LIFE CYCLE ASSESSMENT OF

CONVENTIONAL AND ORGANIC COTTON CULTIVATION

FOR THE

PRODUCTION OF A T-SHIRT

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Summary

1. Goal and Scope Definition

1.1 Abstract

In this paper, the environmental impact due to cultivation of the conventional and organic seed fibers was determined using life cycle assessment (LCA). Beyond this, a standard t-shirt that is produced from cotton fiber was analyzed for environmental impact, though the process does not differ between the cotton fiber types. Conventional cotton cultivation involves more machinery, pesticides, and harmful compounds that organic cotton cultivation purposely abandons. Organic cotton adopts many natural pest controls and utilizes more manual labor and natural manure and composite to nurture the cotton plant. The LCA shows that the conventional cotton cultivation process dominates the environmental impacts, especially for eutrophication and global warming impact. Organic cultivation does require a substantial amount more of land and water use however, but this is a necessary trade-off to avoiding releasing harmful inorganic compounds into the biosphere from pesticide use. This LCA also shows that the chemical oxygen demand is a high concern in cotton manufacturing, where many components of the dyes, bleaches, and washing agents are found in the waste water effluent.

1.2 Introduction

The cotton industry revolutionized the Western world and has grown to one of the most prevalent trade networks globally. More recently, the organic cotton industry has been taking off, and finally stabilizing after years of wavering supply and demand. Now, India is the main supplier of organic cotton, producing almost 75% of the world's supply. In the world rankings according to Textile Exchange, India, Turkey and the United States are ranked 1st, 4nd, and 5th in organic cotton production and are the focal points of this study[1]. The USDA ranks each country's conventional cotton productions as 2nd, 8th, and 3rd respectively making these countries instrumental in both markets[2]. The clothing industry is the biggest cotton consumer, a global market important in all corners of the earth. Thus, a Life Cycle Assessment is performed between conventional and organic cotton in order to compare the environmental viability of each process as the cotton is processed into fabric for a basic t-shirt. This all-encompassing process will help show the differences between the two cultivation practices and how each impacts the environment differently while processing the cotton to a fully functional product pertinent to all consumers.

1.3 Goal Definition

The objective of this LCA is to determine the cotton cultivation method that results in less environmental degradation. The practicality of organic cotton growth is to be fully identified, measured by how much more eco-friendly the practice is or is not for each impact category. Organic versus conventional cultivation practices are directly compared. One blue t-shirt will be produced with each type of cotton, but the manufacturing process for each is identical, so is not a determining factor in the conclusion. It is however a process that is included to make the results more realistic and complete. With this aim, it will be carried out using cradle-to-gate analysis.

This study does not seek to include any economic or social aspects of the market. Though organic cotton is more expensive, this study only seeks to show how the different cotton cultivation practices compare environmentally.

1.4 Scope Definition

This study is aimed at all consumers deciding between an organic or conventional cotton T-shirt. It will be relevant in locations with a high density of cotton production, like India, Turkey and the United States, which is also where most of the collected data is from. It is also pertinent in a consumer mindset since this study serves to inform the consumer of the implications of buying either type of cotton t-shirt. China, India, Pakistan and Turkey are the top 4 cotton consumers with the United States ranking 7th[3], so this is also a geographical limitation. Temporal coverage includes the last 20 years as some cultivation practices have not changed considerably, and the technology is representative of this time span.

Table 1 lays out the included and excluded variables of this particular study[15]. The seeds were excluded from this study because it was found that 20 kg of seed per hectare were necessary for both processes, and land use is more telling for the yields. Also, 5% of the cotton seed waste generated is ordinarily used for the next yield's planting and the rest is either used as feedstock, sold to cottonseed oil manufacturers or deemed waste[18]. Human labor transport of the workers to the farm is excluded for simplicity and the assumption that in many places that the utilized studies take place, employees live close to or on the property. Crop rotation of the land was also excluded because the scope encompasses one growing season of only the direct yield of cotton.

The life cycle impact assessment (LCIA) method utilized in this study was reCiPe, which provides all necessary emission factors. Global warming potential (GWP), nutrient enrichment potential, acidification, and photochemical ozone formation were the main incorporated impact categories analyzed, with considerations of land use and water use. These were chosen because with production involving dyeing, pesticides, and farming, eutrophication and acidification impacts are usually significant. GWP is also a large contributor as machinery is used and products are transported, necessary parts of the production process.

Table 1

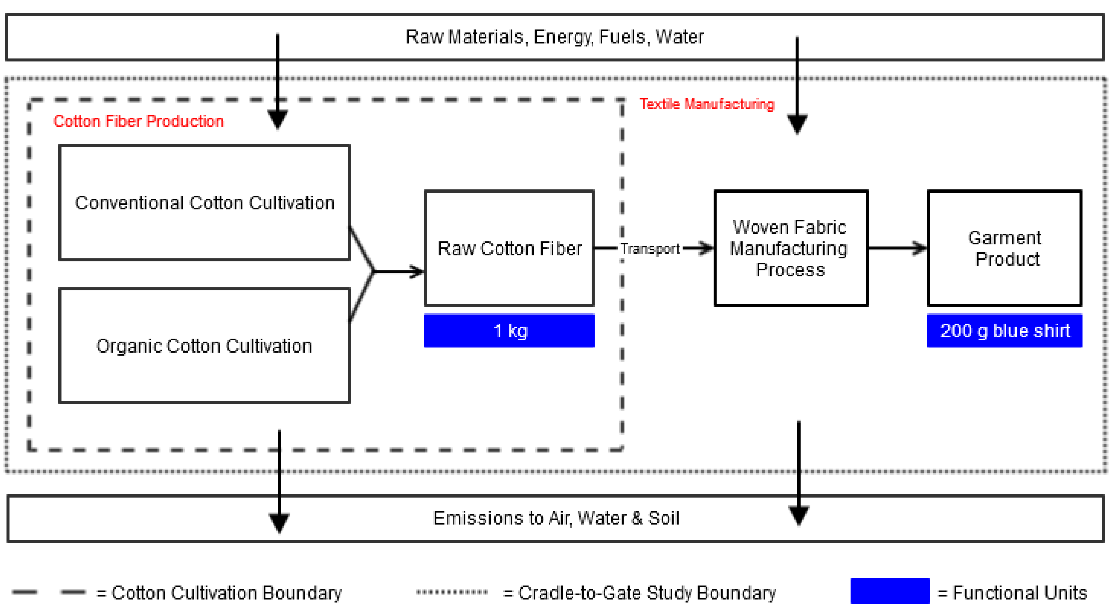
Included	Excluded
+ Cotton cultivation energy, resources and necessary growth additives	- Ancillary material production (dyes, chemicals, etc.)
+ Cotton harvesting energy and resources	- Transport of finished products
+ Saw ginning energy	- Fabric use phase washing and drying
+ Energy and emissions for fabric production	- Fabric end of life
+ Transport of intermediate products on farm and to fabric manufacturer	- Seed purchase and transport
+ Human labor	- Human labor transport
	- Crop rotation

1.5 Functional Unit & Environment System Boundary

The functional unit of an LCA is necessary to define the link between the two compared processes so that they are on the same terms. It is the physical output, and defines the utilization of the product. In this study, there are two functional units. During the cultivation phase, the functional unit will be the product of 1 kg of cotton fiber. After the manufacturing process, the unit of 1 blue t-shirt of approximately 200g will be used and 250g of weaved cotton fiber will have been required for the production of this shirt. This means that all values found in the production stage will be multiplied by 4 to match the functional unit of 1 kg of cotton[17]. The lifespan and end-of-life processes exceed the scope of this cradle-to-gate study. The latter functional unit will be a more accurate representation of the final product, but the means of processing the fibers into a shirt is not different for each type of cotton, as aforementioned. Mainly, dyeing depends on multiple factors but means of cultivation is not listed as a main contributor[4].

Figure 1 outlines the functional units and system boundaries as aforementioned.

Figure 1



2. Inventory Analysis

2.1 Flow Diagram

The basic flow diagrams, including tangible inputs and outputs, are shown below for cultivation and manufacturing. Detailed names and environmental impacts are excluded for simplicity, and listed in detail elsewhere. Figure 2 and Figure 3 show the flow of tangible inputs and outputs for conventional and organic cotton cultivation, respectively. Figure 4 is the detailed manufacturing process adopted by both types of cotton at a standard processing plant that renders cotton fiber into wearable t-shirts.

Figure 2: Conventional Cotton Cultivation Input and Output Flow

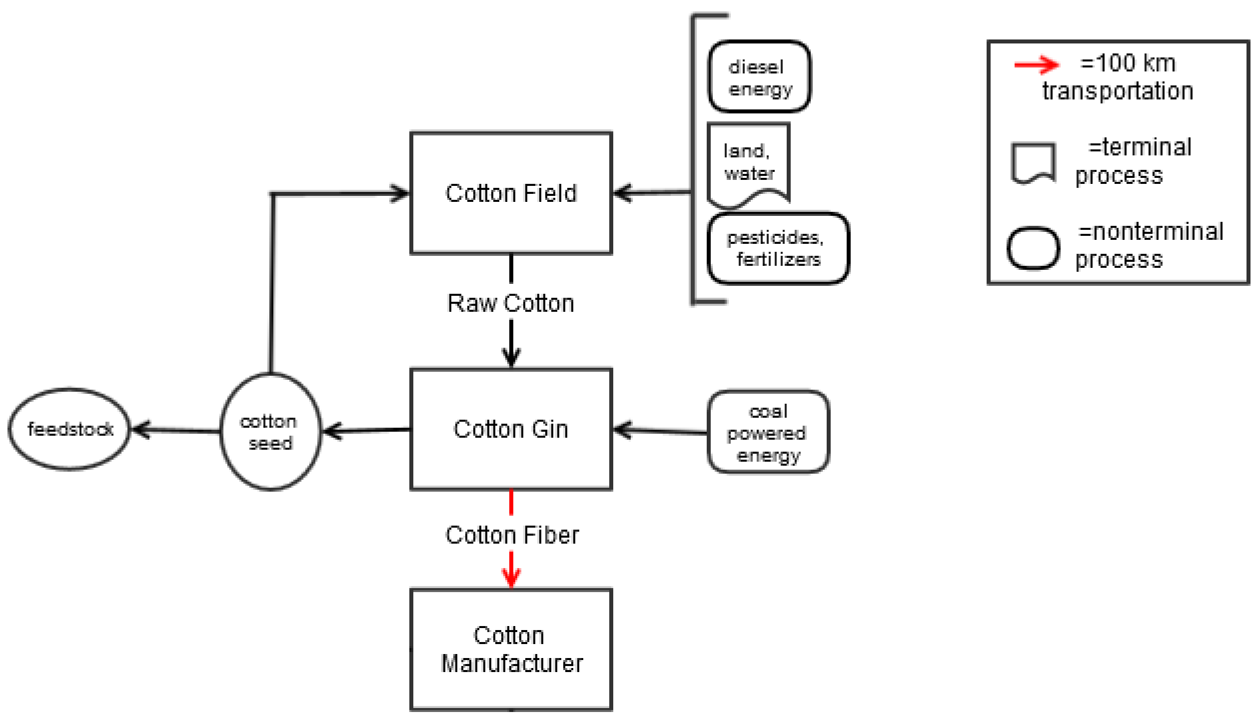


Figure 3: Organic Cotton Cultivation Input and Output Flow

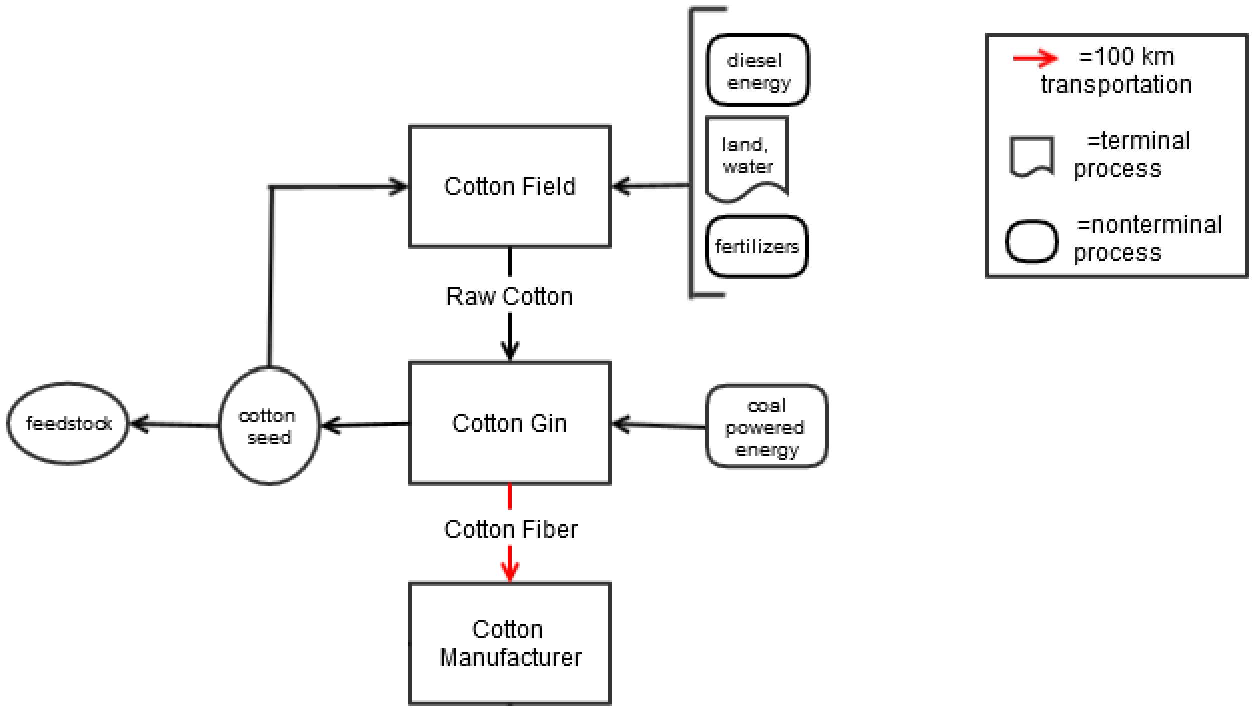
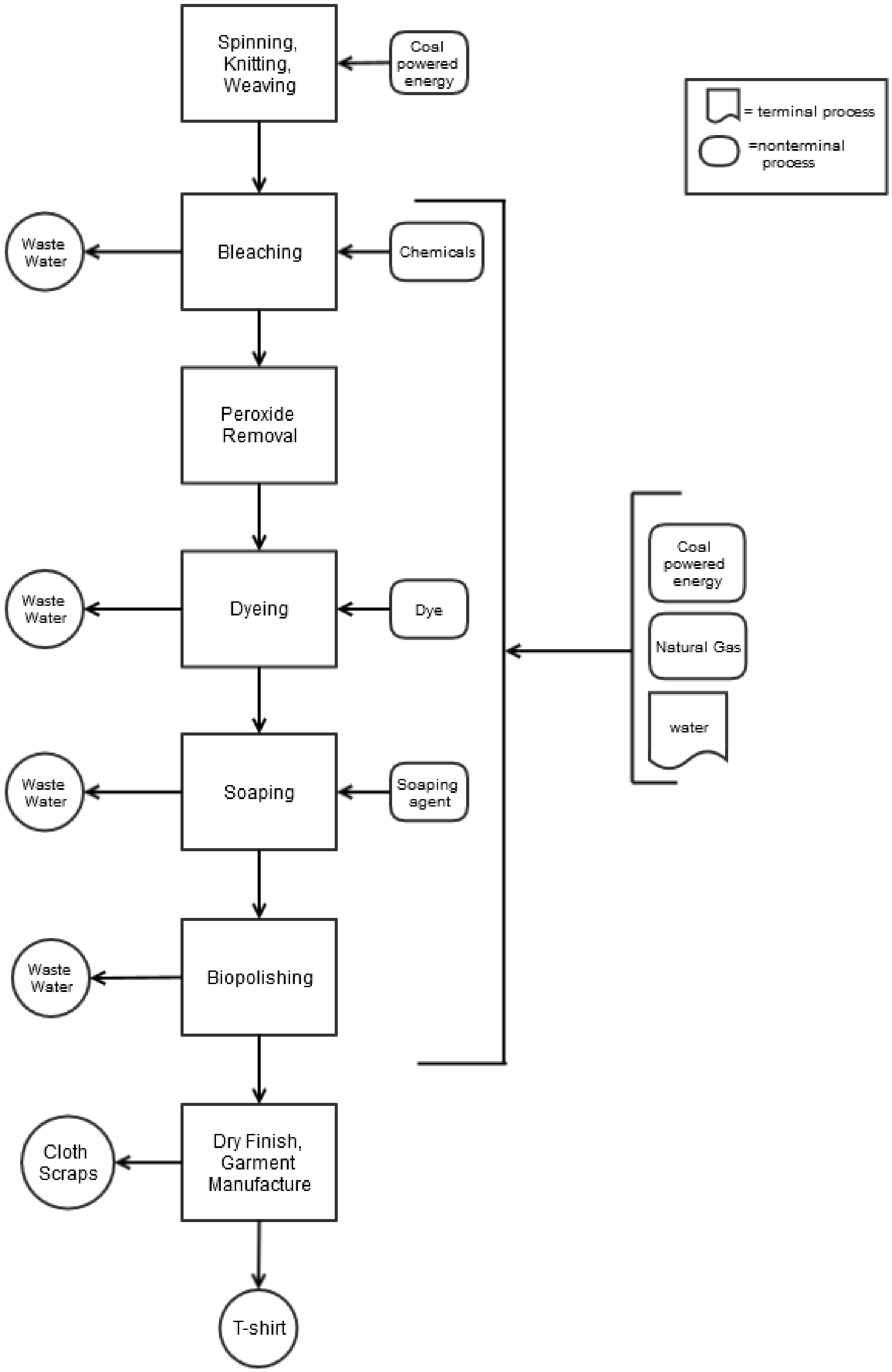


Figure 4: Standard Cotton Manufacturing Inputs and Outputs



2.2 Data Collection & Corresponding Assumptions

Land Use

To calculate the land use input, it was found that approximately double the amount of hectares is needed to produce the same amount of cotton for organic versus conventional methods. The exact land values of 1,127 kg fiber per 1 ha for conventional and 570 kg per ha of cotton fiber[5] for organic cultivation were used for this study. When appropriately rounded, the land use values in terms of the functional unit are 0.001 and 0.0018 hectares per kg cotton fiber respectively. This is an increase of 80% from conventional to organic cotton cultivation.

Electricity Use

The electricity emissions calculated in this study come from the energy mix in India. India uses 69% coal, 14% hydroelectric, 10% natural gas, 4% oil, 2% nuclear, and 1% of assorted renewables[21]. For this study we only calculated emissions from coal, oil, and natural gas, which you can see in Table 2 below. The percentages are different in the table below, but are proportional. The values calculated for the energy mix will be used throughout the study.

Table 2. India's Electricity Mix and Associated Emissions.

India Electricity Mix	Coal (kWh)	Natural Gas (kWh)	Oil (kWh)	Mix
Percent	83.13%	12.05%	48.19%	
kg CO_2	0.324	0.18	0.25	0.303
CH_4 (kg CO_2eq)	0.00006	0.00027	0.00053	0.000108
N_2O (kg CO_2eq)	0.00282	0.00011	0.00067	0.00239

Cultivation

The process of cultivation has three different kinds of impacts: energy use, inputs, and outputs. The inputs include fertilizer (nitrogen, phosphorus, potassium), fungicides, herbicides and insecticides, seeds, water use, and oil use. The outputs include the different emissions to air, soil, and water, cotton fiber and cotton seed.

Urea is the most common nitrogen fertilizer produced and imported in India, and is thus assumed in this study. Urea quickly breaks down into ammonia and carbon dioxide when in the presence of water[6], which leaches into the soil and breaks down quickly to avoid bioaccumulation. Thus the fertilizer will contribute to GHG emissions as well as eutrophication and acidification.

The energy use in conventional cotton cultivation is composed of a combination of human labor and machinery. According to a study in Turkey, the energy required for cultivation was 25% mechanical energy and 75% human labor, and is represented in Table 2 below. Organic and Conventional cotton both use a very similar proportion of human labor to mechanical labor. To cultivate 1 kg of cotton, which requires 0.001 hectares, 1.41 MJ of energy was needed. Harvesting was the largest factor for human labor with 0.64 MJ/kg of cotton, while land preparation had the largest energy demand by machinery, with 0.24 MJ/kg of cotton. This is not a large surprise because in poorer areas of cotton cultivation, the majority of harvesting is done by hand, and land preparation is much more practically performed by a plow than by individuals with hoes. Organic cotton cultivation clearly used more energy, 3.00 MJ, because an 80% larger area of land, or 0.0018 hectares, is required for organic cotton. Machinery and Human Labor energy values were calculated proportionally from the values found for conventional energy consumption in Table 3[12]. The emissions and impact on the environment from human labor are not directly quantifiable. Human labor being quantified in terms of MegaJoules, or in any energy unit at all is a largely debated topic. Practically, it does not make sense because there is no meaningful way to convert the energy use into emissions. Also, the debate is made that the CO_2 emitted by humans would be emitted regardless of if the labor was being utilized or not, so is not necessary to quantify. However for the purpose of this study, human labor has been included to allow a more clear comparison of the two methods of cultivation. The energy values however will not be further quantified or included in the findings of the LCA.

Table 3. Energy Use Distribution of Conventional and Organic Cotton Cultivation[12]

	Energy Equivalence for Conventional (MJ/kg of cotton)	Energy Equivalence for Organic (MJ/kg of cotton)
Human Labor	**1.046**	**2.44**
-Land Preparations	0.012	0.46
-Sowing	0.0037	0.045
-Cultivation Practices	0.39	0.73
-Harvesting	0.64	1.15
-Other Practices	0.0037	0.052
Machinery	**0.36**	**0.55**
-Land Preparations	0.24	0.44
-Sowing	0.021	0.039
-Cultivation Practices	0.017	0.031
-Other Practices	0.078	0.045
Total:	**1.41**	**3.00**

As listed previously, there are a multitude of inputs. The inputs also vary between conventional and organic cultivation. These values were found from source 5, 7, and 9 using the most popular chemicals and fertilizers utilized for cotton production, particularly the United States.

Table 4. Inputs into the Cultivation of Organic and Conventional Cotton.

	Conventional (unit/kg of cotton)	Organic (unit/kg of cotton)
Chemical Fertilizer (kg)	**0.24**	--
-Nitrogen	0.13	--
-Phosphorus	0.056	--
-Potassium	0.054	--
Organic Fertilizer (kg)	--	**6.21**
-Rock Phosphate	--	0.0997
-KCl	--	0.04154
-Manure	--	5.867
-Compost	--	0.2
Seed (kg)	0.0327	0.0589
Chemicals (kg)	**0.0029**	--
-Insecticides	0.002	--
-Fungicides	0.0002	--
-Herbicides	0.0007	--
Land Use (ha)	0.001	0.0018
Diesel-oil (L)	0.0592	0.107
Water for Irrigation (m^3)	6.944	12.50

The emissions from machinery use are quantified by finding the emissions associated with the 0.0592 L of diesel-oil used per kg of cotton. The total kg CO_2eq found from the diesel-oil emissions is 0.158 kg CO_2eq for conventional cotton as seen in Table 13. Organic cotton contributes a larger value, 0.283 kg of CO_2eq, due to the larger area of land required for farming.

Table 5. Greenhouse Gas Emissions from Diesel-Oil Consumption by Machinery in Cotton Cultivation per 1 kg of Cotton Fiber.

	CO_2	CH_4	N_2O
1 L of Diesel conversion units	2.657 kg CO_2	0.0009 kg CO_2eq	0.0191 kg CO_2eq
Emissions for Conventional (kg CO_2eq)	0.157	0.000053	0.0011
Emissions for Organic (kg CO_2eq)	0.283	0.000096	0.0020

The use of chemicals on the cotton crops, occurs in conventional farming. The specific chemicals used in this study was extrapolated from source 9 and the emissions were found in source 7. These values were then converted to our functional unit of 1 kg of cotton. Below you can see the impact of the different chemicals on the water supply.

Table 6. Chemical Emissions to Aquatic Ecotoxicity from 1 kg of Cotton Fiber.

Types of Chemicals	Chemical	Aquatic Ecotoxicity	Units
Pesticide	methyl parathion	2.8	kg of 1,4DB
Herbicide	glyphosate	0.00231	kg of 1,4DB
Insecticide	aldicarb	240	kg of 1,4DB

Ginning

The ginning process is necessary to separate the raw cotton fiber from the cotton seeds that are both found in a cotton plant. A saw gin is assumed because it the only technologically advanced way to separate seed from fiber, and is most efficient and globally accepted. It is much more productive and widely used than the older roller gin that is handheld and less advanced. Figure 5 shows a standard saw gin's energy consumption values[8] for all the internal processes and then converted to be compatible with the functional unit of 1 kg cotton.

Cottonseed is a by-product of the cotton plant, which is primarily grown for its fiber. Cottonseed can produce oil, and falls about fourth or fifth in the world production of oils. In the United States, about 15% of the producer's income is from the seed portion of the crop. The cotton seed market is also very prominent in India, as it is sold off in many of the states, and sells quickly. What isn't sold for oil production is either used for planting the next round of crops or, mainly, cattle feedstock. United Nations Conference on Trade and Development describes the product flow of seed cotton into fiber and seeds, where mass-wise, 42% and 58% respectively are the market ratios. However, this 42% mass accounts for 85% of the commercial value of seed cotton[18]. Thus, a ratio of 85:15 is used for economic allocation of all cultivation impacts.

Figure 5

Energy Consumption by Gin

Function		Saw Gins	
		kWh/bale	MJ/kg
1. Seed Cotton Drying		5.53	0.09
2. Seed Cotton Cleaning		2.60	0.04
3. Ginning		6.38	0.10
4. Lint Cleaning		2.21	0.04
5. Bale Press		3.98	0.06
Value Added		20.70	0.33
6. Seed Cotton Unloading		1.56	0.02
7. Seed Cotton Conveying		1.79	0.03
8. Lint Conveying		4.65	0.07
9. Seed Conveying		1.11	0.02
10. Trash Conveying		4.43	0.07
Materials Handling		13.53	0.21
Total		34.23	0.54
Processing Rate	(kWh/bale	44.20	
	(MJ/kg)	0.70	
Sample Size		15	

The sum of energy output for the actual ginning process (steps 1-5) was 20.98 kWh in the paper used, but when each component was summed, it came out as 20.70 kWh. This latter value was used in this study because where the extra 0.28 kWh came from was unclear. Whether assumptions were made or significant digits were excluded is not stated, so without knowing what that value inherently assumes, it cannot be used. Thus the "Total" value was altered to reflect this "Value Added" change, and the conversions were performed appropriately. This value is added to total energy use of both processes of cultivation. Also, the emissions from the MJ of electricity were found from India's electricity mix, which can be found in Table 2. The total emission from this process is 0.0594 kg CO_2eq, as can be seen in Table 7. The values were converted from MJ to kWh to emissions per kg of cotton.

Table 7. Cotton Gin emissions from 0.7 MJ of Energy Used[10]

	CO_2	CH_4	N_2O
Units	kg CO_2	kg CO_2eq	kg CO_2eq
Emissions	0.0589	2.1E-5	4.65E-4

Transportation

Transportation occurs when the ginned cotton fiber is being transported to the textile factory. Assumptions were made while determining the transportation impacts, such as assuming the cotton would be transported in a standard pick-up truck (9ft x 45ft x 8.5ft) a distance 100 km, the stowage factor for cotton being 4.25 m^3 per metric ton, and that the miles per gallon of the truck while full would be 6 mpg and empty would be 8 mpg. The same constants from the UK government that were used to find diesel emissions from cultivation machinery were used here. Using this data and the assumptions, calculations and conversions showed that 22936 kg cotton are transported in each semi-truck, 105.4 kg CO_2[10,11] is emitted for the full truck traveling the 100 km, and only 79 kg CO_2 is emitted from the empty truck returning that same distance, leading to 8 g CO_2 per kg of cotton.

Table 8. Fuel use of Ginned Cotton to a Textile Factory in a Standard Semi-Truck

	Full Truck	Empty Truck	Units
Mileage	6	8	mpg
Mileage	9.7	12.9	km/gal
Diesel Used	39.20250952	29.40188214	Liters

Table 9. Emissions from Transportation of Ginned Cotton to a Textile Factory

	CO_2	CH_4	N_2O	Total
Conversion Factor	2.657 kg CO_2	0.0009 kg CO_2eq	0.0191 kg CO_2eq	--
Emissions of a Full Truck	104.16	0.035	0.75	104.95
Emissions of an Empty Truck	78.12	0.026	0.56	78.71
Emissions per kg Cotton	0.0079	2.7E-6	5.7E-5	0.008

Textile Plant

In a textile factory, there are a multitude of processes. For cotton fiber to become fabric, and eventually a t-shirt, it must first become fabric. This occurs through the steps of yarn spinning, weaving, and knitting. Once fabric is made, it must go through desizing, scouring, bleaching, peroxide removal, soaping, dyeing, biopolishing, and finishing[19]. This study only focuses on a few of the main steps, including bleaching, peroxide removal, dyeing, soaping, and biopolishing. These processes are analyzed by the functional unit of a 200g t-shirt. When a comparison is made between these processes, it is clear to see which ones have the largest impacts by making additional tables. A woven t-shirt is assumed since this is the most common practice as opposed to knitting. The following processes are utilized in the weaving process[17].

Table 10. Energy and Resource Consumption of Textile Processes for a 200g t-shirt (FU) and Consequential Waste Water COD

	Bleaching	Peroxide Removal	Dyeing	Soaping	BioPolishing	Total
Electricity Consumption kWh/FU	0.023	0.016	0.061	0.035	0.028	0.164
Heat Consumption MJ/FU	0.461	0.138	0.138	0.968	0.415	2.120
Water Consumption m^3/FU	0.013	0	0.007	0.011	0.0066	0.037
Emission to Waste Water kgCOD/FU	15.65	0	0.882	0.882	2.87	20.29

Table 11. Percentage Impacts of Textile Processes for a 200g t-shirt (FU)

	Bleaching	Peroxide Removal	Dyeing	Soaping	BioPolishing
Electricity Consumption kWh/FU	14.09%	9.80%	37.38%	21.45%	17.28%
Heat Consumption MJ/FU	21.75%	6.51%	6.51%	45.67%	19.56%
Water Consumption m^3/FU	34.57%	0	18.61%	29.25%	17.58%
Emission to Waste Water kgCOD/FU	77.15%	0	4.35%	4.35%	14.15%

The emissions found in Table 12 of kg CO_2, g CH_4, and g N_2O were found by calculating the emissions from electricity consumption and heat consumption. India's electricity mix from Table 2 was used to find the emissions. This data will be used for the impact assessment part of the LCA process. The chemical inputs of invadine CWA, Prestogen FPL, H2O2, Jinterge LCF-185, Albaflow JET, and LIPOTOL FMB, and Acid Blue 142, impacted the wastewater emissions in terms of kg of Chemical Oxygen Demand (COD)[14]. Notable takeaways from the process analysis are that 77% of the waste water is due to bleaching, 46% of heat consumption is due to soaping, and dyeing uses the most electricity with 37%[16].

Table 12. Total Emissions from Processing for one 200g t-shirt

	kg CO_2	CH_4 (kg CO_2eq)	N_2O (kg CO_2eq)	m^3 water	kg COD
Total Processing Emissions	0.2282	8.13E-05	0.0018	0.037	20.29

2.3 Data Quality

Having access to quality reliable data has not been an obstacle in this LCA study. A majority of the data came from a few scholarly research papers and LCA studies, and were combined together post-functional unit conversion to paint a complete picture of the processes, input and outputs necessary for this entire process from cotton seed to a fully functional t-shirt.

3. Impact Assessment

3.1 Life Cycle Analysis of Conventional Cotton Cultivation

As can be seen in Table 4, conventional cotton cultivation actively adds 0.13 kg of Nitrogen, 0.056 kg of P_2O_5 equivalence, and 0.054 kg of K_2O equivalence to the soil. These chemical additives to the farmland will lead to potential environmental impacts of eutrophication, GWP and ozone formation. In addition to Table 4, the diesel emissions from machinery in Table 4 lead to GWP and photochemical ozone formation. The water ecotoxicity from the different chemicals added for pest and herbicide control totaled to 242.8 kg of 1,4 DB. The global warming potential from conventional cotton cultivation is 0.579 kg of CO_2eq. The potential eutrophication impacts due to conventional cultivation are 0.274 kg of NO_3eq. The potential acidification impacts are 2.20E-06 kg SO_2eq. The potential photochemical ozone formation impacts are equal to 0.1105 kg NMVOCeq.

3.2 Life Cycle Analysis of Organic Cotton Cultivation

Table 15. Nutrient Content from Soil Additives in Organic Cotton Cultivation

	Manure	Rock Phosphate	KCl	Compost	Total
	kg/kg cotton	kg/kg cotton	kg/kg cotton	kg/kg cotton	kg/kg cotton
Nitrogen	0.029	--	--	0.001	0.0303
P_2O_5	0.012	0.0299	--	0.0003	0.0419
K_2O	0.029	--	0.023	0.001	0.0532

These nutrient values of the soil additives were converted from the inputs of manure, rock phosphate, KCl, and compost. These nutrients will aid in plant growth and development, but will also lead to an environmental impact of eutrophication of groundwater as well as potential ozone formation in the troposphere. The Global Warming Potential from fertilizers as well as diesel is 0.346 kg CO_2eq. The potential eutrophication of groundwater from soil additives in organic cultivation is 0.148 kg NO_3eq. The Acidification potential is 4.06E-06 kg SO_2eq. The potential photochemical ozone formation due to the addition of nitrogen into the environment is 0.02576 kg NMVOCeq.

3.3 Life Cycle Analysis of Cotton Ginning

Cotton ginning values can be seen in Table 7 and are added to the total impact of both cotton types equally. The emissions from this process are CO_2, CH4, and N_2O and led to an impact in the following categories. The global warming potential from 0.7 MJ of electricity used to power a cotton gin for one kg of cotton is 0.0594 kg of CO_2eq. The potential acidification of the environment from the cotton gin is 1.09E-06 kg SO_2eq. The potential photochemical ozone formation from the cotton gin is 1.56E-06 kg NMVOCeq.

3.4 Life Cycle Analysis of Cotton Transportation

Cotton transportation emissions from the farm after ginning to the textile plant is found in Table 8 and Table 9. The global warming potential due to the transportation of cotton is 0.008 kg of CO_2eq. The potential acidification impacts of transportation is 1.34E-07 kg of SO_2eq. The potential photochemical ozone formation impacts is 1.91E-07 kg of NMVOCeq. These impacts are also added equally to both cotton types.

3.5 Life Cycle Analysis of Cotton Manufacturing

The total emissions from manufacturing a cotton t-shirt can be found in Table 12. This data totals the emissions from the 5 different steps of manufacturing that were accounted for. The global warming potential due to the manufacturing of raw cotton fiber into a t-shirt is 0.920 kg CO_2eq. The potential acidification impacts of the manufacturing process is 1.69E-05 kg of SO_2eq. The potential photochemical ozone formation impact is 2.42E-05 kg NMVOCeq. This means that although we have data for this category, it is 4 times less cotton, and so the values were multiplied accordingly.

4.Conclusions

Table 13. Conventional Cotton Impact Assessment for 1 kg Cotton Fiber

Impact Categories	Cultivation	Ginning	Transportation	Processing	Total
Global Warming Impact (kg CO_2eq)	0.579	0.0594	0.008	0.920	1.566
Eutrophication (kg NO_3eq)	0.274	-	-	-	0.274
Acidification (kg SO_2eq)	2.20E-06	1.09E-6	1.34E-07	1.69E-05	2.03E-5
Photochemical Ozone Formation (kg NMVOCeq)	0.1105	1.56E-6	1.91E-07	2.42E-05	0.11053

Table 14. Organic Cotton Impact Assessment

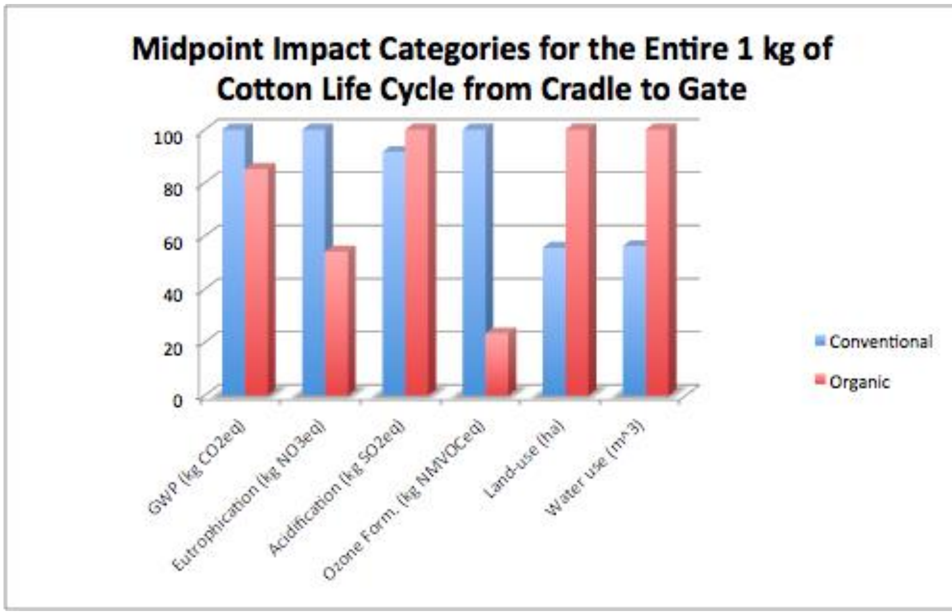
Impact Categories	Cultivation	Ginning	Transportation	Processing	Total
Global Warming Impact (kg CO_2eq)	0.346	0.0594	0.008	0.920	1.334
Eutrophication (kg NO_3eq)	0.148	-	-	-	0.148
Acidification (kg SO_2eq)	4.06E-06	1.09E-6	1.34E-07	1.69E-05	2.22E-5
Photochemical Ozone Formation (kg NMVOCeq)	0.02576	1.56E-6	1.91E-07	2.42E-05	0.0258

Table 15 represents the total impact category values when the cultivation and manufacturing processes were combined. This was done by using a reference flow that stated 250g of cotton fiber go into producing a 200g t-shirt. Thus, 4 200g t-shirts can be made out of the 1kg functional unit for cotton fiber.

Table 15. Impact Category Values for Organic and Conventional Cotton T-shirts

	Conventional	Organic
Global Warming Impact (kg CO_2eq)	1.566	1.334
Eutrophication (kg NO_3eq)	0.274	0.148
Acidification (kg SO_2eq)	2.03E-05	2.22E-05
Photochemical Ozone Formation (kg NMVOCeq)	0.111	0.0258
Land-use (ha)	0.001	0.0018
Water use (m^3)	7.129	12.684

Figure 5. Impact Category Values for Organic and Conventional Cotton T-shirts



This study shows a number of different environmental impacts due to the steps required to make a t-shirt, both by conventional means and by organic farming. For the conventional t-shirt, 37% of the GWP is from cultivation. Cultivation also was the only contributor to eutrophication, a 99% contributor of photochemical ozone formation, and yet only a 10% contributor to acidification. There is a similar trend with the organic cultivation. The eutrophication impact was close to half of the conventional value, and the photochemical ozone formation due to organic cultivation was the main contributor from the whole process with 99% of the impact. Water use by conventional cotton cultivation on the other hand was less than organic cultivation, by 45%, or 5.55 m^3 per kg of cotton grown, which when farming a huge field becomes a massive increase in water consumption. Waste water was created in conventional cultivation by runoff of chemical additives amounted to an impact potential to aquatic ecotoxicity of 242.8 kg of 1,4 DBeq. Manufacturing waste water was due to the chemical additives for the fabrics, such as the bleaching agents, soaping agents, and biopolishing enzymes, which added up to 17.41 kg CODeq. Since land-use is 80% greater with organic farming, it will lead to indirect future problems, such as the transformation of forests to farmland, which will in turn impact everything else. This study shows inconclusive evidence in support of either method. With this study only going to midpoint categories, it is impossible to compare land-use to photochemical ozone formation potential, to GWP. This study does make it clear that although one may believe that organic farming is the more environmentally friendly option, it is not such an obvious answer.

5. Recommendations

It is seen from the conclusion of this study that organic cotton is significantly less harmful to the environment directly, though indirectly the land use and water consumption is not optimal. However, these two higher values for organic farming are a trade-off for less eutrophication, global warming, ozone formation, ecotoxicity and acidification. Thus, recommendations for conventional cotton farming are more necessary since improving organic cotton's land use and water consumption would seem to inevitably lead to conventional cotton cultivation. There are methods currently used to improve organic yield like bio-pests and better irrigation systems like drip irrigation, but these are not a part of wide-scale use because of cost and peoples' reluctance to introduce a new bio-pest species into some ecosystems. A majority of the problem with conventional cotton cultivation is the consequences from the fertilizers and soil additives. These run-off and contribute to eutrophication and acidification and can leach into groundwater and cause health problems. If cotton farmers would invest in more natural fertilizers like manure, this could be mitigated. Also, the pesticides of choice as seen in Table 6 could be changed to compounds that break down faster in the water table so as to avoid bioaccumulation. Pesticides that have a high adsorption would be better because they are less likely to give off vapors, leach through the soil, or be taken up by plants[22]. Proper use, storage and disposal of pesticides are also important to avoid waste of pesticides as well as unnecessary environmental degradation.

Both cultivation practices could burn a cleaner energy than coal or oil for electricity to lessen the gin and manufacturing's impact, though it is also assumed that each burns a portion of natural gas as well due to India's energy mix.

6. Limitations of the Study

There are a few other steps that could be completed to make this study even better. CFC-12 is the aerosol released when herbicides and pesticides are applied across the cotton fields. Quantifying how much CFC-12 is released per amount of pesticide sprayed would be necessary to take into account the impact that CFC-12 would have on the environment and different impact categories. If these impact categories were taken from midpoints to endpoints, the viewing audience would have less trouble determining which impact categories are the most influential.

7. References

1. Pepper, Rhea. "2011 Organic Cotton Market Report." Textile Exchange, 2012. Web. 24 May 2014.

2. MacDonald, Stephen, James Kiawu, and Leslie Meyer. "Cotton & Wool." *United States Department of Agriculture Economic Research Service*. United States Department of Agriculture, 5 Mar. 2013. Web. 25 May 2014. <http://www.ers.usda.gov/topics/crops/cotton-wool.aspx#.U4FSLihluDk>.

3. "Cotton USE Domestic Consumption by Country in 1000 480 Lb. Bales." *- Country Rankings*. United States Department of Agriculture, 2013. Web. 24 May 2014.

4. Murugesh, Babu. "Life Cycle Assessment for the Dyeing and Finishing Process of Organic Cotton Knitted Fabrics." Journal of Textile and Apparel, 2013. Web. 24 May 2014. <http://ojs.cnr.ncsu.edu/index.php/JTATM/article/view/3396>.

5. Lakhal S., Sidibé H., and H'Mida S. (2008) Comparing conventional and certified organic cotton supply chains: the case of Mali

6. "Fertilizer Urea." *Nutrient Enrichment*. University of Minnesota, 2014. Web. 23 May 2014. <http://www.extension.umn.edu/agriculture/nutrient-management/nitrogen/fertilizer-urea/>.

7. Clayton, Zara, Marty Matlock, and Lawton Nalley. "Evaluation of Toxicity in Cotton Production and Toxicity Impact Assessment Methods." University of Arkansas Division of Agriculture, 4 Mar. 2010. Web. 29 May 2014.

8. Funk, Paul A., Robert G. Hardin, Ed Hughs, and Clif Boykin. "Changes in Cotton Gin Energy Consumption Apportioned by 10 Functions." *The Journal of Cotton Science* (2013): n. pag. The Cotton Foundation. Web. 30 May 2014.

9. "Pesticides Commonly Used on Cotton." Toxic Free NC, Mar. 2005. Web.

10. US EPA, Emission Factors for Greenhouse Gas Inventories

11. DECC, Department of Energy and Climate Change's GHG Conversion Factors for Company Reporting (2012)

12. Dagistan E., Akcaoz H., Demirtas B., and Yilmaz Y. (2009) Energy usage and benefit-cost analysis of cotton production in Turkey

13. Wood S. and Cowie, A. (2004) A Review of Greenhouse Gas Emission Factors for Fertiliser Production

14. Alcover F. (2011) Life Cycle Analysis of a T-Shirt

15. Cotton Incorporated (2012) Life Cycle Assessment of Cotton Fiber & Fabric

16. Babu R., Parande A., Raghu S., and Kumar P. (2007) Cotton Textile Processing: Waste Generation and Effluent Treatment

17. Nielsen A. and Nielsen P. (2009) Comparative life cycle assessment of the Elemental T-shirt produced with biotechnology and a Conventional T-shirt produced with conventional technology

18. "Cotton - Uses." UNCTAD. ICAC, 2003. Web. 26 May 2014. <http://r0.unctad.org/infocomm/anglais/cotton/uses.htm>.

19. Marmagne O., Coste C.,(1996) Color Removal From Textile Plant Effluents

20. Murugesh Babu. K and Selvadass M. (2013) Life Cycle Assessment for Cultivation of Conventional and Organic Seed Cotton fibres

21. Ebinger, Charles. "Policy Q & A: India's Energy Policy and Electricity Production." The National Bureau of Asian Research for the Senate India Caucus, Oct. 2011. Web. 30 May 2014.

22. "Ministry of Agriculture." *Environmental Fate of Pesticides*. British Columbia, n.d. Web. 29 May 2014. <http://www.agf.gov.bc.ca/pesticides/c_2.htm>.