

# A Comparative Life Cycle Assessment of Conventional and Organic Cotton in Denim Fabric

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## Abstract

*Purpose:* The textile industry involves processes such as yarn, dyeing, weaving, and finishing from the production of natural and man-made fibers, while the chemical, energy, and water amounts used in these processes and the wastewater it generates have an intense environmental impact. According to the European Environment Agency (EEA) estimates, the amount of clothing purchased per capita in the EU has increased by 40% in recent years. Due to these increases in consumption and awareness of environmental impacts, switching to new business models has become mandatory in the textile industry. This study aims to investigate the contribution of using organic cotton instead of conventional cotton, which is one of the most used raw materials in textiles and grown using dense water and pesticides in reducing the environmental impact of denim fabric production.

*Method:* Life Cycle Assessment (LCA) is a method that calculates the environmental impacts throughout the entire life cycle of a product, starting from obtaining the raw materials, to manufacturing processes, usage, end-of-life, and disposal. In this study, the CML-IA method was applied to investigate the result of substituting organic cotton instead of conventional cotton. As life cycle inventory, primary production data was used during denim production and secondary data from the Ecoinvent Database were used. LCA application from the cradle to the gate was implemented using Simapro 8.5.2 software.

*Results:* As a result of this LCA study, all environmental impacts of denim fabric decreased with the use of organic cotton. A significant reduction in fresh aquatic ecotoxicity with 96% was achieved compared to the use of conventional cotton. Moreover, in terrestrial ecotoxicity and photochemical oxidation potentials, quite remarkable improvements were gathered with 90% and 57%, respectively. As a result, the use of organic cotton as a raw material provides significant advantages, as the main reasons for environmental impacts in cotton cultivation, which is the hot spot of denim fabric, are the use of pesticides and synthetic fertilizers.

*Conclusions:* It is important to use organic products through the manufacturing processes to transfer the traditional linear economy business models of companies to a greener economy. In this way, companies can contribute to reducing their environmental impact with a sustainable approach.

## **1. INTRODUCTION**

Textiles and clothing are the fundamental parts of everyday life and an important sector in the global economy. It is hard to imagine a world without textiles. The total volume of the textile industry, of which about 300 million people work, is 1.3 trillion [1]. The share of the denim market in such a large economy is also quite large and is increasing regularly. The global denim market was valued at \$56,178.1 million in 2017 and is forecasted to witness a CAGR of 5.8% during 2018–2023 [2].

Today's textile industry is one of the largest greenhouse gas sources in the world due to the large size and scale of the industry, as well as the many processes and products involved in the manufacture of textiles and finished fabrics. In 2015, greenhouse gas (GHG) emissions from textiles production totaled 1.2 billion tons of CO<sub>2</sub> equivalent, more than those of all international flights and maritime shipping combined [1,3]. The main source of these emissions is that the raw materials and auxiliary materials used in production harm both the health of people in the supply chain as well as the environment. The high-volume consumption of the materials used in textiles also damages the environment with the rapid depletion of natural resources. Textiles production including cotton farming uses around 93 billion cubic meters of water annually, contributing to problems in some water-scarce regions [1].

Cotton, which accounts for more than 82% of the global fiber consumption, is the most widely used natural fiber [4]. Conventional cotton cultivation has high water and energy consumption, use of fertilizers and pesticides, and land use that can harm the environment and human health [5-7]. Since conventional cotton has significant environmental and health-related damages, alternative sustainable methods are obtaining more attention every day in the denim industry. Organic cotton production is one of these methods with its strict regulations and limits [6,8]. The use of genetically modified organisms is prohibited and there are strict limitations in the use of fertilizers with chemical synthetic pesticides in organic cotton production. Through such arrangements, it reduces the environmental impacts and enables production respectful to nature.

Consequently, cotton as the main raw material of denim fabric, it is important to examine its environmental impacts [9]. To reduce the environmental impacts in the denim industry, the use of organic cotton instead of conventional cotton needs to be evaluated in terms of its environmental impacts. LCA is a comprehensive and systematic tool used to determine the possible environmental impacts of a product, service, or process over the life cycle [10]. According to this methodology

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standardized by ISO 14040 and 14044, the LCA consists of four steps for operation [11,12]. These include the definition of purpose and scope, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA), and interpretation. Although LCA is a very useful tool for determining environmental impacts, life-cycle studies in the field of sustainable textiles are limited in the literature.

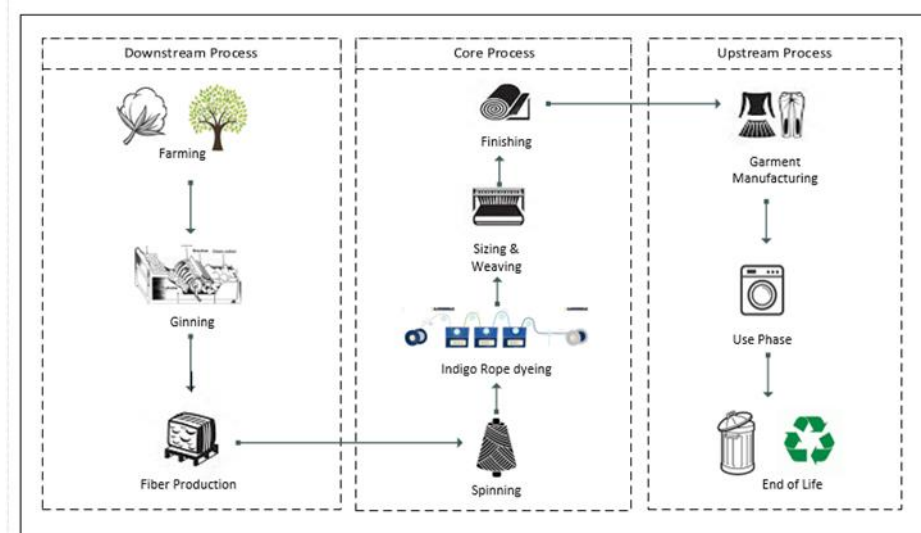
Current studies focused either solely on the impacts of cotton farming systems [8,13,14], or various textile products produced using different cotton fibers such as conventional, recycled, etc. [15-18]. A few studies are examining the contribution of organic cotton use to the environmental impact of the product, and to our knowledge, there is no such study for denim. Baydar et al. (2015) compared eco t-shirt, made of organic cotton and dyed with green dye, with traditional t-shirt made of conventional cotton [19]. Eco t-shirt had a less environmental impact on global warming, acidification, water, and terrestrial eutrophication categories. They also stated that the second most contributing process to the GWP of the t-shirt was cotton cultivation. Khan et al. (2018) made the LCA analysis from cradle to cradle with the information obtained from the literature of the cotton t-shirt produced from conventional and organic cotton [20]. In addition, they discussed in depth the hot spots of white cotton t-shirt production in Bangladesh, adding to the social issues. Sipperly et al. (2019) compared the change in the environmental impact of a standard blue shirt with the LCA when using organic cotton instead of conventional cotton [21]. According to their study, organic cotton was significantly more environmentally friendly for most of the impact category except indirectly the land use and water consumption. Rosa et al. (2019) analyzed the environmental impact of conventional and organic cotton cultivation and fiber production. In their studies, they also made comparisons with fibers such as jute, hemp etc. and stated that the solution to reducing the environmental impact caused by cotton is to use organic cotton [7]. Avadi et al. (2020) conducted an LCA of organic and conventional Mali cotton for agriculture and ginning. According to their studies, organic cotton products had lower environmental impacts other than oxidation, climate change, and eutrophication, despite lower yield [22]. Kazan et al. (2020) evaluated the environmental impacts of cotton woven shirts with scenarios involving organic, conventional, and recycled cotton, natural dyeing, and renewable energy alternatives through the LCA [23]. They concluded that using organic cotton improved the GWP, AP and EP categories due to pesticide and fertilizer elimination. Shah et al. (2018) compared the environmental impacts of organic and BCI cotton cultivation with traditional seed cotton cultivation using LCA [24]. According to the LCA results, organic seed cotton had better results than BCI seed cotton, and traditional seed cotton production, while BCI seed cotton has better results than conventional seed cotton consumption for all categories of environmental impacts.

Although the use of organic cotton for various garments and fibers is available in the literature, there is no such study on denim fabric. To fill this gap in the literature, this study investigated the environmental effects of two denim fabrics with the same production processes when the raw material is organic and conventional cotton.

## 2. MATERIALS AND METHODS

Organic cotton cultivation is gaining importance day by day due to the environmental pollution caused by conventional cotton cultivation. 11% of the pesticides used in the world are used only in conventional cotton cultivation [25]. Therefore, organic cotton cultivation reduces or eliminates the use of chemicals, which greatly reduces harmful environmental impacts [6]. Because organic cotton cultivation is carried out without banned chemicals such as synthetic fertilizers, herbicides, insecticides, growth agents [26]. In addition, the organic productions are certified with various standards (GOTS, OCS), and the chain of custody is provided throughout the entire supply chain [27].

In this study, the LCA method was used to investigate the contribution of organic cotton usage as a raw material to the environmental impacts of denim fabric. Denim fabric production is a complex system that includes many processes such as spinning, finishing, etc. A graphical representation of denim production with upstream, core and downstream processes is given in Figure 1.



*Figure 1. Flow diagram of the denim production process*

Denim fabric production stages are divided into 3 parts: downstream, core, and upstream. The downstream processes of denim production include the cultivation of natural fibers and/or the production of man-made fibers. Although cotton fibers are the main raw material of denim fabric, today they also contain man-made fibers. However, since the raw material of the denim fabric examined in this study is cotton, the use of other fibers has not been mentioned. In core processes are respectively spinning, indigo rope dyeing, sizing, weaving, and finishing. Upstream processes include garment production, use phase, and the life cycle of the product is completed with the completion of the end of life phase.

LCAs of two denim fabric were performed following ISO 14040 and ISO 14044 standards [11,12]. According to these standards, LCA has four steps: goal and scope definition, LCI, LCIA, and interpretation. The LCA steps are given below.

### ***2.1. Goal and Scope***

The goal of this study was to analyze the potential environmental impacts of 1 m<sup>2</sup> denim fabric produced in a textile company located in Turkey. The functional unit was determined 1 m<sup>2</sup> denim fabric. LCA was conducted with a cradle-to-gate approach. System boundaries were selected downstream and core processes with the addition of product delivery to an average customer/retailer.

To determine how the organic and conventional cotton concerns the environmental impacts, two denim fabrics were selected, one made of 100% organic cotton and the other with 100% conventional cotton. All remaining processes of the selected products are the same.

### ***2.2. Life Cycle Inventory Analyses***

The LCA methodology requires a large amount of data from primary or secondary sources. In this study, primary data was process-specific and obtained from a denim mill located in Turkey. For the remaining process, the Ecoinvent V3.0 database was used as secondary data [28]. In the production of organic cotton, organic cottonseed production data were obtained and used for Turkey.

### ***2.3 Life Cycle Impact Assessment***

Comparison of denim fabric produced with two different raw materials with LCA was implemented as a cradle to gate perspective with SimaPro 8.5.2.0 software [29]. The CML-IA was selected as the LCA method and a total of 11 environmental impact potentials were investigated [30]. These potentials are abiotic depletion (ADP), abiotic depletion fossil fuels (ADP\*), global warming (GWP), ozone layer depletion (ODP), human toxicity (HTP), fresh aquatic ecotoxicity (FAEP), marine aquatic ecotoxicity (MAEP), terrestrial ecotoxicity (TEP), photochemical oxidation (PCOP), acidification (AP), and eutrophication (EP).

## **3. RESULTS AND DISCUSSION**

In this study, the environmental impacts of denim fabric produced with two different types of cotton raw materials were assessed with the LCA approach. Since cotton cultivation was the hot spot of denim fabric, it is important to assess the environmental performance of different kinds of cotton types [17]. The results LCA for comparing two denim fabrics with CML-IA Method are given in Table 1 and Figure 2. According to LCA results conducted using the CML-IA method, it was observed that the denim fabric produced with organic cotton has lower environmental impacts than the conventional cotton in all environmental impacts considered.

Table 1. Result of LCA for comparing two denim fabrics with CML-IA Method

Impact category	Unit	Conventional cotton denim fabric	Organic cotton denim fabric
ADP	kg Sb eq.	3.95E-05	2.98E-05
ADP*	MJ	4.92E+01	3.81E+01
GWP	kg CO <sub>2</sub> eq.	4.20E+00	3.34E+00
ODP	kg CFC-11 eq.	4.97E-07	3.51E-07
HTP	kg 1.4-DB eq.	1.49E+00	6.54E-01
FAEP	kg 1.4-DB eq.	2.37E+01	9.14E-01
MAEP	kg 1.4-DB eq.	2.97E+03	1.50E+03
TEP	kg 1.4-DB eq.	1.92E+00	1.85E-01
PCOP	kg C <sub>2</sub> H <sub>4</sub> eq.	9.00E-04	3.87E-04
AP	kg SO <sub>2</sub> eq.	2.70E-02	1.51E-02
EP	kg PO <sub>4</sub> eq.	1.28E-02	9.74E-03

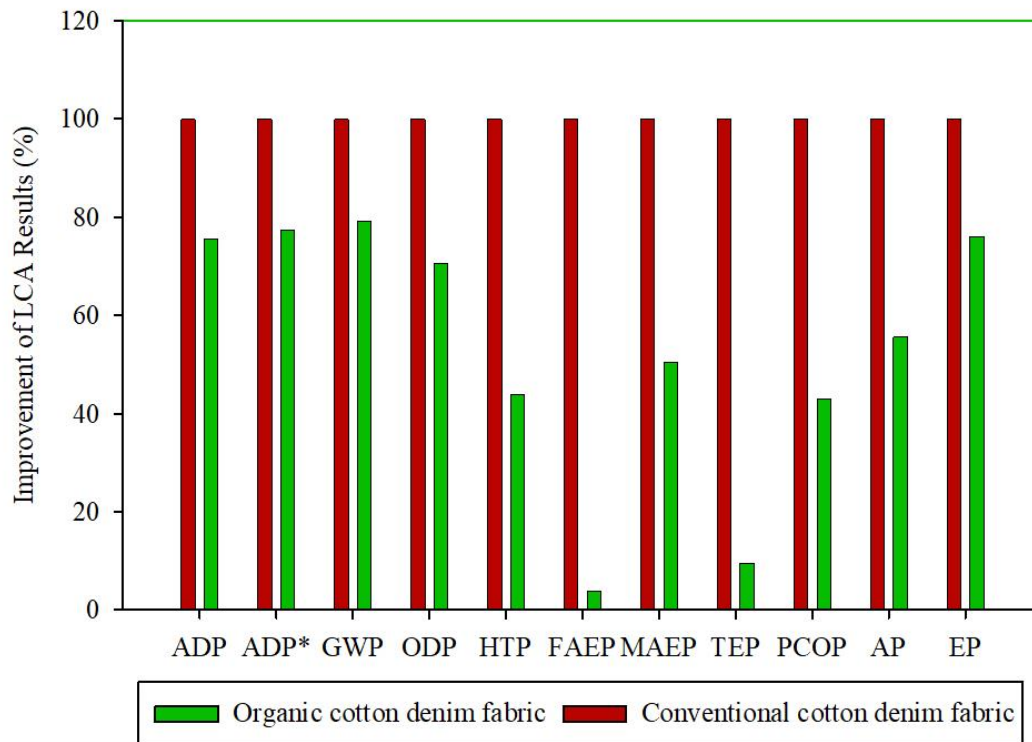


Figure 2. Comparison of LCA Results for two denim fabrics

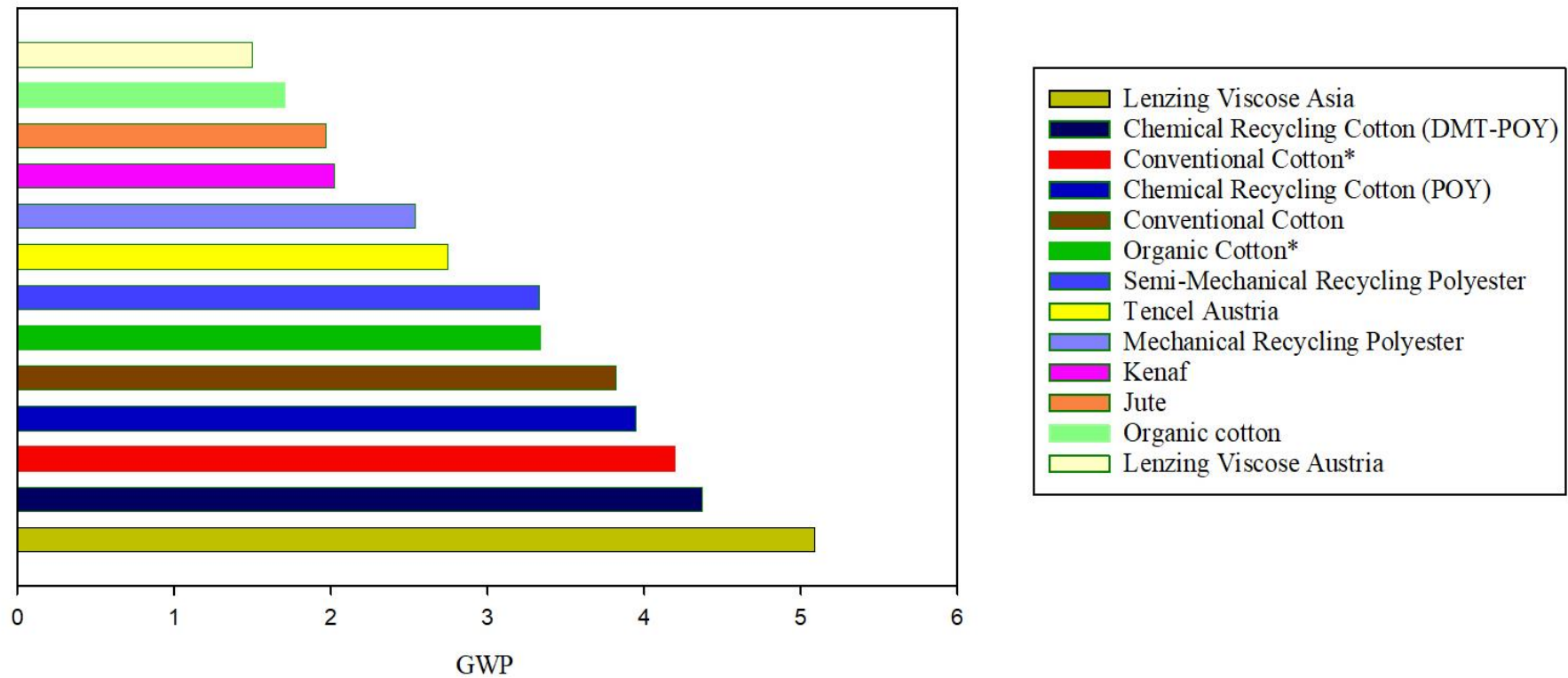
The lowest reduction was achieved in GWP with 21%. This result was in line with the T-shirt study conducted by Baydar et al. (2015), and GWP gain was realized as 22% with the use of organic cotton in their work [19]. According to Sipperly et al.

(2019), GWP improvement was obtained approximately 15% with organic cotton t-shirts [21]. It was clear that using organic cotton as a raw material contributes to the GWP of the product, regardless of whether the product is denim or a T-shirt. The main reasons for the GWP of cotton cultivation are fertilizer and pesticide use with 57% and application of N fertilizer to land with 22% [19]. It is expected for GWP to decrease as the use of fertilizers and pesticides is limited or forbidden in organic cotton. Through substituting conventional cotton with organic cotton, the highest improvement was achieved in the FAEP with a 96% improvement from  $2.37\text{E}+01$  kg 1,4-DB eq. to  $9.14\text{E}-01$  kg 1,4-DB eq.

EP of the denim fabric decreased from  $1.28\text{E}-02$  kg  $\text{PO}_4$  eq. to  $9.74\text{E}-03$  kg  $\text{PO}_4$  eq. an improvement of approximately 24%. Sipperly et al. (2019) showed in their study that the EP value of organic cotton was 46% less than conventional cotton. Nitrate emissions and agricultural chemicals are the main drivers of eutrophication in cotton cultivation. AP decreased by 44% with the use of organic cotton in denim fabric. Kazan et al. (2020) showed that a T-shirt using organic cotton and consuming renewable energy decreased AP 52% [23]. Similarly, La Rosa et al. (2019) showed that organic cotton has 80% more AP than conventional cotton [7]. These results support this improvement achieved for denim fabric.

TEP was reduced from 1,92 kg 1,4-DB eq to 0,18 kg 1,4-DB eq with a 90% improvement. Similarly, a 57% reduction in PCOP and a 56% reduction in HTP are achieved. As a result, the use of organic cotton as a raw material provides significant advantages in terms of environmental impacts due to use of pesticides and synthetic fertilizers in cotton cultivation. Denim fabric produced from organic raw materials had much better results in terms of all environmental impacts. Therefore, organic cotton is a more sustainable alternative to conventional cotton.

As the raw material is the hot spot of denim production and critical to achieving sustainability, it was an interesting research question of how environmental impacts changed with the use of other fibers instead of organic and virgin cotton fibers. How the environmental impacts of 1 m<sup>2</sup> denim fabric changed when selected fibers were used for the functional unit of the study is given in Figure 3. It was noted that substituting the fibers selected from the literature may not be possible as they provide different properties to the fabric, and this supposition only intended to provide a perspective to the decision-makers and designers. In addition, although the production of denim fabric using these fibers may reveal different data such as waste rate, consumption of energy, it was assumed that these values were the same since we investigated them in terms of raw materials



**Figure 3.** Comparison of GWP (kg CO<sub>2</sub> eq.) for other fibers type for 1 m<sup>2</sup> denim fabric. (\*this Study) Data sources: [7,8,31,32]



According to the results, organic cotton denim fabric had an average environmental impact relative to other fibers studied. However, conventional cotton fiber denim fabric was more sustainable than fibers such as Lenzing viscose Asia and chemical recycled cotton (DMT-POY).

#### **4. CONCLUSIONS**

Looking for sustainable alternatives is one of the key points for the textile sector because cotton is the most important natural fiber used in the textile industries worldwide and the hot spot of denim fabric production. In this study, the environmental impacts of conventional and organic cotton denim fabric production in Turkey have examined using the LCA approach.

Thanks to the replacement of conventional cotton with organic cotton, the most significant improvement was achieved in the FAEP categories with 96% and TEP with 90%, respectively. Additionally, 57% in PCOP and 56% reduction were obtained in HTP. Although the lowest decrease was acquired in GWP with 21%, this ratio was still remarkable. Significant reductions in environmental impacts were achieved due to the limitation or prohibition of the use of fertilizers and pesticides in organic cotton and other regulations. According to the results, denim fabric produced with organic cotton has better results than denim fabric produced with conventional cotton in all environmental impact categories. Therefore, organic cotton is a more sustainable alternative to conventional cotton. According to the results, the use of organic cotton in denim fabric production has less environmental impact than fibers such as conventional cotton, Lenzing viscose Asia and chemical recycled cotton.

The results of the study will guide the denim industry experts and scientists. These results showed that the environmental impacts of denim fabric can be reduced by changing with more sustainable raw material preferences. For further studies, this study can be expanded by adding other sustainable raw material alternatives.

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