SUSTAINABLE ACCOUNTABILITY OF A GARMENT PRODUCT

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Abstract

The Clothing industry is one of the most significant contributors to greenhouse gas (GHG) emissions. The changes in buying patterns and consumption habits among people have led to a rise in the demand for clothing articles; hence it becomes vital to understand the environmental cost of every clothing article a customer is purchasing or keeping in their wardrobe. It also becomes essential to give attention to the areas of GHG emissions in the complete supply chain of manufacturing a garment and to make customers aware of it. The next quest of the customer is to know the product's carbon footprint (CFP) which may impact the purchase decision the way it does for product pricing. The same can be achieved while doing the CFP calculation of the product throughout its supply chain. The carbon footprint of a garment is vital, and there are many ways to make policies to reduce it, but it all starts with finding the areas and factors leading to the emission of greenhouse gases. In order to curb GHG emissions in the apparel industry, it is important to understand the different types of emissions and ways of tracking down the carbon footprint since most manufacturers are still finding it difficult to track and process the areas of GHG emissions.

This study examines the carbon footprint of a men's full sleeve formal 100% cotton woven shirt throughout its life cycle. In order to examine the carbon footprint of the shirt, a particular purchase order has been selected, and then the supply network of the order has been examined from drawing out raw materials, to manufacturing and the consumer’s phases, to disposal. It has been conducted using GHG protocol for accounting techniques for carbon emission calculators and life cycle for mapping the entire stages of a product's life, keeping the focus on sustainable design, farming, product, building, manufacturing, and CFP labelling.

Introduction

The rise of fast fashion has increased demand for quick, cheap, and low-quality goods. The increasing volume of garment production and how these garments are used and disposed of has resulted in increased climate change impacts from the garment sector.

Environmental and climatic changes have challenged us in many ways, and now customers are concerned and willing to follow practices which lead to environmental sustainability. It becomes imperative to give attention to areas of greenhouse gas (GHG) emissions in the complete supply chain of manufacturing a garment and to make customers aware of the same.

A garment's carbon footprint is vital, and there are many ways to track and calculate it. The major challenge starts with finding the areas and factors leading to GHG emissions.

Life cycle assessment measures the environmental cost associated with the conceptualisation of a product to the end of its life. Every minute phase of a product's life impacts the environment in many ways. This study examines the carbon footprint of a men's full sleeve formal woven shirt throughout its life cycle.

In order to examine the carbon footprint of the shirt, a particular purchase order has been selected, and then the supply network of the order has been examined from drawing out raw materials to manufacturing and customer use phases, to dispose thereof. This study has been conducted using GHG protocol for accounting techniques for carbon emissions calculator and life cycles for mapping the entire stages of a product's life.

Review of Literature

The apparel and textile sector contributes a significant amount of 1.7 billion tonnes of carbon emissions (International Labour Organization, 2021). The Paris agreement has set forth a limit of less than 2°C of global warming from pre-industrial levels in the future (King and Karoly, 2017). This has led to a revolution where understanding and reducing greenhouse gas (GHG) emissions are becoming the focus of business initiatives. As these initiatives progress, GHG emissions are receiving more attention along firm value chains and product life cycles, starting with raw materials.

In addition to company-specific carbon foot printing, which is from extraction to disposal, the focus is several factors. The factors include a desire among businesses to enhance interactions with customers and other stakeholders, a goal to lower GHG-related risks throughout the value chain, and a potential need to address upcoming product labelling regulations. In order to delineate sources of emissions in the apparel and textile industry during the processing and manufacturing of garments, the entire value chain should be traced. There are specific points to be concentrated in the value chain to understand the environmental impact of the garment industry.

The garment sector has traditionally operated in an unsustainable manner. The garment supply chain does not use materials, energy, and other resources efficiently, resulting in unsustainable levels of waste production.

Fashion items have brief lifespans and usually change before these products serve their purpose. This consumption cycle can result in enormous volumes of garbage since items frequently have synthetic fibres or dangerous chemicals that are difficult to degrade. The natural fibre manufacturing process also requires a lot of water and energy, as does the upkeep of clothing after purchase. Additionally, the worldwide structure of the garment supply chain results in problematic working conditions in contract factories in underdeveloped countries and a significant CO_2 impact. Innovative clothing businesses are working hard to solve these problems and build the industry more sustainable (World Resources Institute, 2004).

Many studies have attempted to calculate carbon emission in the global apparel industry, stating that finishing and dyeing is the major contributor to carbon emissions, followed by yarn and fabric preparation and assembly; however, they are unable to track the transportation impact due to changing consumer behaviour, leading to conflict among the different research findings.

According to the research conducted in 2019 on a men's shirt assembly line in China, the primary cause of carbon emissions is from materials (Zhang and Chen, 2019). Another study on the effects of cotton T-shirt production from China discovered that the dyeing process contributed 35 per cent of the life cycle's carbon emissions but that the garment assembly stage also produced significant emissions of 32 per cent (Zhang et al., 2015).

According to H&M’s Sustainability Performance Report 2019 (H&M, 2020), the post-purchase phase with 13 per cent was the next biggest source of emissions after garment assembly with 12 per cent and raw materials with 8 per cent of emissions, while fabric manufacturing, which in this study included yarn production and dyeing/finishing, was by far the largest source of emissions of 48 per cent.

The conflict in the study findings is due to the energy demand for processing different types of fabrics since the fabric is the central area of carbon emission in the making of a garment. Man-made fabric causes more carbon emissions than fabric made from natural fibre. Organic cotton will cause fewer carbon emissions. The same goes for dyed, printed and grey fabric. Dyed fabric has a larger carbon footprint than grey fabric.

The location of fabric processing plays a vital role too. A manufacturing unit using an alternative energy source will cause less carbon emissions than units using fossil fuels to meet consumer demands.

Fibre	**Greenhouse Gas Emission (Kg CO_2 per tonnes of fibre)**
Nylon	8,070
Viscose	2,118
Polyester	5,357

Acrylic	7,577
Silk	2,031
Cotton	1,755
Flax	335
Polypropylene	3,097
Wool	20,790

Table 1. Greenhouse Gas Emission (Kg CO_2 per tonnes of fibre)

Greenhouse gas emissions during the processing of the different types of fabrics

Concerns related to sustainability can be solved only when we consider all activities associated with garment manufacturing from product conceptualisation to the end of life. To understand the environmental impact of a product with a long and complex supply chain, like cotton, scientists turn to a method called 'life-cycle-assessment' (LCA). The LCA attempts to capture a product's impact by tracking the impacts associated with every activity needed to create, use, and dispose of the product.

Although the LCA method is beneficial for providing accurate information about narrowly defined systems, such studies have significant constraints and limitations. The information gathered in this study is unlikely to fully reflect the unique production circumstances of a given garment manufactured today. There could be significant differences in electricity sources, travel, manufacturing processes, clothing use, and so on. These LCAs must also establish measurement boundaries, which may differ from study to study.

This study has presented the baseline scenario of the carbon footprint of men's full sleeve formal woven shirt manufactured in India. This study included the most industrial production sub-processes and other life cycle stages. Assessment data for the study for garment manufacturing was collected from the primary source.

Scope 1: Direct emission from the company

Scope 2 & 3: Indirect emission from the company

The custom emission factor for India has taken for calculating carbon emissions from company operations.

Scope 1: Direct emissions from company-owned and controlled resources.

Scope 2: Indirect emissions from the generation of purchased energy from a utility provider, in other words, all GHG emissions released in the atmosphere from the consumption of purchased electricity, steam, heat and cooling.

Scope 3: It occurs in the reporting company's value chain, both upstream and downstream emissions.

S.N.	Category	Description
1.	Purchased Goods and services	This category includes all upstream (cradle-to-gate) emissions resulting from manufacturing products purchased or acquired by the company, including tangible goods and services.
2.	Capital goods	This category includes all upstream (cradle-to-gate) emissions from manufacturing capital goods purchased or acquired by the company.
3.	Fuel and energy-related activities	This category includes emissions from the fuels and energy purchased and consumed by the company that are not covered by Scopes 1 or 2.
4.	Upstream transportation & distribution	It includes inbound logistics, outbound logistics (for example, of sold products), and third-party transportation and distribution between a company's facilities.
5.	Waste Generated in the operations	It includes emissions from third-party disposal and waste treatment generated in the company's owned or controlled operations. This category includes emissions from both solid waste and wastewater disposal.
6.	Business Travel	This category includes emissions from employees being transported for business purposes in vehicles owned or operated by third parties, such as aircraft, trains, buses, and passenger cars.
7.	Employee Commuting	This category includes emissions from employee transportation between their homes and their workplaces. Employee commuting emissions can be caused by: • Automobile travel • Bus travel • Rail travel • Air travel
8.	Downstream transportation & distribution	This category includes emissions from the transportation and distribution of sold products in vehicles and facilities not owned or controlled by the company.
9.	Processing of sold products	It includes emissions from third-party processing of sold intermediate products (e.g., manufacturers)
10.	Use of Sold Products	It includes emissions from the use of purchased products.
11.	End-of-life treatment of sold products	It includes emissions from the company's waste disposal and product treatment.

Table 2. Areas for the calculation of Scope 3 CO2 emission

The above details are from the H&M Group Sustainable Performance Report 2019 (H&M, 2020).

Need of the Research

After researching the market and websites, concerns related to the global apparel industry have been identified. The apparel industry is responsible for around 2.1 billion metric tons of GHG emissions annually (Berg and Magnus, 2020). An average consumer throws away around 70 pounds (31.75 kilograms) of clothing annually. Globally, the fashion industry produces around 13 million tons of textile waste each year, 95 per cent of which could be reused or recycled (Niinimäki et al., 2020).

In order to take product responsibility and understand environmental impacts, we need to look at the carbon emissions during the manufacturing of the shirt. It is possible to understand which areas need to be focused on to reduce the environmental impact.

There is a need to create a general overview of GHG emission 'hotspots' in the life cycle of various garments, allowing for initial prioritisation of areas for action. It is also required to promote sharing of carbon emission information to the customer, which will help them in make wise lifestyle/ purchase decisions.

Objective

1. To evaluate the carbon emissions associated with the different stages of shirt manufacturing.
2. To evaluate the environmental impacts of shirt manufacturing from resource utilisation to supply, from raw materials to the disposal of the merchandise at the top of life.
3. To create a tool to calculate CO_2 emission in manufacturing a men's full sleeve formal 100% cotton woven shirt.
4. To identify the carbon footprint of the shirt from cradle to gate.

Product Description: Men's Full Sleeve Formal Woven 100% Cotton Shirt
Colour : *Solid*
Style: *Formal*

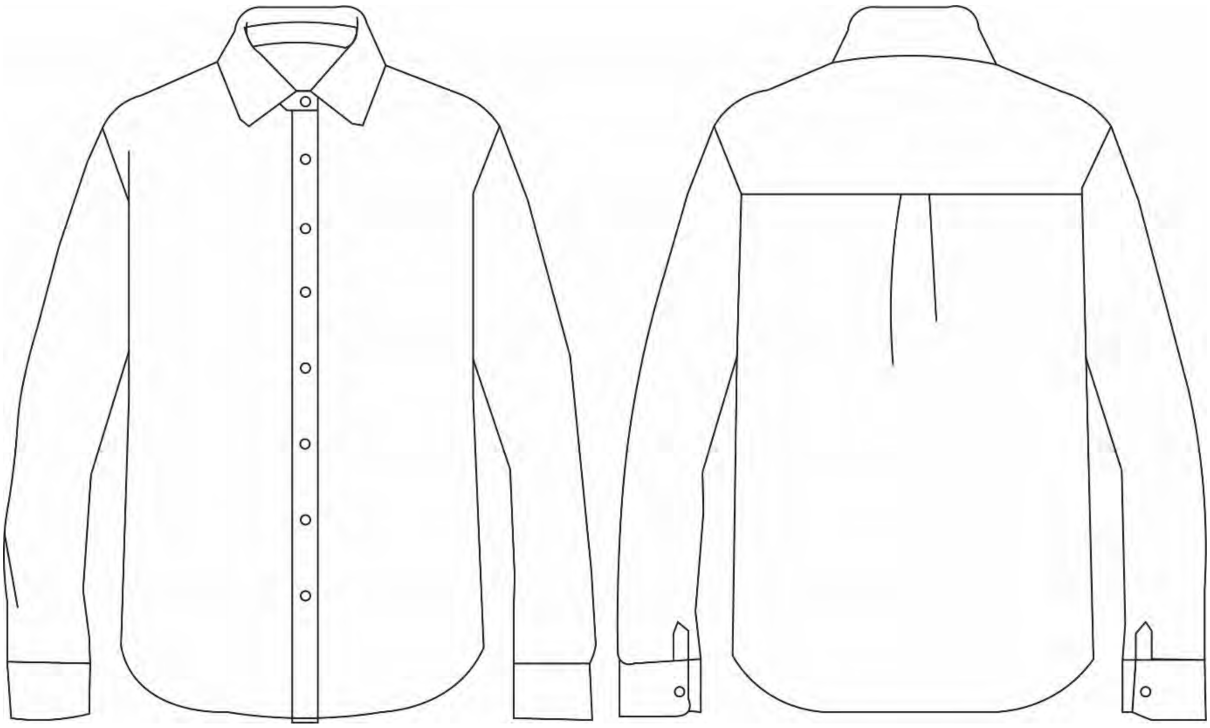

Figure 1. Men's Full Sleeve Formal Woven 100% Cotton Shirt

Methodology

A systematic research literature review was performed to classify peer-reviewed studies that emphasized the assessment of sustainability performance in garment industries. Due to the comprehensive nature of sustainability assessment concepts in apparel industries, a broad literature review was performed with a wide search on relevant literature from journals related to sustainability assessment for data collection and evaluation principles for men's full sleeve formal woven shirt.

For this study, a men's full sleeve formal 100% cotton woven shirt has been examined to carry life cycle analysis because cotton fabrics are the major material for the manufacturing of the shirt.

This study is carried out according to primary data collection. The primary data was collected from a shirt manufacturing company in India. A greenhouse gas protocol calculation tool has been used to calculate the carbon emissions by the manufacturing facilities for assembly and transportation, and for fibre-to-fabric processing; data has been taken from another company which has a vertically integrated facility for fabric processing.

All the activities related to the manufacturing of the shirt have been divided into three categories namely, Scope 1, 2 and 3 emissions.

The LCA consists of primary data collected in the respective areas: cotton cultivation, yarn and fabric processing, fabric and trims, transportation, and garment assembly.

Cradle to Gate Emission mapping of a Men's Full Sleeve Formal 100% Cotton Woven Shirt

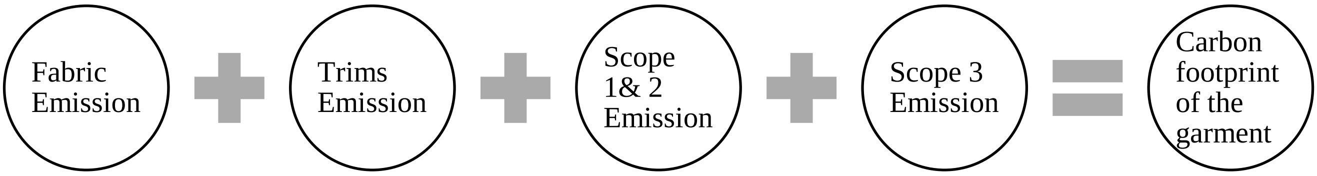

Figure 2. Cradle to Gate Emission mapping of a Men's Full Sleeve Formal 100% Cotton Woven Shirt

Factors	**Parameter**	**Examples**	**Impact on CFP**
	Fabric type	Natural, man-made, synthetic	Natural fabrics contain a lesser carbon footprint than the other two.
	Yarn count	Finer, coarser	
	Weave/ Knit	Mill made/ power loom/ handloom	Handloom has less impact on CFP
	Sizing & Chemicals	Sizing/ desizing	Contributes more CFP
	Wastage	Depends on the complexity of the style/ product	More wastage, more CFP
	Weight	GSM, count/ construction	Heavyweight adds more CFP
	Dye type	Natural, pigment, etc.	Natural dye has less CFP
	Finishing	Flame retardant, wrinkle free, iron free, anti stain	Adding more CFP
Design/ Styling	Fit /Silhouette/Fall/Drape	Wastage of cut parts, trims and accessories	Contributes to the higher carbon footprint
Cutting	Block Development /Garment style/Lay length/Marker way /cut order plan	Wastage in spreading, cutting, fusing, ticketing and bundling	Contributes to the higher carbon footprint
Sewing	Capacity Utilisation/ Quality defects/ performance/ productivity	Rework, rejection and low efficiency	Contributes to more human resources and energy consumption, which leads to more CFP
Finishing	Thread Cutting	Operation redundancy, energy consumption, use	
	Pressing		

	Inspection	of non-recyclable packing materials	High carbon foot print and Greenhouse gas emission
Factory Setup	Waste & maintenance	Wastages from the manufacturing lifecycle, cleaning agents	Prone to emissions, heat, air quality, lighting, waste and maintenance
	Lighting	Lux requirement for working stations	
	Machine type	Printing, sewing & washing machines	
	Utility area	Toilets, canteen, cleaning etc.	
	water consumption	dyeing, processing, washing, printing,	
	Energy Consumption	Servo motor, clutch motor, direct drive	
	Air	Pneumatic, hydraulic	High carbon foot print and greenhouse gas emission
	Steam	Steam boiler and compressor, air conditioners, pumps, fans and blowers	Operation redundancy, energy consumption such as use of steam in the place of water etc, can save CFP generation.
Manufacturing System	Modular, Unit Production, Progress Bundle System, Lean Manufacturing, Make through	Single piece flow/ bundle system	Modular/ lean have less CFP due to lesser Inventory
Machines	Manual, Semi-automatic, automatic (Clutch Motor, Servo motor)	Noise and vibration	More energy efficient, less CFP
Work Force	Semi-Skilled, Skilled, Multi-skilled etc.	Skilled/ trained workforce	More skilled/ trained workforce and more productivity lead to lower CFP
Ergonomics	Motion Economy, Charts, Diagram etc.	Working environment	A better working environment leads to better productivity and lowers CFP level.
Maintenance	Preventive, Predictive, Breakdown	Machine down time	Lesser machine breakdown due to

			regular preventive maintenance lower CFP
Sourcing	Supplier, Inventory, Transportation	Just in time, eco-suppliers, flight, railway road	Inventory for a more extended period releases more Greenhouse gas emissions into the environment
Washing	Dry/ Wet process	Whiskering, laser treatment, stone, softener etc.	High carbon foot print and greenhouse gas emission

Table 3. Factors affecting the carbon Footprint of a garment

Carbon emissions of the different products differ from product to product, but most LCA studies are not necessarily comparing apples to apples because of the study's boundaries, assumptions, and data utilised. For this LCA, we have taken the system constraints of *cradle to gate*, which means mapping carbon emission from raw material procurement till manufacturing.

The boundary of the study

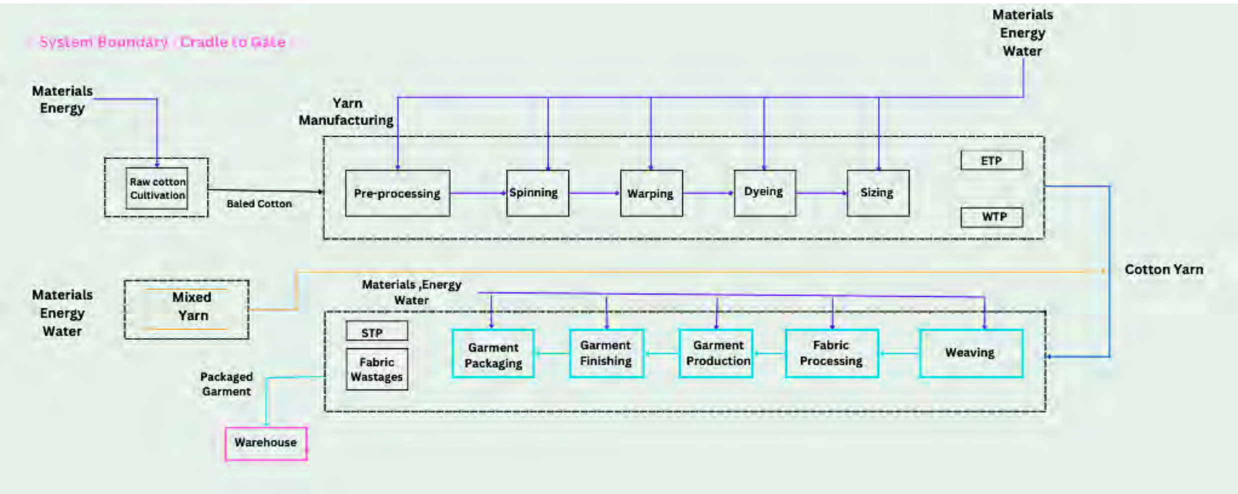

Figure 3. System Boundary of the study

Carbon Emission Calculation Methodology

For the given product, all three areas of emissions are categorised into three scopes, and data has been collected; in the following table, different combustion types of different scopes of emissions has been listed. Scope 3 is the most crucial part of carbon emission tracking as it is always difficult to trace the suppliers for their environmental accountability. For carbon emissions, the different combustion type depends on the types of fuel, mode of travel and energy source. Manufacturing facilities using purchased electricity from coal/ non-renewable resources to fulfil their power consumption demands emit more carbon.

Combustion Type	**Data Required**	**Calculation Formula**	**Includes**
1.Stationary Combustion	• Fuel type • Fuel Usage • Units for usage (Volume or weight)	Emissions = *Fuel x HHV x EF2* Where: Emissions = Mass of CO2, CH4, or N2O emitted Fuel = Mass or volume of fuel combusted HHV = Fuel heat content (higher heating value), in units of energy per mass or volume of fuel EF2 = CO2, CH4, or N2O emissions factor per energy unit	It includes fuel consumption at a facility to meet energy demands. The combustion of fossil fuels by boilers, DG and other equipment causes carbon emissions into the atmosphere.
2.Mobile Combustion	Two of the following: 1. Total fuel used by each vehicle 2. Total distance travelled by each vehicle 3. Fuel efficiency of each vehicle	Emissions GHG, fuel = Fuel Consumption fuel * Emission Factor GHG, fuel	It includes fuel consumption by company vehicles. Combustion of fossil fuels in vehicles emits carbon.
3.Purchased Electricity	Data required: 1. Energy source 2. Energy usage 3. Units (kWh for electricity)	Emissions GHG, fuel = Fuel Consumption fuel * Emission Factor GHG, fuel	It includes electricity and other sources of energy purchased from the local utility. To produce this energy, utilities combust coal, natural gas, and other fossil

			fuels, emitting carbon.
4.Transportation	Data required: 1. Method of travel 2. Travel distance and units/weight distance and units/passenger distance and units	*Emissions GHG, fuel = Fuel Consumption fuel * Emission Factor GHG, fuel*	It includes fuel consumption by vehicles used to conduct company-financed travel. Examples include commercial air travel and use of rented vehicles during business trips.

Table 4. Carbon Emission Calculation Methodology

Data Variable Analysis

Cycle Stages	**Data Type**	**Source**
Cotton cultivation	Cradle to gate cotton fibres ginned at firm.	Primary Data Collection
Yarn & fabric production	Carbon Emission during processing Of fabric	Primary Data Collection
Fabric Transportation	Carbon generated through the transportation vehicle for operational purposes	Primary Data Collection
Garment Assembly	Energy, water, fuel consumption in a manufacturing facility for one garment assembly.	Primary Data Collection

Table 5. Data Variable Analysis

One of this calculation's challenges is reducing any possible bias in quantifying the CFP for the particular product. Studies by different researchers show that most of the time, we typically underestimate the number of processes required for garment transformation. In-depth work is carried out with a well-established Indian garment manufacturing company to model the men's full sleeve formal 100% cotton woven shirt with a detailed description of production, transportation, fabric, and yarn processing. All the information on the stages of raw material procurement, fabric and yarn processing, finishing, and transport of the products were taken from manufacturers who described them in detail. Three emission routes are modelled for the chosen item: Scope 1, Scope 2, and Scope 3. The study was carried out using the LCA method and GHG protocol.

After modelling, the processes are grouped to correspond to fibres, fabric, assembly, and distribution. For each of these major stages, an average carbon impact per kilogram of the process is calculated. Emission factor is based on regional priority.

Name of custom EF	**Scope**	**CH4**	**CO2**	**N2O**
Diesel	Scope 1	0.000003	0.0741	0.0000006
LPG	Scope 1	0.000001	0.0631	0.0000001
Briquette	Scope 1	0.00003	0.112	0.000004
Scope 2			0.85	

Table 6. Fuel Emission Factors

Lookup name	**Scope**	**CH4(gm/unit)**	**CO2(Kg/unit)**	**N2O (gm/unit)**
HGV (all diesel) - tonne.km	Scope 3	0.00004	0.10797	0.0022

Table 7. Transport Emission Factors

CO2 emission/ meter	**2.667 Kg (fibre to fabric stage)**
Fabric consumption per shirt	✓ Solid Fabric: 1.6 m ✓ Check & stripes: 2.2m ✓ The subject case is a solid colour shirt the fabric consumption has been taken as 1.6 m. ✓ CO2 emission from fabric Processing = (2.667*1.6) Kg CO2 emission / shirt = 4.2672 Kg CO2 emission / shirt
CO2 emission during cotton cultivation	✓ Cotton Consumption Per shirt: ✓ Solid Fabric: 1.6 m ✓ Check & stripes: 2.2m ✓ Since the subject case is a solid colour shirt the fabric consumption is taken as 1.6 m. ✓ CO2 emission from Cotton Cultivation = 0.748 Kg CO2 emission / shirt
CO2 emission during garment assembly	✓ Carbon Emission during Garment Manufacturing 435.3890 grams

Table 8. Carbon Emission from different stages

Key Findings

Figure 4 below illustrates the GHG emissions generated by a cotton shirt during garment assembly. It demonstrates the areas in which the GHG emission of a garment depends. In this case, three scopes are mapped for the product's manufacturing stage. Power consumption during manufacturing is the most significant contributor to carbon emissions followed by facility owned combustion. Purchased electricity is drawn from high-GHG coal-fired power plants. Note that if the manufacturing facility uses a renewable source of energy, then the GHG impacts would likely reflect Scope 3—in other words, Scope 3 would generate the most significant emissions.

In similar fashion, raw material and fabric processing energy source is again the most significant cause of GHG emissions, generating nearly 50 per cent of the total. However, if renewable energy is not used in raw materials and manufacturing, Scope 3 GHG emissions would be less than 20 per cent of the total for this garment. This may still be the single largest life cycle GHG impact if each step in raw materials and manufacturing is broken out separately.

It shows that this is the primary area to focus on, if we replace the source of energy, it can reduce a large amount of GHG emissions to the environment.

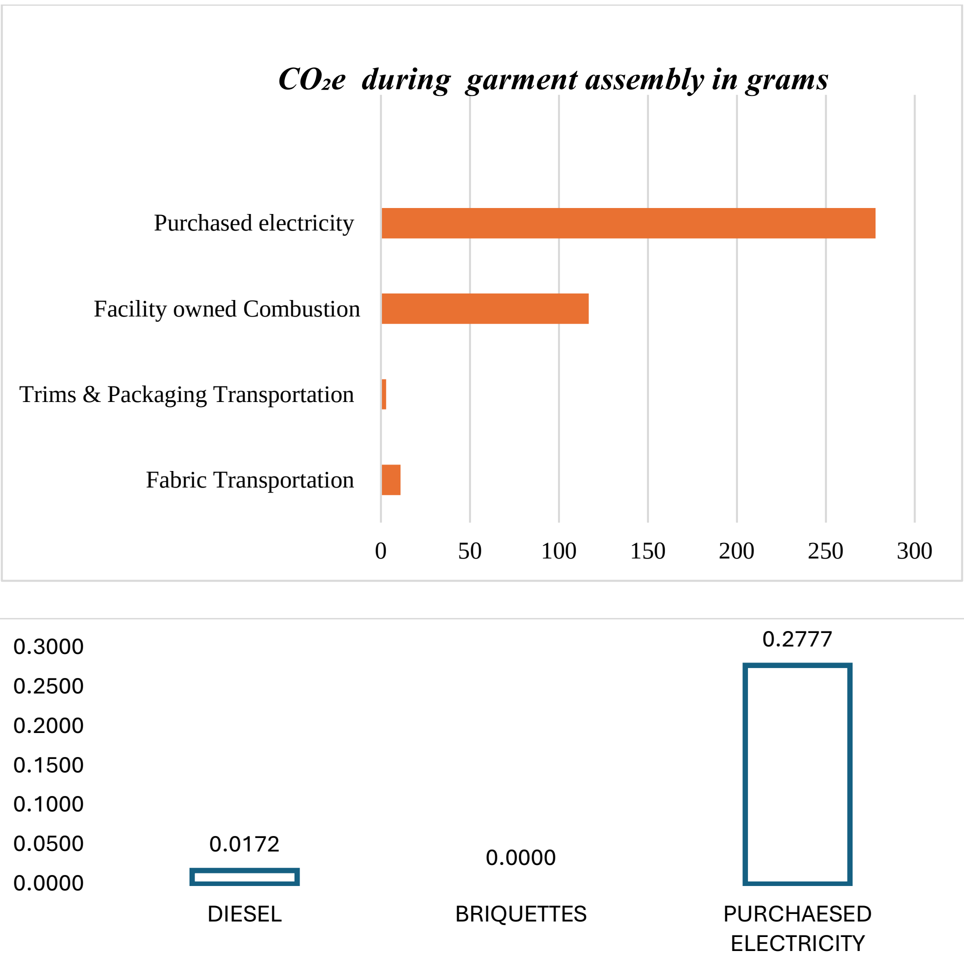

Figure 4. CO2 emission per garment assembly in kilograms (KG)

Energy demands are fulfilled from high-GHG coal-fired power plants. Note that if the manufacturing facility uses a renewable source of energy, then the GHG are impacted.

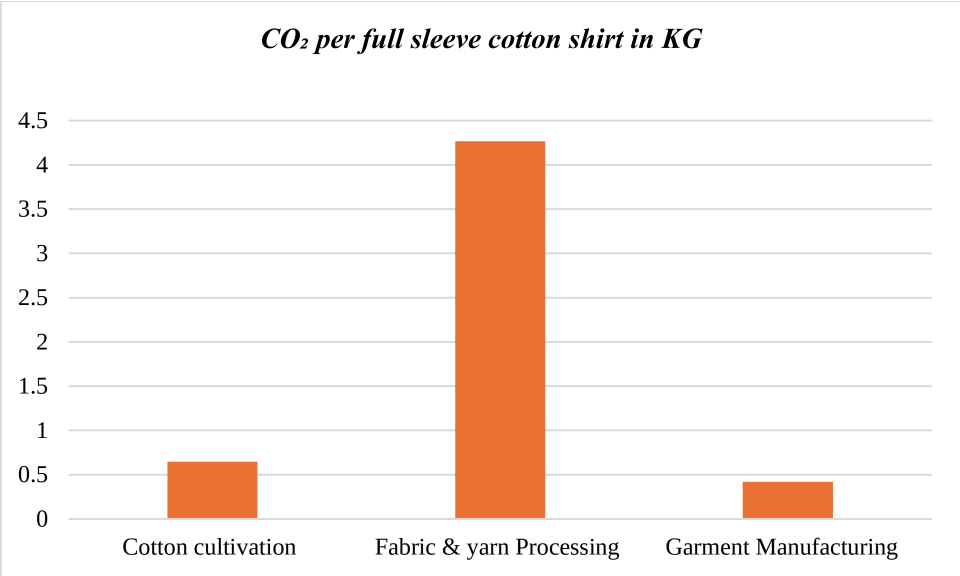

Figure 5. Environmental footprint values calculated for a French brand

Conclusion

This study has calculated using LCA and GHG protocol and provided an estimation of 5.45 kg of CO_2 per shirt. According to the climate summit agreement, limiting global warming impacts to 1.5°C requires a reduction of GHG emissions by a factor of six, which means reducing the footprint to 1 kg of CO_2 per shirt. This work identifies and describes the causes of a CFP from a shirt's complete manufacturing process. It also quantifies the contribution of several life cycle parts in the CFP of apparel products. This study presents the main opportunities to reduce the environmental footprint of a clothing article. The determining action for the reduction of the CFP is directly linked to the electricity mix. Apparel product manufacturing uses a lot of electricity from raw material procurement to yarn and fabric processing, and the carbon emissions per MJ can be potentially reduced by a factor of 10 by using renewable sources of energy. Under the assumption that 100 per cent of the apparel production is relocated to renewable sources of energy, the environmental footprint would be reduced by 350 gm CO_2 equivalent per shirt in the garment assembly phase itself because of the change in the electricity mix and the diminution of transportation. This reduction can lead to the CFP achieving 100gms CO_2 per shirt, which will help to meet the Paris Agreement objectives.

On a company level, the implementing these objectives requires systematic accounting in the CFP of items produced or distributed and possibly the display of their environmental performance to engage consumers in their efforts. On a sector level, the increase of demands for sustainable products and the yearly calculations of the environmental footprint values in the garment sector would allow economic stakeholders to be involved with the performance of the entire industry. Finally, on a national level, reducing the environmental footprint of apparel products is based on efforts to relocate production means (especially those which consume electricity the most; to know in the decreasing order of importance: weaving, spinning, knitting, and some finishing treatments). In addition, monitoring an environmental performance indicator for the sector would be more accessible by using a footprint calculation based on the LCA, which directly reflects the impact of imported products and implements traceability of the imported apparel products.

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