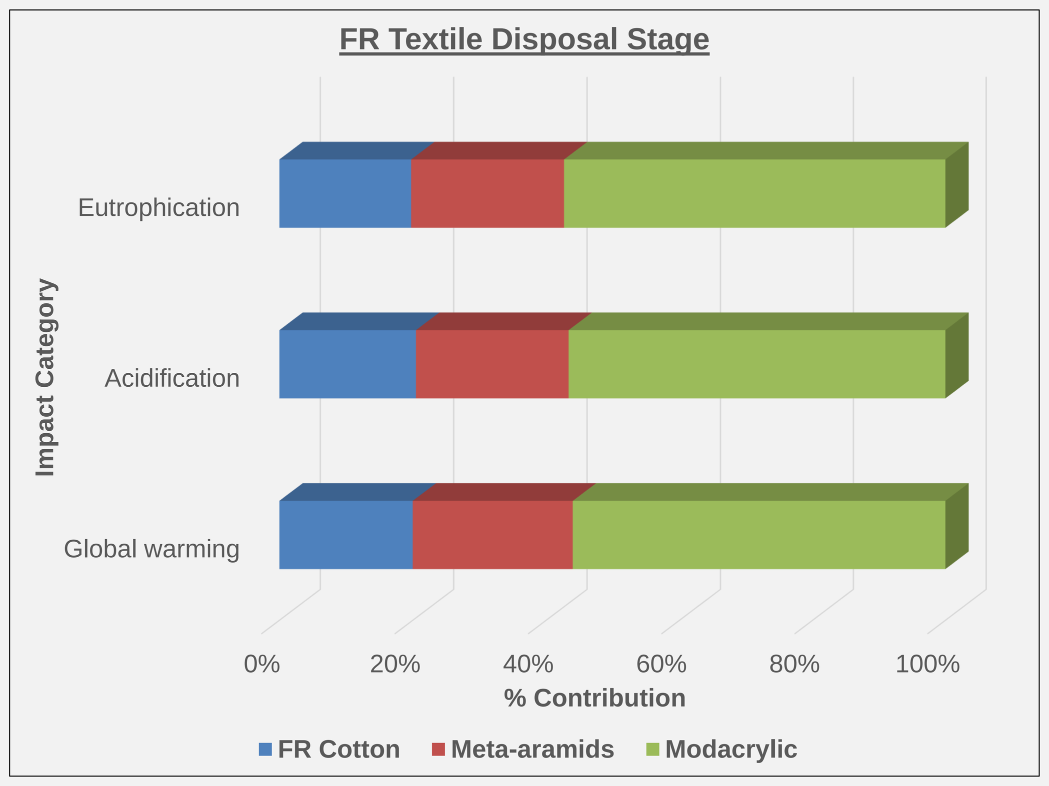
Results

The charts below show the environmental impact results in terms of contribution analysis to the impact categories for the three fibre types under review.



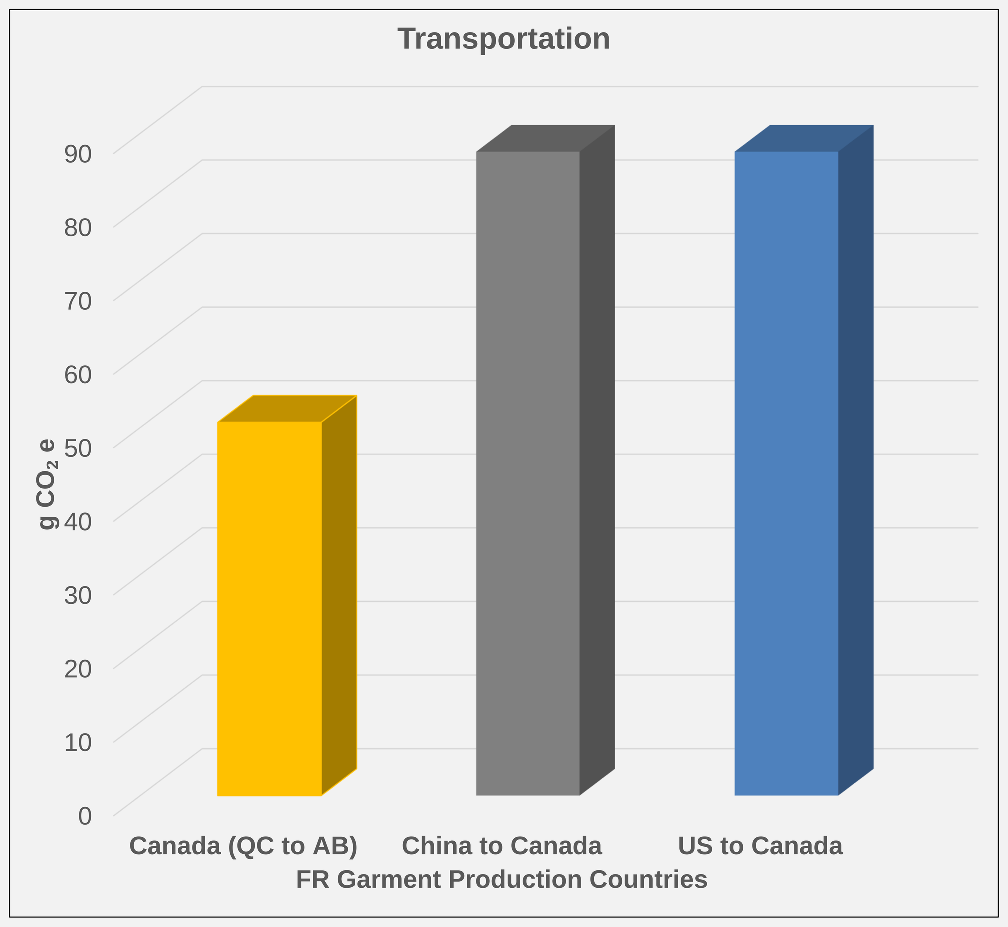






Results

The chart below shows the carbon intensity results for the analysis of emissions from the transportation stage. The analysis was done determine the carbon intensity for the fuels used to transport the garments from the locations where they are produced to the location of the end users.



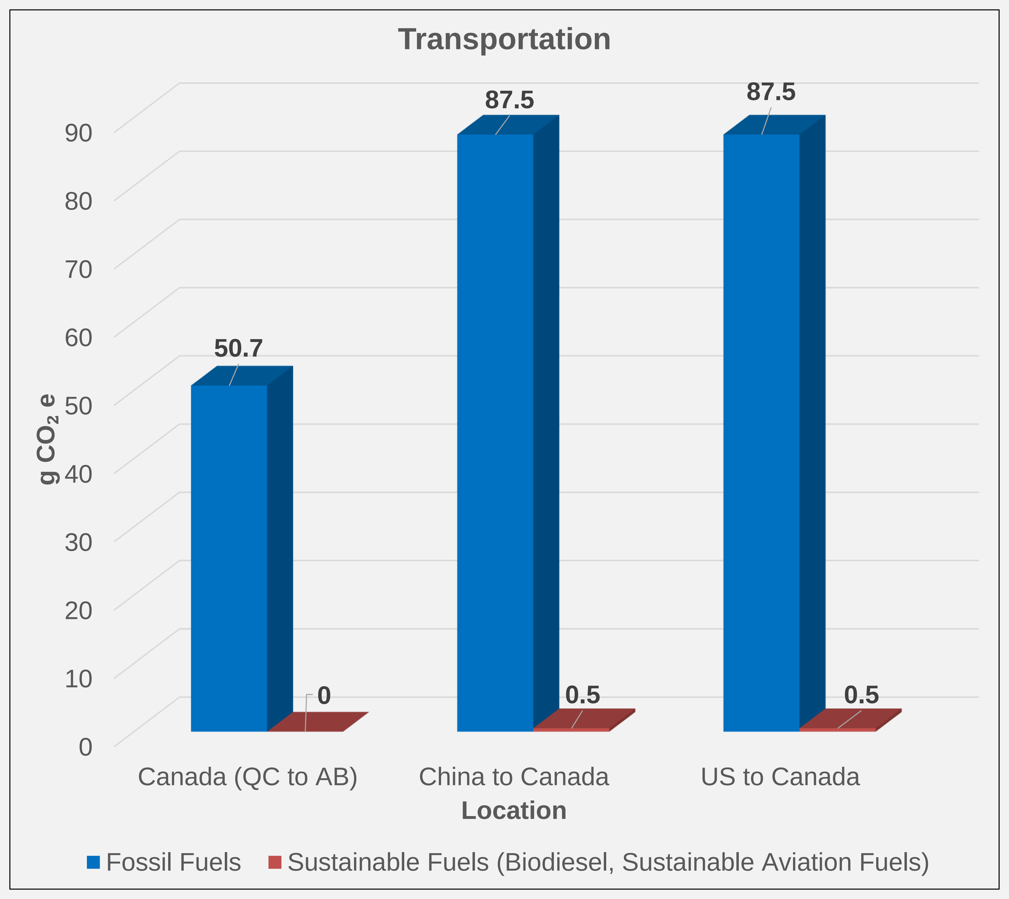
Social Impact Results

A full social life cycle assessment (S-LCA) was not conducted, only the 'worker' category was analyzed. The intent was to determine if there were any social risks in terms of unethical work practices in the FR garment production stage. The analysis considered 3 countries where FR garments were produced – Canada, US and China.

Category	Subcategory	Indicators analysed	Results		
			Canada	US	China
Workers	Child labor	Children in employment, total.	Low risk	No risk	No risk
	Forced labor	Frequency of forced labor.	Very low risk	Very low risk	Very low risk
		Tier placement referring to trafficking in persons.	Low risk	Low risk	Very high risk
	Fair salary	Living wage, per month.	Very high risk	Very high risk	Medium risk
		Minimum wage, per month.	Medium risk	Very high risk	Very high risk
		Sector wage, per month.	Medium risk	Medium risk	Very low risk

Sensitivity Analysis

A sensitivity analysis was done for the transportation stage by replacing conventional fossil fuels used to transport the FR garments with biodiesel and sustainable aviation fuel. The intent was to determine if there would be a variation in carbon emissions at this stage.



Conclusion

- The results show that natural fibres perform poorly during the fibre production phase due to the inputs during the cultivation of the raw materials which in this case includes the growing and harvesting of cotton. The cultivation of cotton involves the use of fertilizers and pesticides as well as the use of fossil fuel powered farm machinery. This resulted in increased emissions that feed into the fibre FR cotton fibre production.
- The FR cotton fibre also performs poorly in the fabric production phase because at this stage the FR chemicals and thermal energy are additional inputs into the product system which do not apply to the synthetic fibres. The results from the three fibres show very little variation in the garment production stages. The reason for this slight variation is that the input into the process is the same for all three fibres.
- The synthetic fibres perform worse than the FR cotton fibres during the disposal stage with the modacrylic fibres performing worse, followed by the meta-aramids and this is because the synthetic fibres have more environmental persistence compared to the natural fibres. This is because synthetics are generally composed of plastics, the fibres at their end of life are a leading cause of micro plastic pollution into the environment.
- In analysing the transportation results, transporting the garments from within Canada i.e. between Quebec and Alberta shows the lowest carbon intensity compared to if the FR garments are imported from either the US or China. The sensitivity analysis also conducted show that the carbon intensity for transportation would be further reduced if sustainable fuels are used to substitute the fossil fuels.
- An uncertainty analysis was also carried out and the results showed similar variation among the three fibres when compared with the base scenario indicating that the FR cotton fibres produce more emissions in the fibre and fabric production stages compared to the synthetic fibres.
- A full S-LCA was not conducted in this study, only the 'worker' stakeholder category was analysed. The subcategories under this category analysed were only the indicators for child labor, fair salary and forced labor. The results showed that child labor was not a risk in all three FR garment production countries (Canada, US and China), however the tier placement for the indicator for forced labor put China in tier 3 when analysed in PSILCA database. Canada and US show very high risk for the living wage indicator, the US and China show very high risk for minimum wage while China shows low risk for the sector wage indicator compared to US and China that show medium risk.

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