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CODEN: IAASCA **ORIGINAL ARTICLE**

Energy consumption and Carbon footprint of Cotton Yarn Production in textile industry

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ABSTRACT
Textile industry with its diverse and complex processes, poses multiple challenges when it comes to standardising and benchmarking its various processes. This study has analysed energy inputs and related emissions of cotton yarn production, from cradle to factory gate boundary, including phases from farm, transport to ginning, ginning, transport to spinning plant and spinning and packaging. The study is conducted, according to International standards Organisation (ISO) 14040 series of standards for Life Cycle Assessment. Obtaining relevant data for various phases was among the challenges addressed in this work, since efforts to compile life cycle inventory data for India are very recent. Also, the relevant data are scattered across diverse sources, or simply not available in the open literature. Data has been collected from various resources such as journal articles, ministry of agriculture data, Indiastat database, personnel communication, reports etc. All the embodied energy inputs for the cotton production, such as fertilizer, pesticides, electricity, human and animal inputs, seeds and diesel are considered. Embodied energy values from this data shows that farming has large variability in the inputs due to geographical variations and farming type and type of the farmers. Diesel and fertilizer input shares the maximum inputs, along with the electricity. Data pertaining to spinning is collected from personnel communication with a spinning mill in Uttarakhand district, India. Data for packaging inputs such as L.D.P.E., H.D.P.E., and cardboard box have been obtained from Ecoinvent database. Electricity is a major input in spinning process, with water being the second major input within plant. Current energy and emissions analysis of yarn production is expected to improve the supply chain by focusing on the phases which have the higher impact which in turn will to enhance decision making in the textile production processes. The analysis revealed that sustainability of farming phase can be improved by using modern better management practices such as drip irrigation and use of organic farming to reduce the overall impacts.
Key words: *Carbon Footprint, Life Cycle Assessment, CO_2eq. – Carbon dioxide equivalent, GHG emissions, Climate change*

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INTRODUCTION

The textile industry is one of the largest industrial sectors in the world. Its supply chain is diverse and complex, including design, raw material harvesting, spinning, yarn production, dyeing, weaving, cutting, stitching and final garment construction. Clothing and textiles contribute to approximately 10% of the total carbon emissions. Textile industry consumes
9-10% of total energy available in India and accounts for 20% of total production cost. Thermal and electrical energy demands are met using coal, firewood and electricity. Thermal energy requirement is derived from firewood, lignite, coal and fuel oil. Combustion of these fuels contributes direct emission of CO_2 [1]. India is a major producer of cotton, and ranks 2nd in export of Cotton. It has a 59% share in consumption of raw material in the Indian textile industry. The need for sustainability in textile industry is being increasingly emphasised due to associated environmental impacts on soil and water [3].
Cotton cultivation is generally known for its unsustainable nature, due to the overuse of fertilisers, pesticides and water [4].Cotton production is both a contributor to and a 'victim' of climate change. Agricultural production, processing, trade and consumption contribute up to 40% of the world's

emissions when forest clearance is included in the calculation. Cotton production contributes between 0.3% and 1% of total global GHG emissions [5]. Present cotton growing practices, are not sustainable: they damage soil, water and associated eco-systems, as well as contribute to extremely high social costs and a threat to regional economies depending on cotton farming and associated textile industries. However, cotton farming requires large amounts of water, (varying from 7-29 tons per kg of raw cotton fibres [6].

Modernisation of the textile industry is rather slow and a lot of manufacturers are still using old inefficient technology[7]. Energy consumption is on the rise due to modern machines and inefficient usage of equipment. The energy cost contributes 15-20% of production cost, next only to raw material cost [8]. However, textile energy studies make up a relatively small share of all industrial energy studies. More energy studies in this sector will help to identify the energy efficiency potential for the industry itself as well as for the other similar industries.[9]

Particulate matter (PM) is the primary air pollutant emitted from cotton ginning. [10] Ismail et al.30 evaluated the energy usage and greenhouse gas (GHG) emission inside cotton gins in Australia. Results showed the electricity and gas usage of 61% and 39% of total energy use, respectively. It was estimated that 60.38 kg CO_2 were produced by energy usage for ginning one bale of cotton.[11]. Hughs et. al (2013) have calculated the energy requirement in U.S. gins to be in the range 33.07kWh/bale to 41.37kWh/bale.[12]

Electricity is the major type of energy used in spinning plants, especially in cotton spinning set ups. In the spinning plant electricity is a major energy source, which is used in humidification in cold weather.

Present study analyses the life cycle energy inputs and emissions related to production of 1 kg cotton yarn in its Cradle to Gate boundary. The study provides relevant recommendations for internal improvements and decisions on pollution prevention, resource conservation, and waste minimization opportunities. Therefore, there is a need for detailed information of energy and water requirement and emissions profile of cotton yarn.

METHODOLOGY

Scope and Boundary of the analysis

LCA includes all four stages of a product or process life cycle: raw material acquisition, manufacturing, use/reuse/maintenance. This paper presents the energy inputs and emissions associated with cotton yarn production system in Indian context, in its Cradle to Gate boundary. Since cotton yarn is an intermediate product and it has a wide variety of applications, the scope of the study was limited to factory gate. The cotton yarn production chain is divided into following processes (i) The agriculture phase includes fuels or energy-intensive material inputs such as fertilizers, herbicides, seeds, diesel fuel, and electricity for irrigation, machinery and labour used for agriculture.(ii) The transportation phase includes moving of agricultural product from farm to the ginning site by truck, (iii) Ginning process which involves electricity consumption, and from there (iv) transport to spinning plants.(v) Conversion of fibre to yarn consists of mainly electricity and water for humidification (vi) Packaging. Life Cycle stages within the boundary under consideration have been modelled in Figure1 illustrates the phase in the life cycle of cotton yarn. Retail Consumer Use and disposal phase have not been considered because of the intermediate nature and unavailability of data.

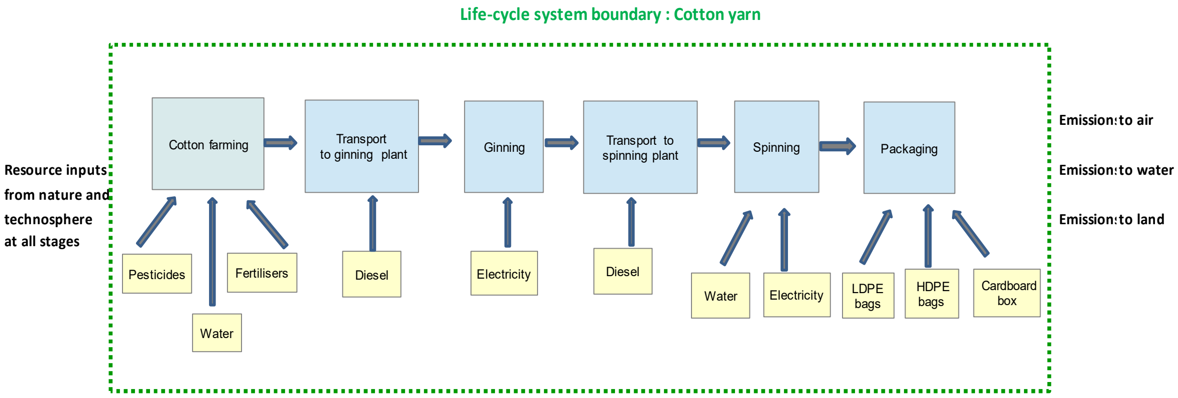

Figure 1: Analysis boundary of the cotton yarn production

Data Sources and Assumptions

This work faced challenges in obtaining relevant data, since data for India are still to be included in LCI databases. The fact, that the relevant data is scattered, and is not available in literature and databases, compelled the data, to be acquired from various sources like journal articles, publications of Ministry of Statistics, Ministry of Agriculture, India Statistical databases. Farming data has wide spatial and temporal variation across the country. The lack of completeness of data and ignorance about the resources used in the farming phase regionally necessitates quantifying the variability. The data from diverse sources have been included in this study, and the mean, mode, median, high value, and low values for each input and yield have been calculated. Energy inputs need to be allocated between cotton and cottonseed as cottonseed is a by-product and used for edible oil extraction and the residue is further used in animal fodder. In the absence of primary data secondary information was obtained from literature, previous studies, and reports of environment and audit agencies. Results from some foreign studies have been used in absence of Indian data leading to the assumption that the energy consumption scenarios are the same between India and the country from which data is taken.

Functional unit:

Functional unit of analysis, for present study is 1 kg of cotton yarn at spinning unit. As the yarn can have various applications, we have analysed the life cycle impact of 1 kg of cotton yarn till factory gate boundary. The analysis can be extended based on its using further processing.

Allocation:

Allocation is to partition the input or output flows of a process or a product system under study and one or more other product systems. The inputs and outputs shall be allocated to the different products according to clearly stated procedures that shall be documented and explained together with the allocation procedure [14]. Cotton production yields two valuable outputs, namely cotton fibre and cotton seed. Various allocation methods are available for life cycle studies

1. Mass based
2. Substitution and
3. Economy based

Thus, the environmental burden can be allocated to respective products at different stages but present study does not compute effects of allocation.

RESULTS AND DISCUSSION

The metrics calculated in this work are energy inputs and resulting GHG emissions related to cotton yarn production, which have been described in the rest of this section. This metric will help in evaluating and comparing the life cycle GHG emissions of various cotton yarn systems. All the phases of production leading to emissions are highlighted, so that focus on the specific inputs can be given to improve the overall sustainability by reducing the energy inputs or by trying alternative inputs or processes.

Energy and emissions analysis of cotton farming:

Farming energy and emission analysis has been carried out to find out which inputs contributes more for energy and emissions at farming stage so that we can focus on specific inputs to improve the sustainability of the farming process. Figure 2 shows the percentage energy distribution at the farming stage for the mean values of the Inputs. From the figure, it is evident that fertilizer consumes major portion of the energy inputs along with diesel used for farming operation and electricity for irrigation.

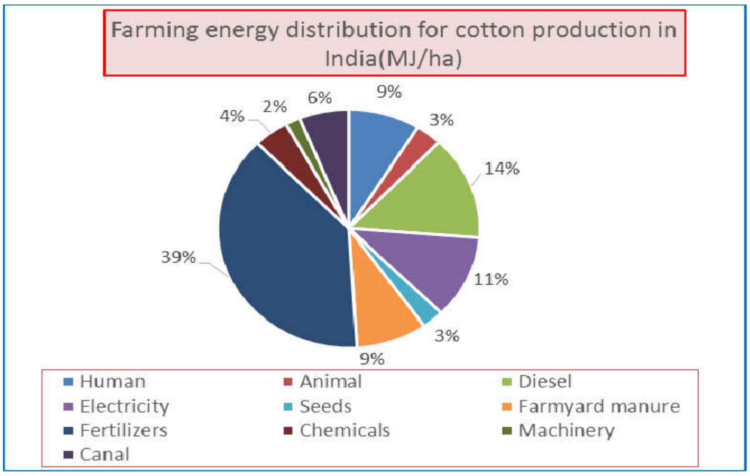

Figure 2: GHG emissions from Cotton farming

Farming emission analysis shows that the farming stage has 2.1076 kg CO_2 eq/kg cotton yarn without allocation and 0.8430 CO_2eq/kg cotton yarn on mass basis and 1.8336 CO_2eq/kg cotton yarn on economy basis. The contribution of emissions from the various inputs has revealed that for the cotton production the highest contribution is from the N_2O Emissions from fertilizer application. Along with this, fertilizer production, diesel used and electricity also contribute largely, which suggests that, there is a need of improvement in the irrigation practices as well as minimal use of organic fertilizers.

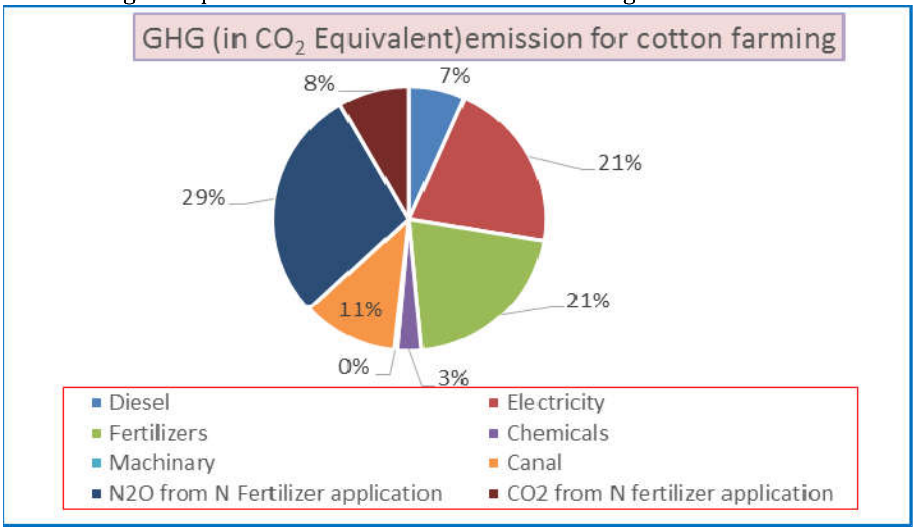

Figure 3*:* GHG emissions from Cotton farming

As the data has been collected from various sources and regions of India, to capture the data variation of cotton farming stage, we have calculated the mean high and low value inputs and outputs which have been used in further calculation to include the sensitivity of the variation.

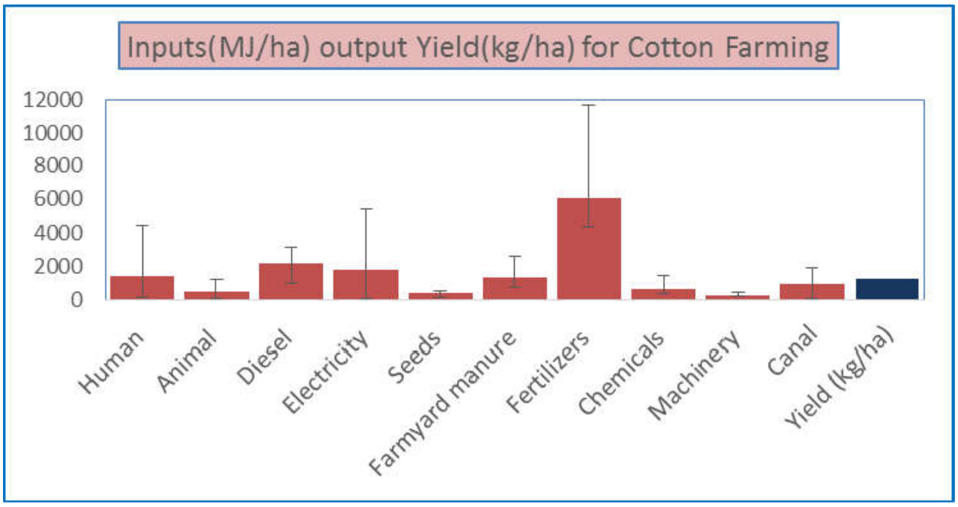

Figure 4*.* Inputs and Outputs of Cotton Farming

Energy and emissions analysis of transport from farming to ginning plant:

Distance of transportation of harvested cotton from farm to ginning plants is estimated to be 200 km roundtrip. The energy inputs of transport have been calculated to be 0.21933 MJ/kg cotton yarn without allocation. 0.087733 MJ/kg cotton yarn with mass allocation and 0.190725 cotton yarn with economy allocation cotton yarn which leads to an emission of kgCO_2 eq/kg cotton yarn.

The analysis has revealed that the transport farming to ginning plant leads to 0.015083 CO_2eq/kg cotton yarn without allocation and 0.0060 CO_2eq/kg cotton yarn on mass basis and 0.013115 CO_2eq/kg cotton yarn on economy basis.

Energy and emissions analysis of Ginning:

It is well known that as much as 60-70% of seed is available from seed cotton during ginning. Average energy inputs required for ginning were calculated for the functional unit. Manpower required to process

1 kg of cotton is calculated to be 0.002 man h/kg. Electrical energy required for the processing of 1 kg of yarn is 0.5863 MJ/kg.

Based on electrical energy consumed for ginning GHG emissions are calculated to be 0.131025 CO_2eq/kg Cotton yarn [15]. Indian national emission factors have been used for the analysis.

Energy and emissions analysis of transport for spinning plant:

Transport data has been obtained by communicating with the firm personnel from Uttarakhand district between 2012-2015 periods. Transport of ginned cotton, plastic and paper cone and packaging material like H.D.P.E., L.D.P.E. and Cardboard box are considered. Employee transport for local and business transport have been considered. The energy inputs from transport are found to be 1.7894 MJ/ kg Cotton yarn. Of this major portion is contributed by transport of raw material which is 1.709 MJ/ kg Cotton yarn.

The emission analysis shows that the transport of raw materials and employee transport related to spinning plant is 0.1452 CO_2eq/kg cotton yarn. This analysis does not include Air and rail transport.

Energy and emissions analysis of spinning:

For the spinning process of cotton yarn, only electrical power is important for the LCA calculation (the maintenance of the machine can be neglected, as well as the making of it) [16]. The total electrical energy consumption is 8.84 MJ/kg cotton yarn. Out of this 97.7% of electrical power is from grid and 2.3% is from DG set. Figure 5 illustrates the percentage distribution of total electricity in various phases of spinning, within the plant. It takes up 44% of energy in spinning step, consisting of both Ring and Rotor spinning, followed by Pre-draw, Lap and combing which consume 16% of energy. This shows that maximum electricity is consumed in spinning phase. Humidification and air conditioning takes 16% of the energy.

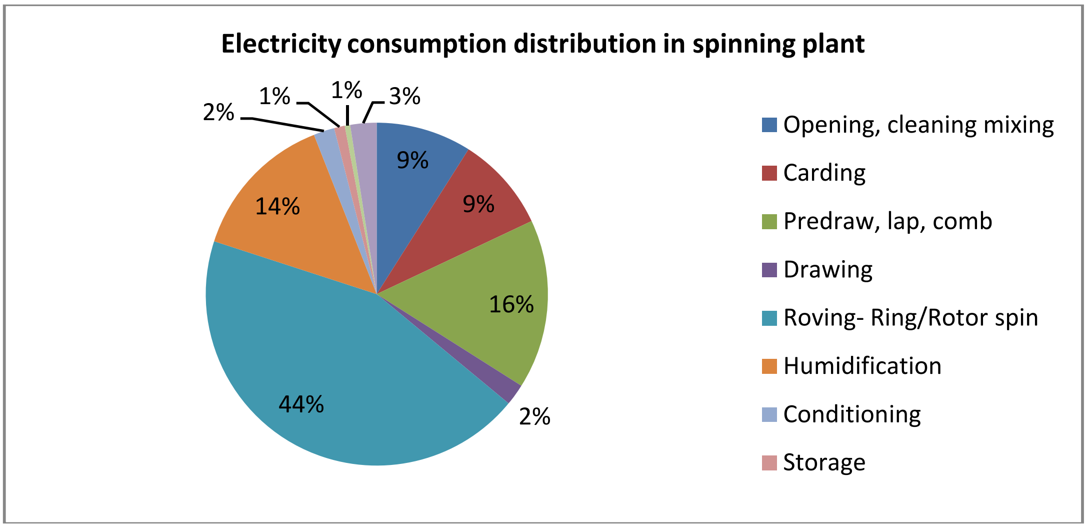

Figure 5: Distribution of electricity emissions in various stages of spinning

The GHG emissions have been attributed to grid electricity and electricity generated from DG set. The analysis shows that grid electricity contributes to 2.137 kgCO2eq/kg of cotton yarn and diesel combustion is responsible for 0.090 kgCO2eq/kg cotton yarn. Figure 3 shows the contribution of grid and DG electricity to total GHG emissions. The emission analysis shows that the spinning emits GHGs which is 2.2273 CO_2eq/kg cotton yarn.

Energy and emissions analysis of Packaging

The total energy inputs from packaging have been found to be 0.1549 MJ/kg of cotton yarn produced. This major energy input of packaging has been contributed by cardboard (0.1432 MJ/kg cotton yarn), HDPE bag (0.0075 MJ/kg cotton yarn), Paper cones 0.0038 MJ/kg cotton yarn) and LDPE packaging (0.0002 MJ/kg cotton yarn).

The energy and emission analysis of packaging material has revealed that this phase contributes to 0.0075 CO_2eq/kg cotton yarn and cardboard has the highest contribution to GHG emissions. Reuse and recycling scenarios of packaging materials have not been considered in this analysis.[17]

Based on mass allocation the Life Cycle analysis of cotton yarn production, Figure 6 shows that Life cycle GHG emissions for cotton yarn are highest in spinning stage . It is followed by farming phase which is the next highest contributory phase. The next most important phases are ginning and transport to spinning plant.

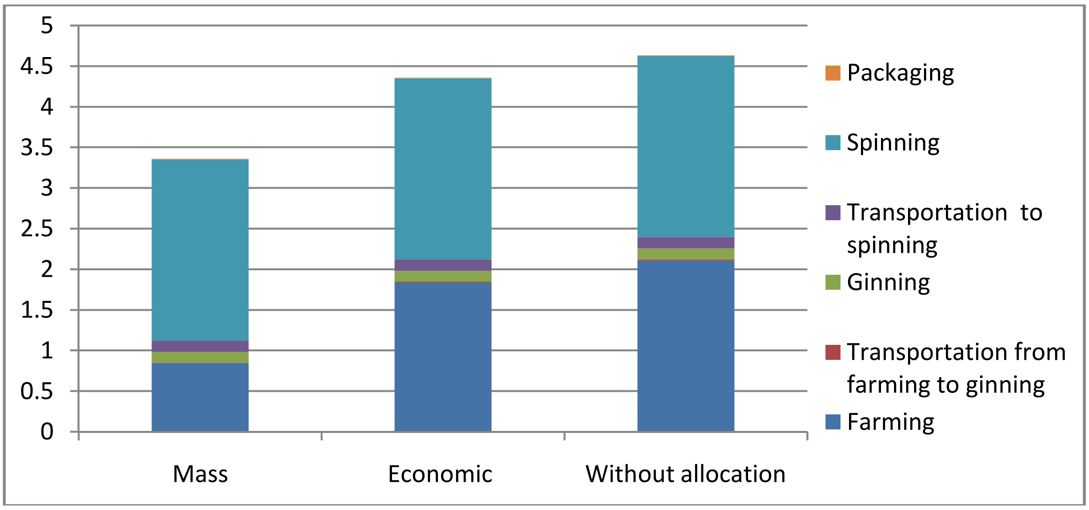

Figure 6: Distribution of electricity in various stages of life cycle stages of cotton yarn

RECOMMENDATIONS

The life cycle analysis of cotton yarn production has revealed that manufacturers need to focus on spinning and farming phases in order to reduce overall emissions from cotton yarn production. The manufacturers can reduce the carbon footprint in spinning stage by the following measures.

- Electrical meters to quantify the optimal power consumption based on output of machine.
- Use of DG waste heat will lead to reduced thermal and air pollution as less flue gases of high temperature will be released.
- Installation of Solar power system to meet partial load during peak or daytime
- Overall equipment efficiency of machine based on ideal cycle time.
- Machine modification or technological upgradation
- Improving the loading of motors, as the quantum of energy saving will depend on the extent of loading.
- Efficient blowers should be used for higher CFM.

The analysis revealed that sustainability of farming phase can be improved by using modern better management practices such as drip irrigation and use of organic farming to reduce the overall impacts. Reduced fertiliser application will substantially control the GHG emissions.

The prospect of energy recovery from cotton ginning waste can lead to substantial emission reduction. Almost half the plants thermal requirements can be met by a bioenergy unit in the plant.

Transport emission contribution can be reduced by sourcing raw materials from nearby suppliers and using larger vehicles to reduce the number of trips.

CONCLUSION

There is a general consensus among scientific community that cotton is a better option as it is a natural fibre. Therefore, there is a need for detailed information of energy and emissions profile of cotton yarn. Results for the Cotton yarn production pathway aim to highlight the life cycle GHG emissions in Indian context. This is the first life cycle study of Indian textile products/processes pathways. Findings from the current emissions analysis of yarn production are expected to improve the supply chain by focusing on the phases which have the higher impact, which in turn will help to enhance decision making in the textile production processes. This study will give a benchmark for comparing cotton yarn with other fibre yarns.

NOMENCLATURE

LCI – Life Cycle Inventory
MJ/kg – Mega Joules/kg
LCA – Life Cycle Assessment
CO_{2eq} – Carbon dioxide equivalent
ISO – International Standards Organization

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