UTILIZING BIODIESEL FROM COTTONSEED OIL FOR THE TRANSPORTATION OF COTTON TEXTILE PRODUCTS: A LIFE CYCLE APPROACH

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Thesis for the Master’s Program in Bioengineering

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ETHICAL DECLARATION

I hereby declare that I am the sole author of this thesis and that I have conducted my work in accordance with academic rules and ethical behaviour at every stage from the planning of the thesis to its defence. I confirm that I have cited all ideas, information and findings that are not specific to my study, as required by the code of ethical behaviour, and that all statements not cited are my own.

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13.07.2023

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ABSTRACT

UTILIZING BIODIESEL FROM COTTONSEED OIL FOR THE TRANSPORTATION OF COTTON TEXTILE PRODUCTS: A LIFE CYCLE APPROACH

Çinar, Iraz

Master’s Program in Bioengineering

Advisor: Assoc. Prof. Dr. Fehmi Görkem Üçtuğ

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Petroleum-based diesel fuel is derived from limited and depleting non-renewable crude oil reserves, and both its production and consumption is one of the main contributors to greenhouse gas (GHG) emissions. Biodiesel is a more sustainable and environmentally friendly option derived from renewable resources and is claimed to have lower GHG emissions. The use of biodiesel therefore has great potential to mitigate the impacts of climate change, which has been highlighted in various international actions on climate change. Within the scope of international actions and regulations on climate change, biodiesel has been identified as a high potential player in reducing carbon emissions. In addition, within the scope of these actions and regulations, it is also stated that textile industry outputs are among the most important factors that increase global warming. Because the textile industry involves the frequent use of fossil fuels. Therefore, it is of great importance to ensure transformation with sustainable alternatives as much as possible in the sector in order to reduce environmental impacts. Based on this, this thesis analyzes the impacts of biodiesel derived from cottonseed oil for the transportation of cotton textile products on climate change. CCaLC2 Carbon Footprint Software was used to evaluate the environmental impacts of biodiesel in this analysis with a life cycle approach. The result of this study indicates that the use of biodiesel produced from cottonseed oil for the transportation of cotton textile reduces greenhouse gas emissions coming from the use of petroleum-based diesel for the transportation by approximately 45.6%.

Keywords: Life Cycle Assessment (LCA), Life Cycle Impact Analysis, Cottonseed Oil, Biodiesel, Transportation, Carbon Footprint.

ÖZET

PAMUKLU TEKSTİL ÜRÜNLERİNİN TAŞINMASINDA PAMUK TOHUMU YAĞINDAN ELDE EDİLEN BİYODİZELİN KULLANIMI: YAŞAM DÖNGÜSÜ YAKLAŞIMI

Çinar, Iraz

Biyomühendislik Yüksek Lisans Programı

Tez Danışmanı: Doç. Dr. Fehmi Görkem Üçtuğ

Haziran, 2023

Petrol-bazlı dizel yakıtlar, sınırlı ve tükenmekte olan yenilenemeyen ham petrol rezervlerinden elde edilmektedir. Ayrıca, hem üretimi hem de tüketimi sera gazı emisyonlarına katkıda bulunan başlıca unsurlardan biridir. Biyodizel ise yenilenebilir kaynaklardan elde edilen daha sürdürülebilir, çevre dostu bir seçenektir ve daha düşük sera gazı emisyonlarına sahip olduğu iddia edilmektedir. Bu nedenle biyodizel kullanımı, iklim değişikliğine ilişkin çeşitli uluslararası eylemlerde vurgulanan iklim değişikliğinin etkilerini azaltmak için büyük bir potansiyele sahiptir. İklim değişikliğine ilişkin uluslararası eylemler ve düzenlemeler kapsamında biyodizel, karbon emisyonlarının azaltılmasında yüksek potansiyele sahip bir oyuncu olarak tanımlanmaktadır. Ayrıca, bu eylem ve düzenlemeler kapsamında tekstil endüstrisi çıktılarının küresel ısınmayı artıran en önemli faktörler arasında yer aldığı da belirtilmektedir. Çünkü tekstil sektöründe fosil yakıtlar sıkça kullanılmaktadır. Dolayısıyla çevresel etkilerin azaltılması için tekstil sektöründe mümkün olduğunca sürdürülebilir alternatiflerle dönüşümün sağlanması büyük önem taşımaktadır. Buradan yola çıkarak bu tez, pamuklu tekstil ürünlerinin taşınmasında pamuk tohumu yağından elde edilen biyodizelin iklim değişikliği üzerindeki etkilerini analiz etmektedir. Bu analizde biyodizelin çevresel etkilerini yaşam döngüsü yaklaşımıyla değerlendirmek için CCaLC2 Karbon Ayak İzi yazılımı kullanılmıştır. Bu çalışmanın sonucu, pamuk tohumu yağından üretilen biyodizelin pamuklu tekstil ürünlerinin nakliyesinde kullanılmasının, nakliye için petrol-bazlı dizel kullanımından kaynaklanan sera gazı emisyonlarını yaklaşık %45,6 oranında azalttığını göstermektedir.

Anahtar Kelimeler: Yaşam Döngüsü Değerlendirmesi, Yaşam Döngüsü Etki Analizi, Pamuk Tohumu Yağı, Biyodizel, Ulaşım, Karbon Ayakizi.

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LIST OF ABBREVIATIONS

GHG: Greenhouse Gas
EU: European Union
EU-ETS: European Union Emissions Trading System
UN: United Nations
UNFCCC: United Nations Framework Convention on Climate Change
CDM: Clean Development Mechanism
JI: Joint Implementation
MRV: Measurement, Reporting and Verification
NDCs: Nationally Determined Contributions
SDGs: Sustainable Developmen Goals
CBAM: Carbon Border Adjustment Mechanism
WTO: World Trade Organisation
IPCC: Intergovernmental Panel on Climate Change
ICAC: International Cotton Advisory Comittee
LCA: Life Cycle Assessment
f.u.: functional unit
GWP: Glbal Warming Potential
CF: Carbon Footprint
AP: Acidification Potential
EP: Eutrophication Potential
PSP: Photochemical Smog Potential
ODP: Ozone Layer Depletion Potential
HTP: Human Toxicity Potential
VOC: Volatile Organic Compound
CO_2: Carbon dioxide
CO_2eq.: Carbon dioxide equivalent
SO_2: Sulphur dioxide
NO_x: Nitrogen oxides
R11: Trichlorofluoromethane
DCB: Dichlorobenzene

CHAPTER 1: INTRODUCTION

1.1.Sustainability

In recent years, sustainability has gained increasing traction as a critical concept. Various disciplines or contexts define sustainability differently, but it refers to the ability of a system to endure over time. Sustainable development was first defined in the Brundtland report, in 1987, which is regarded as the basis for long-term economic development on the basis of meeting current needs without compromising the capability of future generations of meeting the same needs (Wilkinson, Hill and Gollan, 2001; Scoones, 2007).

Figure 1. Three main pillars of sustainability (Source: von Keyserlingk et al., 2013).

Sustainability can also be defined as the interconnected aspects of social, economic, and environmental sustainability that have to be addressed to achieve sustainable development. These aspects include reducing poverty, protecting the environment, promoting social equity, and creating economic prosperity. Sustainability requires taking a holistic approach that considers the needs of all stakeholders and the environment. To achieve a sustainable future, people and societies must ensure the health of the planet and its inhabitants. This is done by addressing the interrelated needs of economic growth, social justice, and environmental protection.

Among the most important aspects of social sustainability is the promotion of equity, justice, and well-being on the social scale. This subject matter encompasses, for example, human rights, community development, health and safety, education, and social cohesion as well as other factors. It also emphasizes the importance of inclusion, participation, and empowerment on the part of individuals, families, and communities alike. A key component of this pillar is acknowledging and addressing social issues and improving the quality of the lives of the people, as sustainable development cannot be achieved without addressing these issues. In other words, it can be defined as the ability of a society to provide for the current and future needs of its members, promoting social justice, equity, and well-being at the same time. The core aspects of it promote inclusive communities, protect human rights, promote social cohesion, and foster social resilience and coordinated social change, through the installation of human rights structures.

Economic sustainability is regarded as a concept that emphasizes growth, efficiency, and prosperity that is a by-product of sustainable economic development. An approach to economics that is responsible and equitably based involves the reduction of the negative impact that can be perceived on both society and the environment when it is taken from a responsible and equitably based perspective. To ensure equitable distribution of benefits and resources, fair trade is committed to stimulating innovation, promoting sustainable consumption and production patterns, and supporting a fair industry (Barbier, 1987). As a result of this, an economy is able to sustain long-term growth, development, and prosperity while considering the efficient and responsible use of resources in order to contribute to its prosperity. In this regard, economic systems should be designed in a way that promotes long-term stability, equity, and well-being for both present and future generations.

Throughout the process of managing the natural environment, environmental sustainability refers to the preservation and protection of the natural environment and its resources. Environmental sustainability practices include reducing pollution, conserving energy and water, protecting biodiversity, mitigating climate change, and promoting sustainable land use. Ecological balance and ecosystem viability are fundamental to environmental sustainability. To put it simply, this concept refers to the effective use and management of natural resources aimed at conserving and protecting the environment for future generations. This type of planning minimizes bad effects on ecosystems, reduces pollution, preserves resources, and promotes the survival of the planet over the long term.

Global challenges and emerging trends have increased the importance of environmental sustainability in recent years. Resources are becoming more scarce and depleting, the environment is being polluted and degraded, social and economic impacts are occurring, and regulatory and market forces are driving environmental sustainability. A number of factors are responsible for this, including climate change and biodiversity loss. Ecosystem conservation and restoration, renewable energy, sustainable agriculture, and sustainable consumption and production patterns are among the potential solutions to sustainability. In addition to reducing reliance on fossil fuels, renewable energy can also mitigate the effects of climate change. Land degradation can be reduced, and biodiversity can be enhanced through sustainable agriculture and forestry practices. Increasing resilience and providing ecosystem services can be achieved by conserving and restoring ecosystems. Additionally, sustainable consumption and production patterns can promote resource efficiency and minimize waste.

Considering environmental issues as well as economic growth is crucial to sustainable development. It is becoming increasingly important that developing countries must take concrete steps to meet their development goals to prevent adverse effects on future generations due to climate change. Human-induced climate change can be reduced by achieving the United Nations Sustainable Development Goals (SDGs)(Fuso Nerini et al., 2019).

Top 5 Global Risks in Terms of Likelihood

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1st	Infrastructure breakdown	Blow up in asset prices	Asset price collapse	Asset price collapse	Storms and cyclones	Income disparity	Income disparity	Income disparity	Interstate conflict	Involuntary migration	Extreme weather	Extreme weather	Extreme weather	Extreme weather
2nd	Chronic diseases	Middle East instability	China economic slowdown	China economic slowdown	Flooding	Fiscal imbalances	Fiscal imbalances	Extreme weather	Extreme weather	Extreme weather	Involuntary migration	Natural disasters	Climate action failure	Climate action failure
3rd	Oil price shock	Failed and failing states	Chronic diseases	Chronic disease	Corruption	Greenhouse gas emissions	Greenhouse gas emissions	Unemployment	Failure of national governance	Climate action failure	Natural disasters	Cyberattacks	Natural disasters	Natural disasters
4th	China hard landing	Oil price shock	Global governance gaps	Fiscal crises	Biodiversity loss	Cyberattacks	Water crises	Climate action failure	State collapse or crisis	Interstate conflict	Terrorist attacks	Data fraud or theft	Data fraud or theft	Biodiversity loss
5th	Blow up in asset prices	Chronic diseases	Deglobalization (emerging)	Global governance gaps	Climate change	Water crises	Population ageing	Cyberattacks	Unemployment	Natural catastrophes	Data fraud or theft	Climate action failure	Cyberattacks	Human-made environmental disasters

Top 5 Global Risks in Terms of Impact

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1st	Blow up in asset prices	Blow up in asset prices	Asset price collapse	Asset price collapse	Fiscal crises	Financial failure	Financial failure	Fiscal crises	Water crises	Climate action failure	Weapons of mass destruction	Weapons of mass destruction	Weapons of mass destruction	Climate action failure
2nd	Deglobalization	Deglobalization (developed)	Deglobalization (developed)	Deglobalization (developed)	Climate change	Water crises	Water crises	Climate action failure	Infectious diseases	Weapons of mass destruction	Extreme weather	Extreme weather	Climate action failure	Weapons of mass destruction
3rd	Interstate and civil wars	China hard landing	Oil and gas price spike	Oil price spikes	Geopolitical conflict	Food crises	Fiscal imbalances	Water crises	Weapons of mass destruction	Water crises	Water crises	Natural disasters	Extreme weather	Biodiversity loss
4th	Pandemics	Oil price shock	Chronic diseases	Chronic disease	Asset price collapse	Fiscal imbalances	Weapons of mass destruction	Unemployment	Interstate conflict	Involuntary migration	Natural disasters	Climate action failure	Water crises	Extreme weather
5th	Oil price shock	Pandemics	Fiscal crises	Fiscal crises	Energy price volatility	Energy price volatility	Climate action failure	Infrastructure breakdown	Climate action failure	Energy price shock	Climate action failure	Water crises	Natural disasters	Water crises

🟦 Economic 🟩 Environmental 🟧 Geopolitical 🟥 Societal 🟪 Technological

Figure 2. Five major risks categorized by colours in terms of likelihood. (Source: Willige, 2017)

In the Figure 2 above, the text inside the boxes may not be visible, but the colour codes of the boxes are more important here than the text. At the top of this figure are the 5 biggest global risks in terms of likelihood of occurrence from 2007 to 2020. At the bottom of the figure are the 5 biggest global risks in terms of the impact they would have if these 5 big risks were to materialize. From 2007 to the early 2010s, the colours blue, orange and red predominate. These colours represent economic, geopolitical, and societal risks respectively. However, it is seen that the weight of the colour green has increased since 2010, and as approaching to the present day, it is seen that 5 of the 5 major risks in terms of probability of occurrence, and 3 of 5 effects it will create in case of occurrence are environmental. This reveals that the biggest problem of the world at present is environmental. Therefore, any attempt to reduce environmental impacts is of great importance.

1.2.Climate Change

Climate change has widespread effects across the globe such as melting the polar ice caps and rising sea levels. The weather is extreme in some regions more frequently and heavy rainfall occurs more often while in others, heat waves and droughts are more common. Natural consequences of climate change include high temperatures, droughts, wildfires, floods, erosion, biodiversity loss, and trouble accessing clean water (Fawzy et al., 2020). These devastating consequences are likely to cause social problems such as unemployment, commercial problems such as changes in tourism and energy demand, and regional problems such as changes in natural resources. It is unlikely that climate change will improve without immediate action. Many aspects of our daily lives are affected by the threat.

Global temperatures increased by 1.1°C in 2019 compared to pre-industrial levels, making it the warmest decade ever recorded between 2011 and 2020. Global warming increases by 0.2°C every ten years as a result of human activity. It is possible for catastrophic and deadly changes to occur when temperatures rise by 2°C, potentially negatively impacting people, and the environment. Accordingly, the international community acknowledges that limiting temperature increases to 1.5°C is essential (Hoegh-Guldberg et al., 2019).

Climate change and greenhouse effect are strongly correlated. This is because of the number of gases in the atmosphere acting as greenhouse gases and trapping heat from the sun and preventing it from escaping into space. The effect of this is to contribute to global warming. There are some gases that occur naturally, but there are also some that are produced by human activities, namely carbon dioxide (CO_2), methane, nitrous oxide, and fluorinated gases. Carbon dioxide produced by humans is the largest contributor to global warming, and its concentration in the future is expected to be significantly higher than pre-industrial levels. The atmosphere is also affected by other greenhouse gases released by human activities, although these gases are less significant and remain longer in the atmosphere (Althor, Watson and Fuller, 2016; Pareek, Dhankher and Foyer, 2020).

The combustion of coal, oil, and gas releases significant amounts of carbon dioxide and nitrous oxide. As trees absorb carbon dioxide from the atmosphere, deforestation and tree cutting contribute to the release of CO_2 into the atmosphere. Methane is also released during digestion by cows and sheep, due to livestock farming. Fertilizers containing nitrogen produce nitrogen oxide as a result of agricultural activities (US-EPA, 2021).

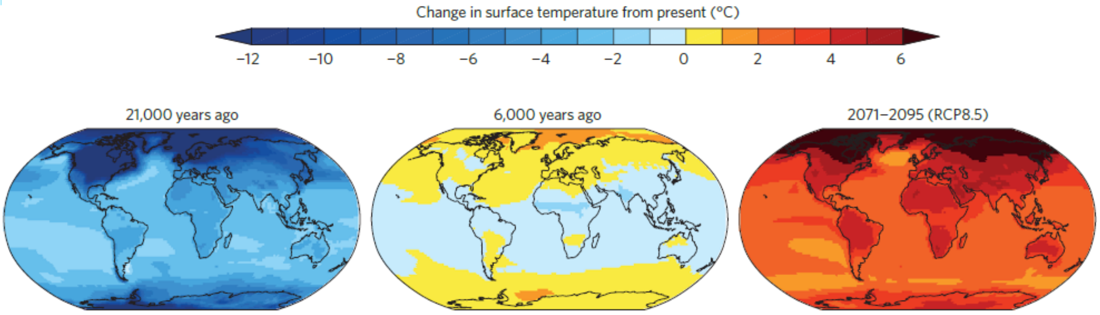


Figure 3. Global temperature change over the time (Source: Clark et al., 2016).

1.3.International Actions Regarding Climate Change

Scientists predict that global warming above 1.5°C will have serious consequences if it continues (Hoegh-Guldberg et al., 2019). In order to control the effects of climate change in the short and long term, countries must take significant steps to reduce greenhouse gas emissions while adapting to current and future changes. Government regulation, energy conservation, and the development of renewable energy sources can all be classified as part of this category.

The European Union (EU) has adopted several policies and laws to deal with climate change. There are thousands of heavy energy-consuming installations in the EU that are regulated by the EU Emissions Trading System (EU-ETS) (Centre for European Policy Studies, 2011). With the help of emission allowance trading, this system promotes the development of low-carbon technologies.

The Paris Agreement was established in 2015 as a measure to stop global climate change, but there is still much more work to be done to accomplish the goals in the agreement. As part of their efforts to achieve the Paris Agreement goals, the EU has implemented several policies and initiatives in conjunction with other countries in order to achieve those objectives (Falkner, 2016).

As of 2020, the EU aims to agree on a strategy for accession to the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement. Toward this end, the European Commission revealed the Green Deal in November 2018 as part of its comprehensive climate-neutral strategy for the EU. This plan aims to achieve a greenhouse gas emissions-free economy by 2050 (Fetting, 2020). To achieve the target, all industries, transport, agriculture, and forestry are expected to contribute to this transformation. As the target requires investments in research and innovation, a significant portion of the long-term climate-related budget has been allocated to other financing programs for this purpose. Additionally, it has been proposed that the EU Climate Law be used to enforce.

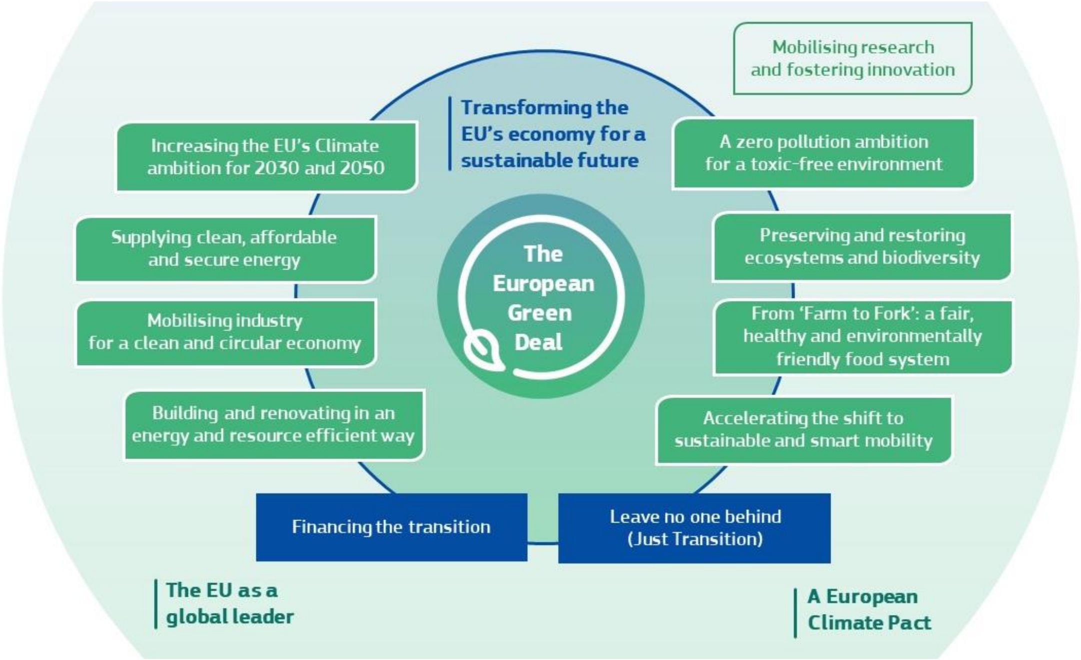


Figure 4. The Green Deal elements (Source: European Comission, 2019).

1.3.1. Kyoto Protocol

The Kyoto Protocol is an international agreement addressing global climate change that was established under the UNFCCC. The convention was adopted in Kyoto, Japan, in 1997 and entered into force in 2005. As a means of reducing greenhouse gas (GHG) emissions and promoting sustainable development, the Kyoto Protocol was developed. From 2008 to 2012, industrialized countries committed to binding emission reduction targets (Breidenich et al., 1998).

The agreement outlines three mechanism to help countries fulfil their emission reduction objectives, including emissions trading scheme which allows countries to trade emission allowances, providing an economic incentive to reduce emissions costeffectively; clean development mechanism (CDM), which allows developed countries to invest in projects that aims to reduce emissions in developing nations in exchange for certified emission reduction credits; joint implementation (JI) which promotes cooperation between developed countries by enabling them to invest in emission reduction initiatives in other developed countries and count the resulting emission reductions towards their own targets (Breidenich et al., 1998; Maamoun, 2019).

Global awareness about climate change was raised through the Kyoto Protocol, which initiated international efforts to combat it. In spite of this, the effectiveness of the scheme has been questioned, since major emitters such as the United States and China are excluded as a result of some of its limitations.

1.3.2. EU Emissions Trading System

The EU implemented the EU-ETS to reduce GHG emissions as a market-based mechanism that operates on cap and trade. Participants in the program are required to cap, or limit, the total amount of greenhouse gas emissions released by their facilities. This cap is gradually reduced over time to achieve emission reduction targets. As part of the cap, companies are allocated emission allowances, each of which represents the right to emit one tonne of CO_2 or its equivalent (Centre for European Policy Studies, 2011).

Emission allowances can be purchased or traded by participating companies according to their individual requirements. The result of this is the creation of a market in which companies possessing excess emissions allowances may sell them to companies facing emission limits. Purchasing additional allowances or selling unused allowances provides companies with an economic incentive to reduce emissions. Purchasing additional allowances or selling unused allowances provides companies with an economic incentive to reduce emissions (Teixidó, Verde and Nicolli, 2019). Thus, it promotes low-carbon practices, cleaner technologies, and energy efficiency improvements to reduce emissions. As a result, EU-ETS supports EU's overall climate targets and contributes to the transition to a low-carbon economy.

In order to strengthen its effectiveness and address challenges, EU-ETS has evolved over time. There have been some reforms, such as the creation of a Market Stability Reserve, which addresses market imbalances, and a linear reduction of the cap, which ensures emissions reduction.

1.3.3. Cancun Agreements

In 2010, at the sixteenth United Nations Conference on Climate Change, held in Cancun, Mexico, a set of decisions and outcomes, known as the Cancun Agreements, were reached. Those agreements provided a framework for global cooperation and advanced international efforts to address climate change (Rajamani, 2011a).

The key elements of the agreements include mitigation, recognizing the need for deep cuts in GHG emissions to limit global temperature rise, emphasizing the importance of nationally appropriate mitigation actions by both developed and developing countries, and encouraged the formulation of low-carbon development strategies. It has highlighted in the agreements that the importance of adaptation measures to address climate change impacts, particularly in vulnerable developing countries. It established the Cancun Adaptation Framework to enhance adaptation action, support developing countries in building resilience, and promote international cooperation. Also, it is stressed that there is a need for scaling-up financial resources to support developing countries in their climate change efforts. It established the Green Climate Fund as a mechanism to channel funds for climate projects in developing countries, and mobilize resources from various sources, including the public and private sectors. The importance of technology transfer and cooperation to enable developing countries to access and utilize environmentally sound technologies is recognized in the context of these agreements. It is included within the Cancun Agreements, the Technology Mechanism comprising the Technology Executive Committee and the Climate Technology Centre and Network to facilitate technology development and transfer. Finally, these agreements emphasize the importance of transparent and accountable reporting of GHG emissions and mitigation actions. It established guidelines for measurement, reporting, and verification (MRV) to enhance confidence in climate commitment implementation (Liu, 2011; Rajamani, 2011b; Nash, 2017).

Following the Cancun Agreements, future climate negotiations, including the 2015 Paris Agreement, built on the principles of the UNFCCC.

1.3.4. Paris Agreement

An international treaty known as the Paris Agreement was adopted by the UNFCCC in 2015. It is primarily intended to fight climate change by stepping up international efforts to reduce greenhouse gas emissions and by trying to limit temperature increases to 1.5°C above pre-industrial levels, in addition to promoting climate resilience and adapting to climate change. According to this agreement, nations are required to submit nationally determined contributions (NDCs), or strategies for reducing greenhouse gas emissions and preparing for climate change. Additionally, the agreement establishes a framework for monitoring progress towards these objectives, as well as financial and technical assistance to assist poor nations in implementing the agreement (Delbeke et al., 2019; Falkner, 2016; Horowitz, 2016; Savaresi, 2016).

It is important to note that despite a few challenges during its implementation, the agreement has played a crucial role in raising global awareness of the urgency of tackling climate change and instigating action toward the creation of a sustainable future.

1.3.5. The Green Deal

In 2019, the European Commission launched a comprehensive policy initiative called the Green Deal. A strategy to reach climate neutrality and transform the EU's economy into a sustainable and inclusive one is laid out in the deal. It encompasses a wide range of measures and targets aimed at addressing climate change, promoting sustainable growth, and improving EU citizens' well-being. By 2050, the Green Deal seeks to make the EU climate neutral. As part of this process, it is necessary to reduce GHG emissions to net-zero levels and to balance any remaining emissions through the removal or offset of carbon. It is essential that significant reductions in emissions across all sectors are made to achieve climate neutrality, and investments in renewable energy sources, energy efficiency measures, and clean technologies are made for the future. During the course of the agreement, renewable energy and energy efficiency will be prioritized as means of transitioning to a sustainable energy system. Moreover, it encourages the use of renewable energy, the deployment of renewable technologies, and the deployment of energy-saving measures in buildings, transport, and industry. Circular economy, biodiversity and ecosystem restoration, transition, and social dimensions are some of the factors to be considered under the Green Deal (Koundouri, Devves and Plataniotis, 2021; Bernstein et al., 2022).

Figure 5. Objectives of the Green Deal (Source: EU-ASEAN, n.d.).

In order to promote a circular economy, the Green Deal encourages recycling and reuse as well as reducing resource consumption, improving waste management and bolstering resource conservation (D’Amato, Korhonen and Toppinen, 2019). The deal emphasizes the importance of protecting ecosystems and restoring them, preserving biodiversity, and addressing natural habitat loss, aiming to halt biodiversity loss, promote sustainable land use practices, and integrate biodiversity considerations into policy and decision-making processes. The deal prioritizes the need to protect and restore ecosystems, preserve biodiversity, and address natural habitat loss, and it aims to halt biodiversity loss, promote sustainable land use practices, and incorporate biodiversity considerations into decision-making and policy. It also stresses the importance of ensuring a just transition, a transition to a sustainable economy that is both socially fair and leaves no one behind, by investing in the development of skills and social inclusion, and supporting workers and regions affected by the transformation (Fetting, 2020; Čavoški, 2022; Filipović, Lior and Radovanović, 2022; von Homeyer, Oberthür and Dupont, 2022).

In brief, the Green Deal represents an EU-wide strategy for tackling climate change and promoting sustainable development. Aiming to position Europe as a global leader in sustainability and innovation, it aligns with international commitments, such as the Paris Agreement.

1.3.5.1.Sustainable Development Goals

The Sustainable Development Goals (SDGs), commonly referred to as the Global Goals, were adopted by United Nations member states in 2015. The SDGs will offer a thorough framework for international development initiatives in 2030 that addresses important social, economic, and environmental challenges (Sachs et al., 2019; Zamora-Polo and Sánchez-Martín, 2019; Koundouri, Devves and Plataniotis, 2021).

Figure 6. SDGs defined by United Nations (Source: United Nations, 2015).

In accordance with the universality principle, all countries are required to meet the SDGs, regardless of their development level. Among the SDGs are poverty eradication, education, health, gender equality, sustainable cities, climate change, biodiversity, and peace and justice. They all contribute to a balanced and coordinated approach to sustainable development. Cooperation and partnerships between governments, civil society, the private sector, and other stakeholders are essential to progress and achievement of the goals (Fuso Nerini et al., 2019; Fonseca, Domingues and Dima, 2020).

1.3.5.2.Carbon Border Adjustment Mechanism

Carbon border adjustment mechanism (CBAM) was approved by the EU's governing bodies in December 2022 (Bellora and Fontagné, 2023). Their disclosures were contained in press releases and a document that was presented to the European Council. Several states and the European Parliament need to confirm the agreement for it to become final. By January 2026, carbon certificates will be required for imports after a transitional reporting period starts in October 2023. In addition, this mechanism is intended to analyse the implications of this policy for transatlantic trade, the World Trade Organization (WTO), and potential developments in the United States (Mehling and Ritz, 2020; Bacchus, 2018).

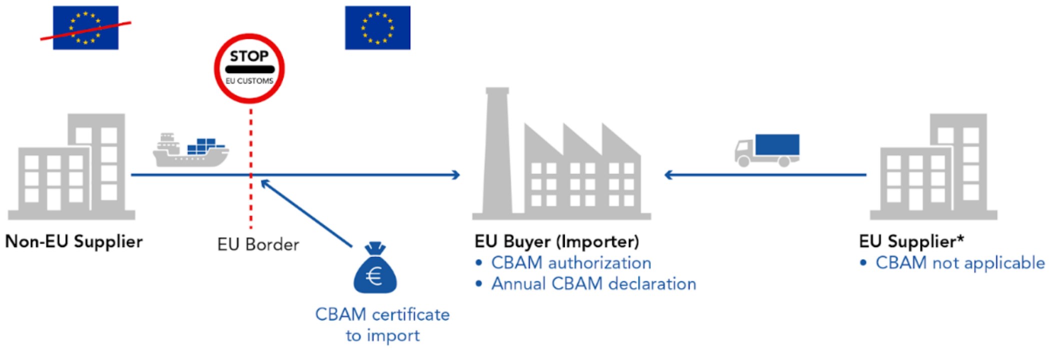


Figure 7. Illustration for EU CBAM (Source: The Conference Board, 2022).

The EU proposes to reduce greenhouse gas emissions by 55% by 2030 from 1990 benchmark levels through Fit for 55 packages that include cap-and-trade measures of EU-ETS. However, as a result of carbon pricing policies, domestic production may have some disadvantages, resulting in a shift in production and emissions to other jurisdictions, known as leakage. The government has implemented mechanisms to reduce leakage by levelling the playing field between domestic producers and importers, who may not face carbon taxes (European Comission, 2019).

Fit for 55 packages were developed by the EU to help reduce greenhouse gas emissions by 55% by 2030, on the basis of 1990 benchmark levels. It is expected that the implementation of the EU-ETS will play a significant role in achieving this goal, because it encompasses cap-and-trade measures across a range of industries. The downside of carbon pricing policies, however, is that they may cause the transfer of production activities and associated emissions to other jurisdictions - commonly referred to as leakage. Policymakers have responded to this problem by implementing a number of mechanisms which are designed to ensure fairness between domestic producers and importers who do not have to pay carbon taxes (Marcu et al., 2021). It is possible to provide free allowances under the EU-ETS under the assumption that industries are at a high leakage risk since they are highly energy intensive, or trade exposed. However, this approach has several disadvantages from the standpoint of climate change. Ultimately, the EU wants to replace it with a CBAM, which assigns a carbon price to imported carbon-intensive goods based on certificates representing embedded emissions. Therefore, leakage risks are reduced, and the EU is able to claim climate leadership at the international level, while also incentivizing foreign producers to reduce emissions.

CBAM represents an important milestone for EU policymakers who have attempted to link trade and climate within WTO systems since the 1990s but have been met with opposition from developing economies. European public opinion has overwhelmingly endorsed the inclusion of key climate and social tenants in its trade strategy.

Since 2019, there have been discussions and negotiations about how to develop and implement the CBAM in the EU. A temporary agreement went into effect in December 2022, with its first scope focusing on carbon-intensive businesses such those that produce aluminium, cement, energy, fertilizers, iron and steel, and hydrogen. Accordingly, importers will disclose their carbon intensity levels and be eligible to pay a lower CBAM fee due to their lower export emissions intensity. During the transition phase, which runs from October 2023 to December 2025, reporting firms and EU representatives will have an open conversation. To avoid border adjustment and accelerate climate change efforts, trading partners will be encouraged to comply with climate policies.

Figure 8. The timeline of EU CBAM (Source: The Conference Board, 2022).

Hydrogen, iron and steel subproducts, and some hydrogen subproducts were successfully added to CBAM during the following negotiations. Organic chemicals and polymers may also be included under CBAM in the future. It is still unclear which goods will be covered under CBAM, but the goal is to include all products currently covered by the EU-ETS by 2030 (Bacchus, 2018; Mehling and Ritz, 2020; Marcu et al., 2021; Bellora and Fontagné, 2023). CBAM is to be extended in the future to cover a wider range of goods and services as part of an EU project to develop a method for determining embodied emissions in downstream goods.

In short, it is intended with CBAM to reduce carbon emissions by ensuring that imported goods are subject to a regulatory framework that imposes carbon prices similar to those imposed under the EU-ETS, which aims to ensure that imports and domestic goods are priced for carbon in a way similar to that of the EU-ETS.

1.4.Relevance of Textile Industry to Climate Change

The textile industry plays an important role in the climate change due to the high amount of carbon emissions, energy consumption, and environmental pollution it produces. The textile industry, through its production, processing, and disposal process, contributes significantly to GHG emissions, water consumption, and chemical pollution, making it one of the major contributors to environmental degradation in the world. It has devastating consequences for the environment, including increased global warming as well as ocean acidification, and can lead to long-term ecological damage as well. A more sustainable approach is essential for the textile industry to mitigate its negative effects on the environment by adopting more environmentally friendly practices (Köhler et al., 2021). Due to the use of petroleum-based materials, the energy-intensive production process, and the pollution resulting from the textile processes, the textile industry contributes a significant amount to global emissions. To reduce emissions and switch to renewable energy sources, it is imperative that the industry takes steps (Peters et al., 2015; Leal Filho et al., 2022).

According to the United Nations Framework Convention on Climate Change (UNFCCC), approximately 10% of total carbon emissions are attributed to the textile and clothing sector. Based on a report by Quantis, 8% of global greenhouse gas emissions come from the apparel and textile industry. Another report by the Ellen MacArthur Foundation indicates that textile industry emissions were around 1.2 billion tons of CO_2 equivalent in 2015. Additionally, the sector is also responsible for 20% of industrial water pollution, creating a need for improved water management, and reducing the environmental impact of textile production. As a result, it is clear that textile and clothing industry must be an integral part of any comprehensive climate change strategy.

Efforts need to be made to address the environmental impact of the textile industry through a combination of measures. Among these measures are the adoption of sustainable production practices, the promotion of circular economy principles, the improvement of energy efficiency, and the reduction of chemical use and waste generation.

1.5.The Share of Cotton in Textile Industry

The Green Deal, CBAM, and sustainability are all closely intertwined with the production of cotton and its waste products. Many countries benefit economically and socially from the use of cotton, which is a versatile and widely used natural fibre. However, cotton and its waste products pose environmental and sustainability concerns.

Several reasons make cotton production and waste management relevant to the EU's Green Deal, which aims to achieve climate neutrality and environmental sustainability. As a result of the extensive use of water, pesticides, and fertilizers in cotton cultivation, as well as the soil degradation and loss of biodiversity caused by these practices, the cultivation of cotton can have significant environmental impacts. Thus, promoting sustainable cotton farming practices and reducing the ecological footprint of cotton production are vital to fostering sustainable agriculture and protecting ecosystems as part of the Green Deal.

As CBAM is a policy tool proposed by the EU to address the carbon leakage issue, which occurs when strict climate policies in one region led to an increase in carbon-intensive imports from regions with lower environmental standards, cotton products are among the goods that could be subject to CBAM regulations, as they are traded globally, and their production processes vary in terms of environmental performance. By adopting greener technologies and reducing carbon emissions across the cotton value chain, CBAM can incentivize cotton producers, especially in countries with weak sustainability practices.

Furthermore, cotton waste management is crucial to sustainability. Cotton waste includes byproducts from the various stages of cotton production, including stalks, seeds, and leftover fibres. In order to minimize negative environmental impacts, such as methane emissions from landfill disposal, cotton waste needs to be properly managed. In addition, cotton waste can be recycled and upcycled, reducing virgin material usage, and promoting the circular economy.

Since Turkey has a strategic geographical location, agricultural capabilities, and textile industry, it has a significant export and import potential for cotton. Because of its long history of cotton cultivation and strong textile sector, it is a major player in the global cotton market. As a result of favourable climate conditions and agricultural practices, Turkey produces a lot of raw cotton, which contributes to the global cotton supply. As one of the biggest cotton-producing countries in the world, Turkey exports raw cotton fibre, cotton yarn, and cotton fabrics. Turkish cotton exports consist of raw cotton fibre, cotton yarn, and cotton fabrics (Devikarani et al., 2022; Tokel et al., 2022). As of the 2019-2020 season, Turkey was the seventh-largest cotton exporter worldwide, according to the International Cotton Advisory Committee (ICAC). Despite this, Turkish cotton exports have decreased in recent years, primarily due to a decrease in domestic cotton production and increased competition from other cotton-producing countries. Although Turkey is not among the top 10 cotton exporters globally for the 2020/21 marketing year, it continues to be an important player. Bangladesh, China, and Vietnam are Turkey's major cotton export markets (Devikarani et al., 2022).

Despite being a cotton-producing country, Turkey imports cotton and cotton products to sustain its manufacturing capacity and meet the diverse needs of its textile and apparel industry. According to the ICAC, Turkey was the world's fifth-largest cotton importer in the 2020/2021 marketing year. Uzbekistan, Turkmenistan, Brazil, Greece, and the United States are Turkey's main suppliers of cotton.

1.6.Life Cycle Assessment

Life cycle assessment (LCA) is a method of assessing the environmental impact of goods, services, and operations throughout the entire lifecycle. A detailed and quantitative analysis of the environmental consequences of each stage in life cycle of a product, including the extraction of raw materials and the disposal of the final product, is conducted (Hauschild, Rosenbaum and Olsen, 2017).

1.6.1. Definition of Life Cycle Assessment Methodology

Analysing the environmental impacts of products and processes throughout their life cycle is the goal of LCA. There are typically four phases in this assessment: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation.

Figure 9. The essential steps of LCA. (Source: Paradigm Sustainability Solutions, n.d.).

Defining the study's goals and scope is the first step in setting its boundaries. It identifies its purpose and intended applications. The life cycle inventory phase involves gathering data on the inputs, outputs, and emissions associated with the product or process being studied. Life cycle impact assessments evaluate the effects of inputs, outputs, and emissions on the environment. The last part of the process is the analysis and interpretation of results derived from a LCA study.

Diverse industries have used it to assess the environmental impact of their operations, including agriculture, construction, electronics, and transportation. For example, construction professionals use LCA to assess the environmental impacts of building materials, as well as design options. Farmers use LCA to evaluate farming practices and food products. E-waste disposal methods and electronic devices' ecological footprint have also been evaluated by electronics manufacturers using this method. Further, LCA has been applied to assess the environmental impact of various modes of transportation and fuel sources in the transportation sector.

The evaluation of a product or process using LCA requires precise and thorough data, which can be challenging. The LCA process has been simplified and automated with the use of new software programs and databases. LCA offers a thorough evaluation of the environmental effects of a product or procedure so that it is possible to use this information to make informed decisions and to identify areas for improvement.

Analysing the whole life cycle of a product or process can minimize environmental and financial impacts. Hence, by implementing LCA, businesses can reduce their environmental impact and improve their overall performance, which encourages sustainable development. Moreover, LCA can also enable companies to demonstrate their commitment to sustainability and ecological responsibility, giving them a competitive edge (Hauschild, Rosenbaum and Olsen, 2017).

1.6.2. Goal and Scope Definition

LCA process begins with the definition of goals and scope, which identify the assessment's purpose, boundaries, and specific objectives. The purpose of this phase is to establish a clear, consistent, and meaningful framework for the entire LCA study.

The main goal of an LCA study is to evaluate the environmental impacts of any product, service or operation evaluate alternatives, help decision-making, or meet regulatory requirements. In order to accomplish, it is necessary to include extraction, manufacture, transportation, usage, and disposal of raw materials. To establish system boundaries, it is recommended to use cradle-to-grave (from raw material extraction to the end of life), cradle-to-gate (from raw material extraction to the factory gate) or other specific boundaries as required by the study objectives. In addition to all these, a functional unit (f.u.) that is a quantifiable measure that serves as the basis for comparing different products or systems must be specified in the study. It represents the specific functionality or service provided by the product, such as per kilogram, per kilowatt-hour, or per passenger-kilometre. Also, the data needed to conduct the LCA study are identified, including information on energy consumption, emissions, resource use, and other relevant parameters. Data sources and availability are considered, and strategies for data collection are established. Time frame and/or geographical scope of the assessment is another point that needs to be determined. This may include considering the specific time period or regions for which the assessment is applicable. Assumptions made during the study, such as data gaps or simplifications, are acknowledged. Limitations of the assessment, such as uncertainties or lack of data precision, are also identified (Klöpffer, 1997; Finkbeiner et al., 2006).

1.6.3. Life Cycle Inventory Analysis

During an LCA, inventory analysis plays a critical role in collecting, compiling, and evaluating data regarding the inputs and outputs associated with each stage. Materials, energy, and emissions are inventoried in a flowchart throughout the life cycle so that subsequent impacts can be assessed and interpreted.

Once collected from various sources, the data is classified and organized based on the stages of the life cycle (e.g., raw material extraction, manufacturing, use, disposal), as well as all the inputs and outputs. This is critical for further analysis. It is required that all data must be quantified using appropriate measurement units. The data under the same category should be converted into the same consistent units (e.g., mass, energy) to facilitate meaningful comparisons and calculations. Afterward, the quantified data should be aggregated to provide a comprehensive picture of the environmental impacts associated with the entire life cycle of the product. For better interpretation and comparison, normalization techniques may be applied to standardize the data and express the impacts in terms of a common reference (e.g., per f.u. or per unit of GDP). As part of the inventory analysis, sensitivity analysis can be conducted to determine the impact of uncertainties or variations on input data. This helps identify critical parameters or data sources that significantly affect assessment outcomes (Klöpffer, 1997; Finkbeiner et al., 2006).

1.6.4. Life Cycle Impact Analysis

Impact assessment is a significant stage in an LCA, since potential environmental impacts are quantified and evaluated in categories. There are several categories, such as acidification, eutrophication, photochemical smog, and human toxicity as well as the carbon footprint. An impact assessment is intended to provide a comprehensive understanding of a product's or system's potential ecological consequences.

Relevant impact categories are chosen based on the objectives and scope of the LCA. Impact assessment results are interpreted and communicated to stakeholders if applicable. This involves summarizing the environmental impacts in a clear and understandable manner, so that it highlights the significant contributors to the environmental impacts and potential hotspots.

Through the impact assessment outputs, decision-makers can determine the environmental impacts of a product or system based on different impact categories. It is useful for reducing environmental burdens and improving sustainability performance by identifying key areas for interventions or improvements.

1.6.5. Life Cycle Interpretation

As the final step in the LCA process, interpretation involves analysing, communicating, and translating findings into meaningful insights and recommendations. In addition to integrating the findings from defining goals, analysing inventories, and analysing impact, it involves making informed decisions and identifying areas of improvement. The interpretation of LCA is crucial to transforming raw data into meaningful information that can be used by decision-makers to approach their choices in a sustainable manner.

1.7.Literature Review

Within the scope of this thesis, biodiesel production processes, textile product production processes and related environmental impact analysis studies were examined.

Biodiesel can be produced from many different sources. A general summary of the studies on biodiesel production is given the Table 1.

Table 1. General summary for biodiesel production from different raw materials.

Raw materials	Year	Location	Reference
Rice bran	2023	Thailand	(Akkarawatkhoosith et al., 2023)
Horse oil	2023	Kyrgyzstan	(Aydın, Oğuz and Öğüt, 2023)
Mahua	2022	India	(Tirkey, Kumar and Singh, 2022)

Table 1 (Continued). General summary for biodiesel production from different raw materials.

Sterculia foetida and rice bran	2022	Indonesia and Malaysia	(Kusumo et al., 2021)
Rapeseed	2022	UK	(Gupta et al., 2022)
Cottonseed	2022	India	(Ganesan et al., 2022)
Dodonaea plant	2022	Pakistan	(Bukhari et al., 2022)
Linseed and rubber seed	2021	India	(Sudalaiyandi et al., 2021)
Palm	2021	Malaysia	(Yung, Subramaniam and Yusoff, 2021)
Coconut	2021	Mexico	(Lugo-Méndez et al., 2021)
Beef tallow	2020	Mexico	(Vargas-Ibáñez et al., 2020)
Cottonseed	2020	Turkey	(Yeşilyurt and Aydın, 2020)
Olive cake	2019	Jordan	(Sandouqa, Al-Hamamre and Asfar, 2019)
Olive oil	2019	Iran	(Dehghan, Golmakani and Hosseini, 2019)
Soybean	2019	Brazil	(Woyann et al., 2019)
Cottonseed and rice bran	2019	India	(Sundar et al., 2019)
Castor	2018	Egypt	(Keera, El Sabagh and Taman, 2018)
Neem seed	2018	Bangladesh	(Banik et al., 2018)
Jatropha curcas	2018	Mexico	(Fuentes et al., 2018)

Table 1 (Continued). General summary for biodiesel production from different raw materials.

Waste olive oil	2018	Iran	(Mihankhah, Delnavaz and Khaligh, 2018)
Coconut shell	2018	India	(Vinukumar et al., 2018)
Coco coir	2018	USA	(Ott et al., 2018)
Mahua	2017	India	(Aalam and Saravanan, 2015)
Rubber seed	2017	Thailand	(Roschat et al., 2017)
Palm	2017	Colombia	(Castanheira and Freire, 2016)
Cottonseed	2017	Brazil	(Lima et al., 2017)
Cottonseed	2017	Bangladesh	(Payl and Mashud, 2017)
Sunflower	2016	USA	(Harris et al., 2016)
Peanut	2016	Turkey	(Hürdoğan, 2015)
Sunflower	2016	Italy	(De Marco et al., 2016)
Soybean	2015	Brazil	(Castanheira et al., 2015)
Brown seaweed	2013	Denmark	(Alvarado-Morales et al., 2013)
Castor	2013	Portugal	(Dias et al., 2013)
Jatropha	2012	India	(Kumar et al., 2012)
Soybean and rapeseed	2011	China	(Qiu et al., 2011)
Microalgae	2011	China	(Gong and Jiang, 2011)
Waste vegetable oils	2010	Portugal	(Morais et al., 2010)
Municipal sewage sludges	2010	USA	(Kargbo, 2010)

Table 1 (Continued). General summary for biodiesel production from different raw materials.

Oleaginous microorganisms	2009	China	(Meng et al., 2009)
Linseed	2009	Turkey	(Demirbaş, 2009)
Waste tallow	2008	Pakistan	(Bhatti et al., 2008)
Karanja	2004	India	(Gupta, 2004)

A summary of studies that address biodiesel production through the LCA approach is given below.

In the study of (Alvarado-Morales et al., 2013), an LCA and an energy analysis were conducted to improve the sustainability of seaweed-based biofuel production in Nordic conditions. The study by (Willfahrt et al., 2019), LCA was conducted on corn to produce bio-gasoline, resulting in a 52.1% reduction in GHG emissions compared to 2005 gasoline baseline, with corn stover utilized as feedstock and biochar applied to agricultural soils. There are detrimental effects of fossil fuels on the environment, specifically greenhouse gas emissions, as discussed by (Lima et al., 2017). This study examined how agriculture, cotton ginning, crushing, oil refinement and transesterification of the oil affect the environment as part of a cottonseed biodiesel manufacturing chain in Bahia, Brazil. According to (Fuentes et al., 2018), using biodiesel as fuel for transportation could reduce the emissions of greenhouse gases from the transportation industry. Among the potential sources of oil for biodiesel is Jatropha curcas from Mexico. Jatropha methyl ester production in Mexico is analysed using the LCA technique in order to determine the GHG emissions and energy balances of the process. There is another study conducted by (Kumar et al., 2012), focuses on the production of biodiesel using Jatropha curcas, in India. The results of the study showed that biodiesel provide a GHG emissions reduction of 40% to 107% compared to petroleum-based diesel depending on methodology and irrigation. (Castanheira et al., 2015) presents an LCA of soybean methyl ester, analysing three pathways for biodiesel production and transportation from Brazil to Portugal. The study found that the lowest environmental impacts were achieved when biodiesel was produced in Portugal using imported soybean grain or oil, and that reducing land-use change and optimizing transportation routes in Brazil can further reduce the environmental impact of biodiesel production. In a different study by (Castanheira and Freire, 2017), the results of an environmental life cycle assessment of biodiesel manufactured in Portugal from palm oil imported from Colombia are presented. An evaluation of land use changes, fertilization plans, and potential biogas management strategies at the extraction mill was conducted to assess the direct and indirect effects of these changes. There is also, a gate-to-gate LCA is presented in a study of (Yung, Subramaniam and Yusoff, 2021) for the production of palm biodiesel in Malaysia. According to results of the paper, replacing fossil-based methanol with biomethanol produced from biogas is the most preferred option, saving up to 63% fossil resources and reducing global warming impact by 22%. In a study by (Gupta et al., 2022), the biodiesel sector in the UK has a high demand for biodiesel, thereby the study focuses on the LCA of biodiesel production from rapeseed oil and the influence of process parameters and scale. The paper presents the results of a LCA of rapeseed oil-based biodiesel production, investigating the influences of process operating conditions and production scales. The study found that the rapeseed agriculture stage caused more than 65% of the CO_2 emissions, with GHG emissions from agricultural soil contributing to the global warming potential augmentation. (İşler Kaya and Karaosmanoğlu, 2022) evaluates the environmental impacts of using safflower oil and molasses-based bioethanol as alternatives to fossil fuels in Turkey. finding that all three biofuels are more advantageous in most categories except mineral and land use. The results show that all the biofuels are more advantageous than fossil fuels in all categories except mineral and land use.

When the literature is examined, no study has been found to date on the production of biodiesel from cottonseed oil and its redirected use for transportation in the cotton sector. Therefore, this thesis is original in terms of the way and method it examines.

1.8.Incentives and Regulations for Biodiesel in Turkey

Many countries around the world offer biofuel incentives of different sizes and shapes. A number of them include support for products used in biofuel production, incentives for labour, capital, and land, tax reductions or exemptions for the products produced, support for storage and distribution infrastructures, support for purchase at consumption stage, and incentives for vehicles in which those products are consumed. Market price supports for the products, support for the storage and distribution infrastructures for the products, and support for the vehicles in which the products are consumed are among them. Biofuel tax incentives are not just beneficial economically, but also for the environment and social welfare.

In the early 2000s, the production of biofuels was introduced to Turkey, as it was elsewhere in the world. In 2001, the Ministry of Industry and Trade established a biodiesel working group. According to Petroleum Market Law No. 5015, biodiesel was included among blended products in 2003 (Çelebi and Uğur, 2015).

TSE issued the biodiesel requirements that the General Directorate of Electrical Power Resources Development Administration suggested in 2003 as TSE requirements in September and October 2005 to comply with EU regulations. According to these regulations, a maximum of 5% might be used to blend bioethanol with gasoline derivatives and biodiesel with diesel. As the regulations allow, when a product is put on the market, it is required to have a red paint mark. According to a decision in 2006, by the Energy Market Regulatory and Supervisory Authority (EPDK), it is required biodiesel producers to obtain a "processing license" to prevent unregistered production and control the sector. With Petroleum Law No. 5574 adopted in 2007, the quality control of biodiesel producers and the amount of production to be offered to the market in the following year are determined by EPDK. Besides that, biodiesel from vegetable oils requires reports from the Ministry of Environment and Forestry and TUBITAK in addition to an EPDK license (Dağdelen, 2015; Çelebi and Uğur, 2015).

By decree of the Council of Ministers, a maximum of 2% of the Special Consumption Tax (SCT) amount charged on gasoline, up to the ratio of the amount of bioethanol to the total amount of the mixture, is exempt from taxation in the case of blending bioethanol produced from agricultural products produced within the borders of the country with gasoline. According to SCT Circular Nos. 8, 2005 and 13, 2006, if biodiesel is mixed with diesel, a maximum of 2% of the SCT amount assessed on diesel is exempt from taxes, up to the ratio of the quantity of biodiesel to the entire amount of the blend (Dağdelen, 2015; Çelebi and Uğur, 2015).

CHAPTER 2: MATERIALS AND METHODS

2.1.Goal and Scope Definition

The main objective of the LCA conducted is to calculate the environmental impacts of biodiesel produced from cottonseed oil to be used in the textile industry for the end-product transportation. In line with the results of this LCA, it is aimed to evaluate the environmental impacts of the biodiesel produce, and to compare petroleum-based diesel and biodiesel in terms of their global warming potentials. Besides that, the environmental impacts of biodiesel production from cottonseed oil are analysed.

The f.u. for the LCA of biodiesel production was chosen as 1000 kg cottonseed biodiesel (Lima et al., 2017), and of the transportation of cotton textile products were chosen as one t-shirt (Güngörmüşler et al., 2022).

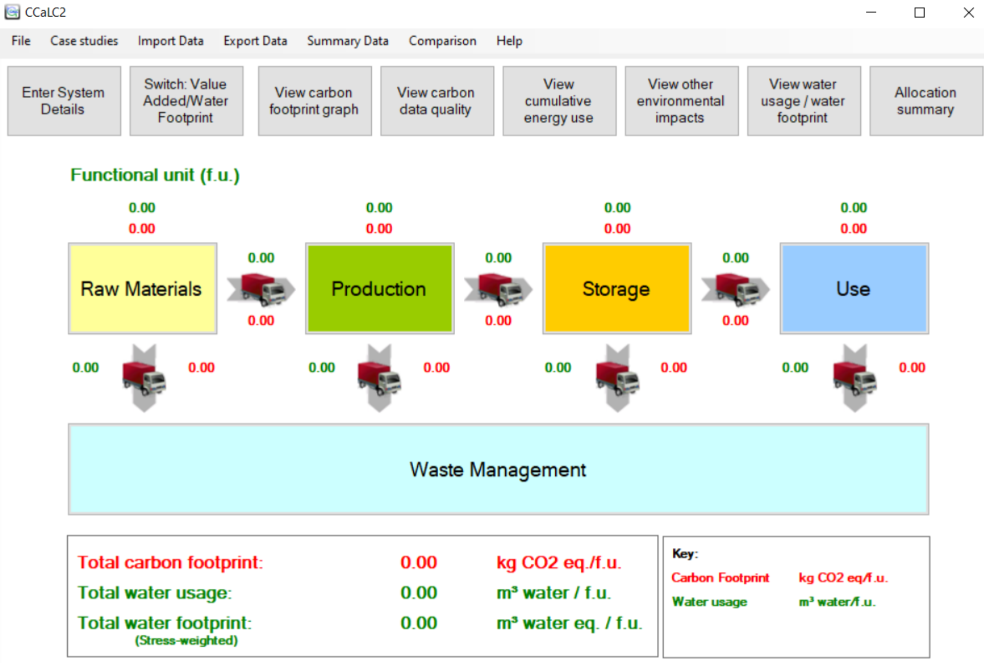
Table 2. Functional units (f.u.) for the life cycle assessment studies conducted.

Cottonseed biodiesel production	1000 kg cottonseed biodiesel
Transportation of textile products	1 cotton t-shirt

The scope of this study includes agriculture, cotton ginning, cotton crushing, oil refining, transesterification of refined cottonseed oil, and transportation of a cotton textile product with the biodiesel produced.

2.2.Life Cycle Assessment Methodology

CCaLC2 Carbon Footprint software was used for the LCA study to be conducted within the scope of the thesis and the environmental impacts required for the study were calculated using the CLM 2001 methodology within the framework of ISO 14040 and ISO 14044 standards (Klöpffer, 1997; Finkbeiner et al., 2006).



Total carbon footprint: 0.00 kg CO2 eq./f.u.

Total water usage: 0.00 m³ water / f.u.

Total water footprint: 0.00 m³ water eq. / f.u.
(Stress-weighted)

Key:
Carbon Footprint kg CO2 eq/f.u.
Water usage m³ water/f.u.

Figure 10. The user interface of CCaLC2 carbon footprinting software.

Products and processes are evaluated for their potential environmental impact using several categories of environmental impacts in the LCA approach. In this section, the environmental impacts of the cottonseed biodiesel considered into 6 categories, including global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), photochemical smog potential (PSP), ozone depletion potential (ODP), and human toxicity potential (HTP).

GWP refers to the amount of heat trapped by a greenhouse gas in the atmosphere over a certain period, compared with CO_2. GWP is expressed as carbon dioxide equivalent (CO_2eq). The acidification potential (AP) is used to indicate how much an activity or product will contribute to acid rain. There are several factors that can lead to the acidification of soil and water, including sulphur dioxide (SO_2) and nitrogen oxides (NO_x) emissions. Eutrophication potential (EP) reflects the possibility that an activity or product may contribute to eutrophication, which refers to the excessive growth of algae and other aquatic plants in water bodies caused by nutrient pollution. Eutrophication is considered in this assessment based on nitrogen and phosphorus emissions. The ability of an activity or product to contribute to the generation of ground-level ozone and other photochemical oxidants is measured by the photochemical smog potential (PSP). It accounts for nitrogen oxides (NO_x) and volatile organic compounds (VOCs), which combine with sunlight to generate photochemical smog. The ozone layer depletion potential (ODP) identifies activities and products that might contribute to this depletion of the stratospheric ozone layer. In addition, it considers the emission of substances which interact with ozone molecules and destroy them. As the name indicates, the human toxicity potential (HTP) is a measure of the potential to harm human health from an activity or product. It considers the emissions of substances that can affect human health in a negative way, such as carcinogens, respiratory irritants, and neurotoxins (Hauschild, Rosenbaum and Olsen, 2018).

2.3.Life Cycle Inventory Analysis

2.3.1. System Boundaries

In this study, all processes for biodiesel production from cottonseed oil to be used in the transportation of cotton textile products were modelled and input/output data from the literature were entered into CCaLC2.

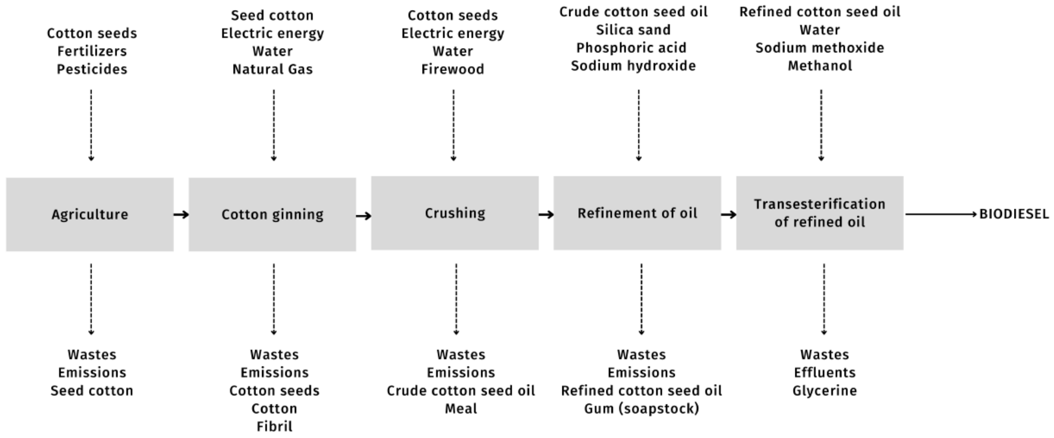


Figure 11. System boundaries and workflow to produce biodiesel from cottonseed oil.

In the LCA, a total of 5 stages for biodiesel production were defined as agriculture, cotton ginning, crushing, refinement of oil, and transesterification of the refined oil, respectively. The system boundaries and flowchart for this LCA exercise are given in Figure 11 above.

2.3.2. Life Cycle Inventory

Input and output data from the literature are optimized according to the model designed, and the inventory list is given for each stage, described in Figure 11, to biodiesel production in Tables 3, 4, 5, 6, 7.

Table 3. Inventory of agriculture phase for 1000 kg biodiesel production from cottonseed

Inputs	**Quantity**	**Ecoinvent dataset (CCalC Library) or reference study**
Raw materials		
Cottonseed	54.05 kg	cottonseed, at regional storehouse, USA
Pesticides Unspecified	27.02 kg	pesticide unspecified, at regional storehouse, Europe
[Thio]Carbamate-compounds	6.28 kg	[thio]carbamate-compounds, at regional storehouse, Europe
Diazine-compound	0.38 kg	diazine-compounds, at regional storehouse, Europe
Phthalimide-compound	0.19 kg	phtalamide-compounds, at regional storehouse, Europe
Pyrethroid-compound	1.14 kg	pyretroid-compounds, at regional storehouse, Europe
Orgonaphosphorus-compund	13.13 kg	organophosphorus-compounds, at regional storehouse, Europe
Diphenylether-compound	0.76 kg	diphenylether-compounds, at regional storehouse, Europe

Table 3 (Continued). Inventory of agriculture phase for 1000 kg biodiesel production from cottonseed.

Glyphosate	11.80 kg	glyphosate, at regional storehouse, Europe
Metolachlor	4.76 kg	metolachlor, at regional storehouse, Europe
[Sulfonyl]Urea-compound	2.86 kg	[sulfonyl]urea-compounds, at regional storehouse, Europe
Triazine-compound	2.86 kg	triazine-compounds, at regional storehouse, Europe
Potassium chloride, as K_2O	884.13 kg	potassium chloride, as K_2O, at regional storehouse, Europe
Phosphate fertilizer, as P_2O_5	618.87 kg	Fertiliser, P
Urea, as N	677.85 kg	urea, as N, at regional storehouse
Nitrogen fertilizer, as N	123.70 kg	Fertiliser, N
Limestone	3,438.53 kg	limestone, milled, loose, at plant
Gypsum	2,456.20 kg	Gypsum
Transport		
Transport, agricultural	11.42 tkm	Transport, tractor and trailer
Outputs		
Carbon dioxide (CO_2) (air)	2,719.77 kg	carbon dioxide
Dinitrogen monoxide (N_2O) (air)	16.94 kg	nitrous oxides
Ammonia (NH_3) (air)	126.55 kg	ammonia
Nitrogen oxides (NO_x) (air)	3.62 kg	nitrogen oxides (as NO_2)

Table 3 (Continued). Inventory of agriculture phase for 1000 kg biodiesel production from cottonseed.

Phosphate (PO_4) (surface water-river)	1.14 kg	phosphate
Products		
Seed cotton	19,030.0 kg	

Table 4. Inventory of cotton ginning phase for 1000 kg biodiesel production from cottonseed.

Inputs	**Quantity**	**Ecoinvent dataset (CCalC Library) or reference study**
Raw materials		
Seed cotton	*19,288.5 kg*	
Water, well	1,805.4 kg	Process water - from ground water
Wood waste	142.03 kg	Resinous wood, DE
Natural gas, high pressure	6,139.4 MJ	heat, natural gas, at boiler condensing modulating >100kW
Electricity, medium voltage, production BR, at grid/BR U	3,707.2 MJ	electricity in Turkey
Transport		
Transport	192.88 tkm	transport, van <3,5t, Europe
Outputs		
VOC, volatile organic compounds (air)	0.02 kg	acetone
Carbon dioxide (air)	239.92 kg	carbon dioxide
Sulfur dioxide (air)	0.04 kg	sulphur dioxide

Table 4 (Continued). Inventory of cotton ginning phase for 1000 kg biodiesel production from cottonseed

Carbon monoxide (air)	0.70 kg	carbon monoxide
Wood waste	1,311.6 kg	treatment of waste wood, untreated, sanitary landfill, CH
Products		
Cottonseed	10,030.0 kg	
Cotton	7,618.9 kg	
Fibril	327.88 kg	

Table 5. Inventory data of crushing phase for 1000 kg biodiesel production from cottonseed.

Inputs	**Quantity**	**Ecoinvent dataset (CCalC Library) or reference study**
Raw materials		
Cottonseed	*10,300 kg*	
Water, well	3,666.8 kg	Process water - from surface water
Firewood	478.19 kg	Wood - pine log
Electricity, medium voltage, production BR, at grid/BR U	1,911.7 MJ	electricity in Turkey
Transport		
Road, lorry B7 {BR}	782.80 tkm	transport, lorry 16-32t, EURO5
Outputs		
VOC, volatile organic compounds (air)	0.17 kg	acetone

Table 5 (Continued). Inventory data of crushing phase for 1000 kg biodiesel production from cottonseed.

Carbon dioxide (air)	791.35 kg	carbon dioxide
Sulfur dioxide (air)	0.10 kg	sulphur dioxide
Carbon monoxide (air)	2.43 kg	carbon monoxide
Waste, inorganic	721.00 kg	disposal, inert material, 0% water, to sanitary landfill
Products		
Crude cottonseed oil	1,030.0 kg	
Meal	8,549.0 kg	

Table 6. Inventory data of refinement of oil phase for 1000 kg biodiesel production from cottonseed.

Inputs	**Quantity**	**Ecoinvent dataset (CCalC Library) or reference study**
Raw materials		
Crude cottonseed oil	*1,029.4 kg*	
Phosphoric acid	1.18 kg	phosphoric acid, industrial grade, 85% in H2O, at plant
Sodium hydroxide	1.35 kg	Sodium hydroxide (NaOH) (concentrated)
Silica sand	2.00 kg	silica sand, at plant
Transport		
Transport	863.67 tkm	transport, van <3,5t, Europe

Table 6 (Continued). Inventory data of refinement of oil phase for 1000 kg biodiesel production from cottonseed.

Outputs		
Waste in incineration	2.35 kg	Incineration - biodegredable waste
Products		
Refined cottonseed oil	1,000.00 kg	
Gum (soapstock)	29.41 kg	

Table 7. Inventory data of transesterification of refined cottonseed oil phase for 1000 kg biodiesel production from cottonseed.

Inputs	**Quantity**	**Ecoinvent dataset (CCalC Library) or reference study**
Raw materials		
Refined cottonseed oil	*1,000.00 kg*	
Methanol	94.13 kg	methanol, from biomass, at regional storage
Hydrochloric acid	11.76 kg	hydrochloric acid, 30% in H2O, at plant
Sodium methoxide	26.61 kg	sodium methoxide, at plant
Tap water	700.00 kg	tap water, at user, Europe
Silica sand	0.32 kg	silica sand, at plant
Heat, light fuel oil	920.00 MJ	heat, light fuel oil, at industrial furnace 1MW, Europe
Outputs		
Waste in incineration	1.89 kg	wastewater treatment - industrial,2

Table 7 (Continued). Inventory data of transesterification of refined cottonseed oil phase for 1000 kg biodiesel production from cottonseed.

Wastewater from vegetable oil refinery	466,67 kg	wastewater treatment, condensate from light oil boiler, to wastewater treatment, class 2
Products		
Biodiesel	1,000 kg	
Glycerin	127.27g	

2.3.2.1.Assumptions Made During the Preparation of the Life Cycle Inventory

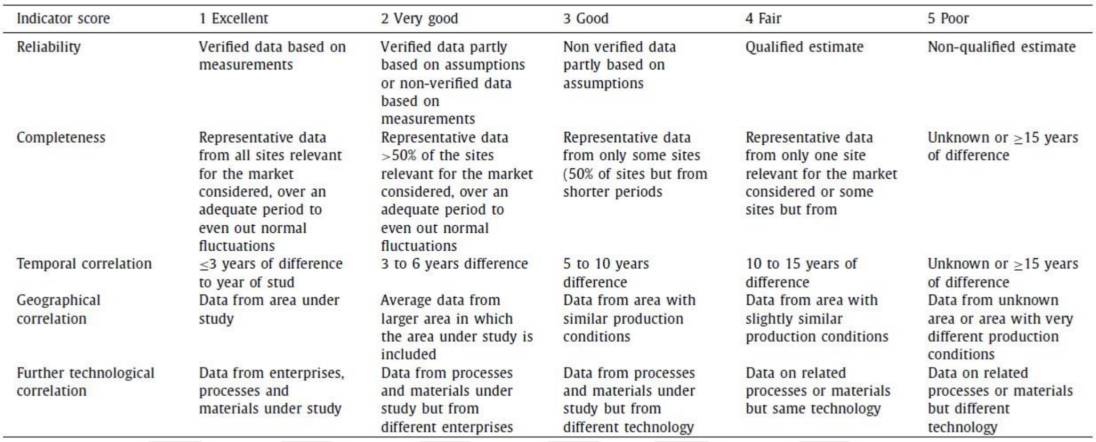
Since the CCaLC2 database does not include any data on electricity in Turkey, data for the entries specified as "electricity in turkey" were manually entered into CCaLC2 (Atılgan and Azapagic, 2016). Furthermore, another data that could not be found in the CCaLC2 database was a generic VOC data. For this reason, acetone was entered as a VOC according to the literature research (Zhao et al., 2016). Although this introduces a certain margin of error, this error is considered to be tolerable as the total mass of acetone is a very small fraction of the total life cycle inventory.

Inputs, which are outputs of the previous phase, written as italic in the inventory tables and are not considered in the life cycle impact calculations.

Finally, as the outputs such as cotton, meal and glycerine produced during biodiesel production is used in other industries, the carbon footprint in the life cycle calculation is neglected.

2.3.2.2.Data Quality Analysis

In the context of life cycle inventory analysis, evaluation of data quality is an essential component of the process. It evaluates several aspects of a life cycle inventory. There are several aspects to take into account when determining data quality such as reliability, completeness, temporal correlation, geographical correlation as well as further technological correlation. Data must be assessed before becoming the subject of a life cycle inventory analysis in order for the results to be considered reliable. The objective of data quality assessment is to ensure that the accuracy, the completeness, and the reliability of the data are evaluated to ensure that an accurate assessment of the environmental impact of a product or process can be made. The matrix used for data quality analysis is given in Figure 12.



Indicator score	1 Excellent	2 Very good	3 Good	4 Fair	5 Poor
Reliability	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non verified data partly based on assumptions	Qualified estimate	Non-qualified estimate
Completeness	Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data $>$50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sites (50% of sites but from shorter periods	Representative data from only one site relevant for the market considered or some sites but from	Unknown or $\geq$15 years of difference
Temporal correlation	$\leq$3 years of difference to year of stud	3 to 6 years difference	5 to 10 years difference	10 to 15 years of difference	Unknown or $\geq$15 years of difference
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials but same technology	Data on related processes or materials but different technology

Figure 12. Data quality analysis matrix (Source: Adsal, Üçtuğ and Arıkan, 2020).

In this thesis, based on the data used (Lima et al., 2017), it is evaluated that the reliability is very good (2), completeness is very good (2), temporal correlation is very good (2), geographical correlation is good (3), and technological correlation is excellent (1). Thus, the average data quality was found to be very good (2).

CHAPTER 3: RESULTS AND DISCUSSION

Regulations such as EU-ETS and the upcoming CBAM are critical for all importing and exporting industries. These regulations aim to reduce carbon emissions to zero, thereby preventing global warming. Therefore, it is very important to analyse products and methods that reduce carbon emissions in order to compete in the market and profit from carbon taxes. For this reason, in this thesis, the environmental impacts of biodiesel from cottonseed oil other than carbon footprint are analysed only for the production phase. However, the global warming potential coming from carbon footprints was analysed in detail.

3.1. Life Cycle Impact Analysis

In this section, the life cycle impact results obtained as a result of the LCA of biodiesel production from cottonseed oil are presented. Life cycle impacts are analysed under 6 headings as global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), photochemical smog potential (PSP), ozone layer depletion potential (ODP), and human toxicity potential (HTP).

3.1.1. Carbon Footprint Results

After entering all the data from the inventory list into the CCaLC2 system, the carbon footprint for biodiesel production from cottonseed oil was found to be 1.99 kgCO_2eq. It has been observed that the largest input for carbon footprint comes from production processes. The negative value from raw materials is due to the fact that, as mentioned above, the sole purpose of cotton production is not to produce biodiesel and therefore the outputs from the previous step are excluded from the calculation as they will be used as useful products in other industries.

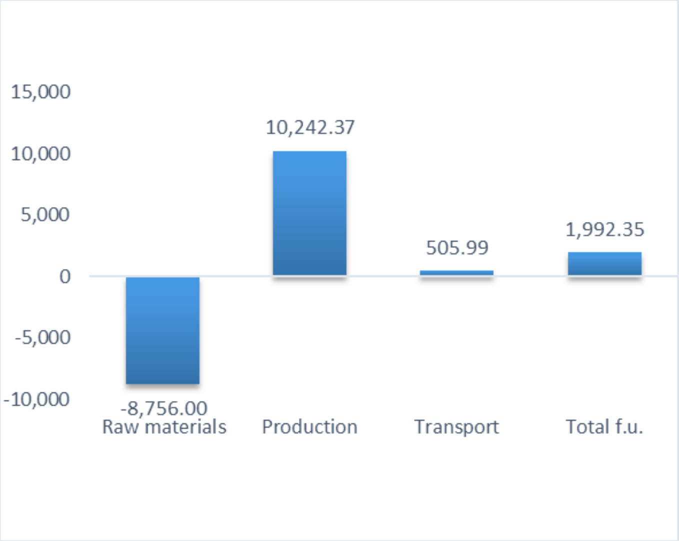


Figure 13. Carbon footprint ($kgCO_2eq/f.u.$) results of cottonseed biodiesel production.

3.1.2. *Acidification Potential Results*

When the LCA of the processes for obtaining biodiesel from cottonseed is made, it is seen that the production stage increases the AP the most, as it is shown in the Figure 14.

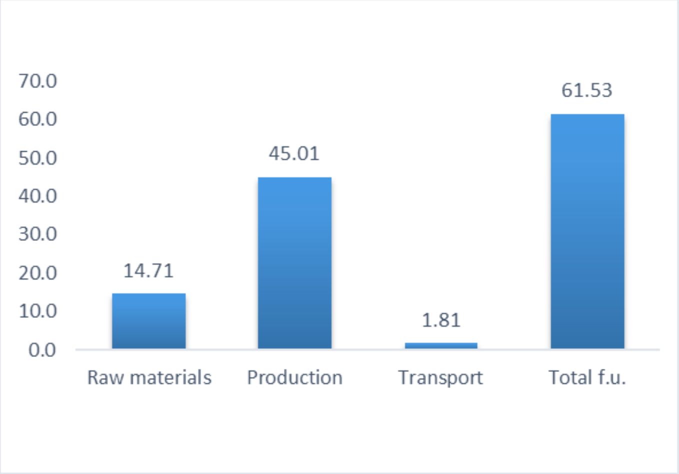


Figure 14. Acidification potential ($kgSO_2eq/f.u.$) results of cottonseed biodiesel production.

It is illustrated in Figure 15 that the transportation accounts for 2.9% of the AP and raw materials for 23.9%. As mentioned above, production has the largest share, accounting for 73.2% of this potential.

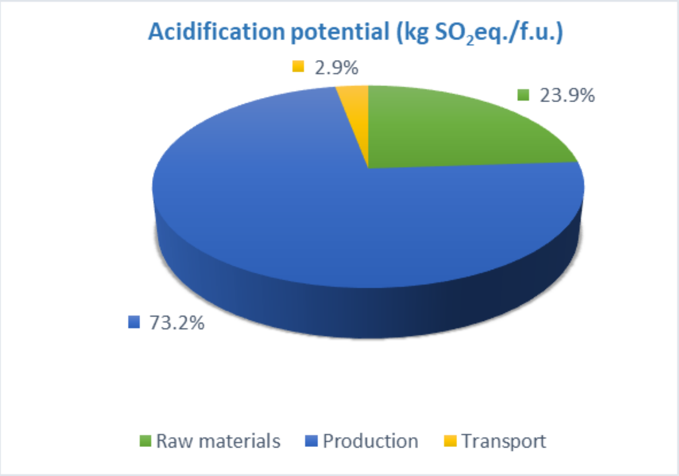


Figure 15. The share of the inputs on acidification potential (kgSO_2/f.u.).

A more detailed analysis reveals that the AP is mostly caused by direct emissions during the agriculture phase, mostly produced by ammonia and some by nitrous oxide.

3.1.3. Eutrophication Potential Results

It can be seen in Figure 16 that the raw materials used for obtaining biodiesel from cottonseed contribute most to EP.

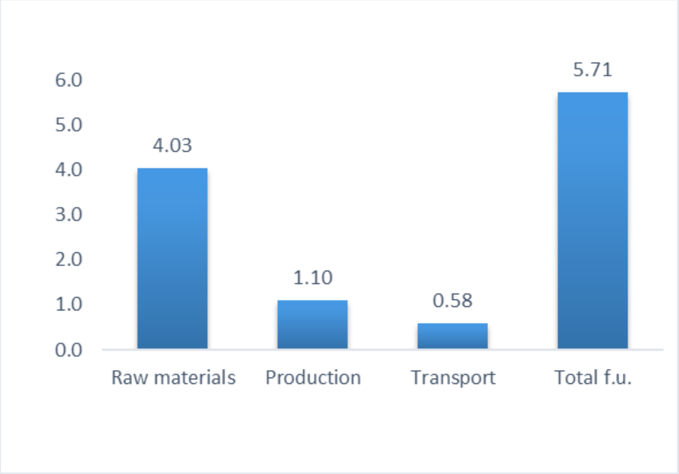


Figure 16. Eutrophication potential (kgPO_4eq/f.u.) results of cottonseed biodiesel production.

According to the results in Figure 16, the contribution of each step to the eutrophication potential was calculated. Accordingly, raw materials account for the majority of the result with 70.6%, production stages with 19.3%, and transportation with 10.1%. The shares of these steps are visualized in Figure 17.

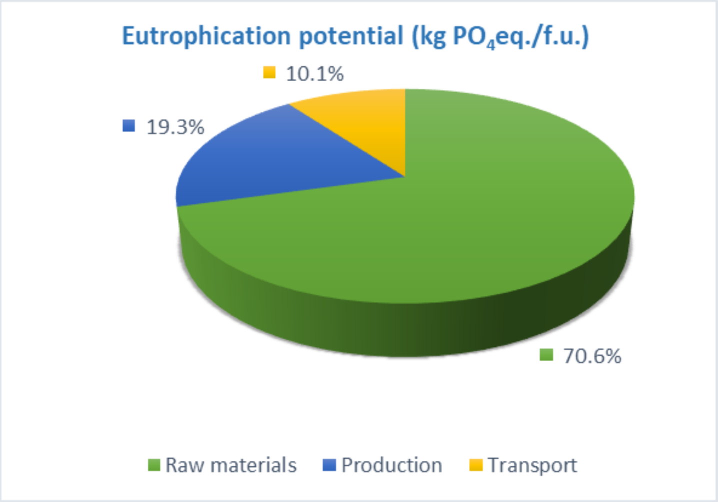


Figure 17. The share of the inputs on eutrophication potential (kgPO_4eq/f.u.).

A more detailed analysis of this data shows that urea used in biodiesel production processes responsible for the EP rise.

3.1.4. *Photochemical Smog Potential Results*

The results show that raw materials used to obtain biodiesel from cottonseed oil responsible for PSP most, as it is shown in Figure 18 below.

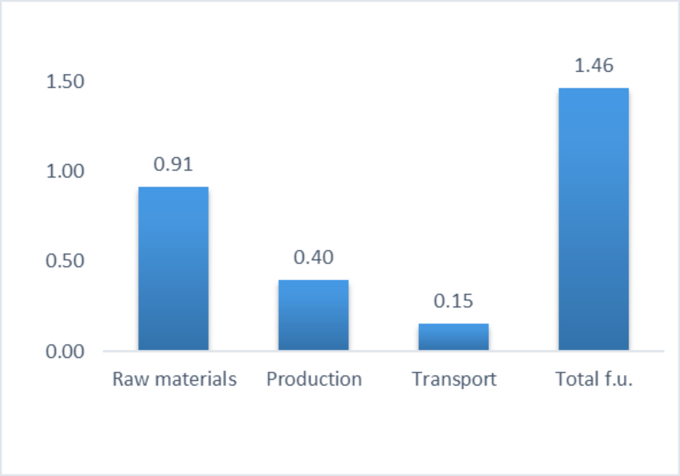


Figure 18. Photochemical smog potential (kgC_2H_4eq/f.u.) results of cottonseed biodiesel production.

When the share of LCA inputs on PSP is calculated according to the data in Figure 18, the share of transportation on PSP is 10.6%, the share of production is 27.1% and the share of raw materials used is 62.3%, as Figure 19 illustrates.

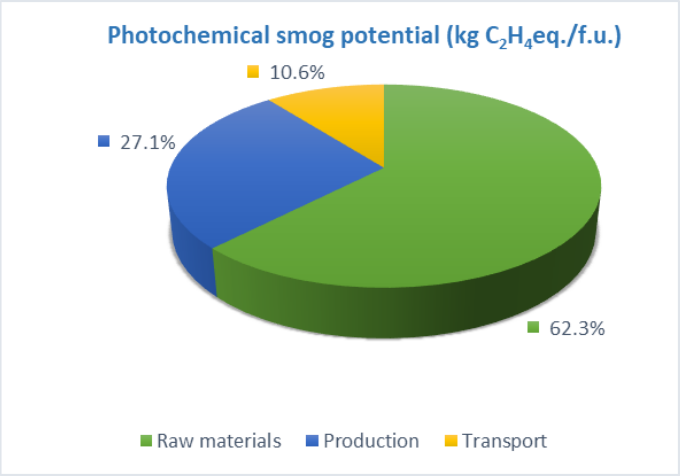


Figure 19. The share of the inputs on photochemical smog potential (kgC_2H_4eq/f.u.)

When this data is analysed in detail, it is found that urea is the raw material that contributes the most to PSP.

3.1.5. Ozone Layer Depletion Results

As can be seen in Figure 20, the raw materials used for biodiesel production contributed the most to the ODP.

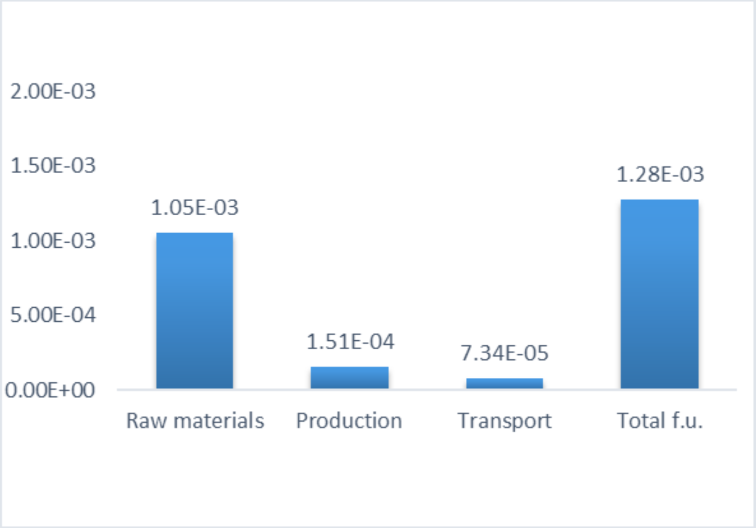


Figure 20. Ozone layer depletion potential (kgR11eq/f.u.) results of cottonseed biodiesel production.

The share of inputs on ODP is calculated as 5.8% for transportation, 11.8% for production and 82.4% for raw materials used as shown in Figure 21.

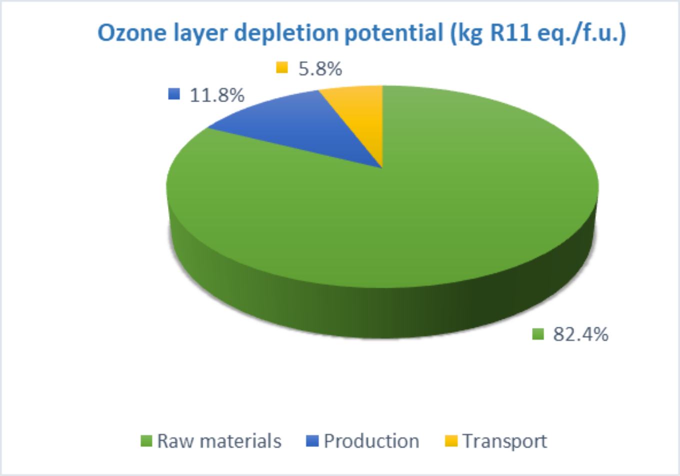


Figure 21. The share of the inputs on ozone layer depletion potential (kgR11eq/f.u.).

CCaLC2 data was analysed for the raw material information with the highest impact on ODP, and it was found that 82.4% of this share was caused by pesticides, which are mostly used.

3.1.6. *Human Toxicity Potential Results*

Figure 22 shows that HTP is mostly caused by the raw materials used. However, it is worth noting that production is also an important contributor.

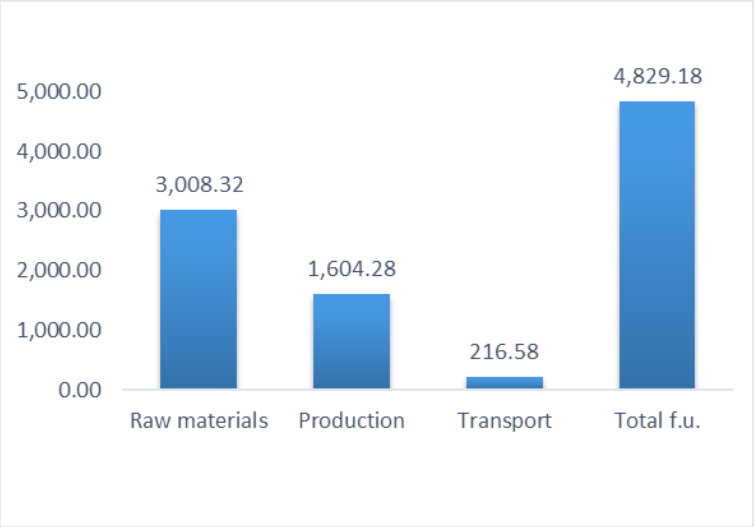


Figure 22. Human toxicity potential (kgDCBeq/f.u.) results of cottonseed biodiesel production.

Based on the data in Figure 22, the share of inputs in the HTP was calculated. Accordingly, the share of raw materials is 62.3%, the share of production is 32.3% and the share of transportation is 4.5% and shown in Figure 23.

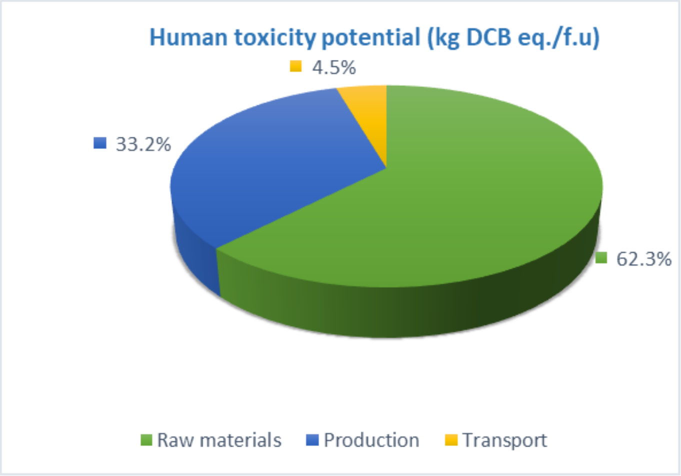


Figure 23. The share of the inputs on human toxicity potential (kgDCBeq/f.u.)

When the CCaLC2 data examined to determine what contributed to these steps, it was found that urea increased the share of raw materials, while the share of production was due to the water waste generated during the transesterification of refined cottonseed oil.

3.2.Impact of Using Cottonseed Biodiesel on Carbon Footprint

As stated in the goal and scope definition, section 2.1, the main objective is to compare carbon footprints of petroleum-based diesel and biodiesel so that analyse the impact of using biodiesel in the transportation of cotton textile products.

As a result of LCA conducted in this study, it is found that the carbon footprint of biodiesel is 1.99 kg CO_2eq. Biodiesel, also called biogenic fuel, is a type of fuel produced from living things or their byproducts. Carbon emission amounts during combustion are one of the primary distinctions between biogenic fuels and petroleum-based diesel fuels. Although carbon dioxide is released during biogenic fuel combustion, this is seen as a normal element of the carbon cycle. This is because the amount of carbon dioxide absorbed by the plants or other organisms used to produce biogenic fuels is offset by the carbon emissions during the combustion of the fuels. Therefore, in the carbon footprint calculations for biodiesel produced from cottonseed oil, only the amount of carbon released from production is considered. However, the carbon footprint of petroleum-based diesel is also required to make a comparison. For this reason, research has been conducted for the carbon footprint of petroleum-based diesel, but no generic data was found that included both production and combustion. As a result of the research, the carbon footprint of petroleum-based diesel production is found as 0.49 kg CO_2eq in the Ecoinvent Database of CCaLC2. Besides, it is found that the emission factor for the combustion of petroleum-based diesel is 10.21 kg CO_2/gal. The carbon footprint (CF) for the combustion of petroleum-based diesel was calculated based on the emission factor together with the knowledge that the density (ρ) of carbon is 0.85 kg/l.

Table 8. List of the variables used for the calculation of carbon footprint from the combustion of petroleum-based diesel.

Description	**Symbol**	**Value**	**Unit**
Emission Factor	EF	10.21	kg CO_2/gal
Density	ρ	0.85	kg/lt
Gallon	gal	3.79	lt

The calculation of carbon footprint of petroleum-based diesel combustion is given below.

$$\mathrm{CF} = \left(\frac{10.21\ \mathrm{kg\ CO2}}{\mathrm{gal}}\right) \times \left(\frac{\mathrm{gal}}{3.79\ \mathrm{lt}}\right) \times \left(\frac{\mathrm{lt}}{0.85\ \mathrm{kg}}\right)$$

$$\mathrm{CF} = 3.17\ \mathrm{CO2\ eq}$$

To find the total carbon footprint of petroleum-based diesel, both production and combustion values were summed, and calculated as 3.66 kg CO_2eq.

As a result, the life cycle carbon footprint of petroleum-based diesel is found to be 3.66 kg CO_2eq, while the life cycle carbon footprint of cottonseed biodiesel is found as 1.99 kg CO_2eq as illustrated in Figure 24 below. Based on this information, it is calculated that the use of biodiesel from cottonseed reduces carbon emissions by 45.6% compared to petroleum-based diesel.

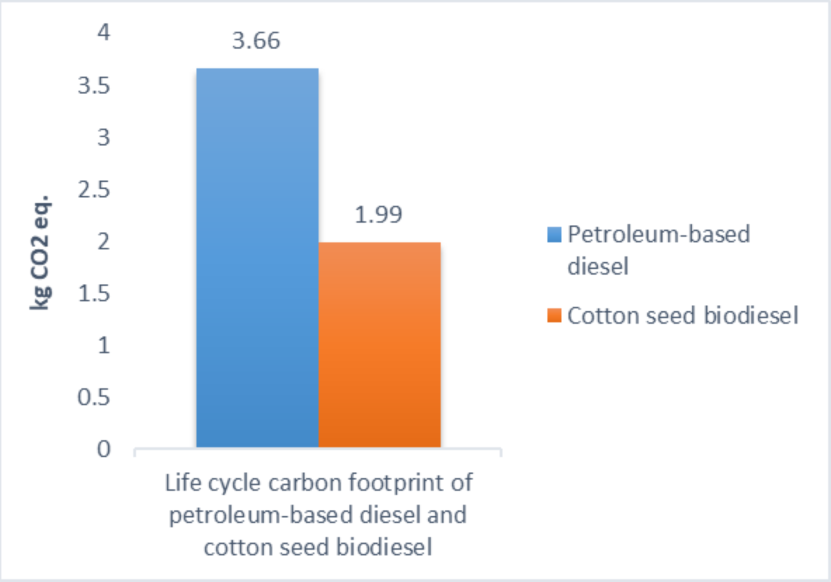


Figure 24. Life cycle carbon footprints (kgCO_2eq) of cottonseed biodiesel and petroleum-based diesel.

3.3.The Effect of Using Cottonseed Biodiesel Instead of Petroleum-based Diesel in the Transportation of Cotton Textile Product

According to data by (Güngörmüşler et al., 2022), the share of the life cycle carbon footprint of transporting 1 cotton t-shirt 2200 km with a EURO5 truck using petroleum-based diesel is determined as 0.092 kg CO_2eq. In the same scenario, using biodiesel is calculated to reduce the life cycle carbon footprint of 1 cotton t-shirt by 0.05 kg CO_2eq. This means, while the share of transporting 1 cotton t-shirt 2200 km with a truck using petroleum-based diesel was 1.91%, the share of transportation in the life cycle carbon footprint decreased to 1.05% when cottonseed biodiesel was used in the same scenario.

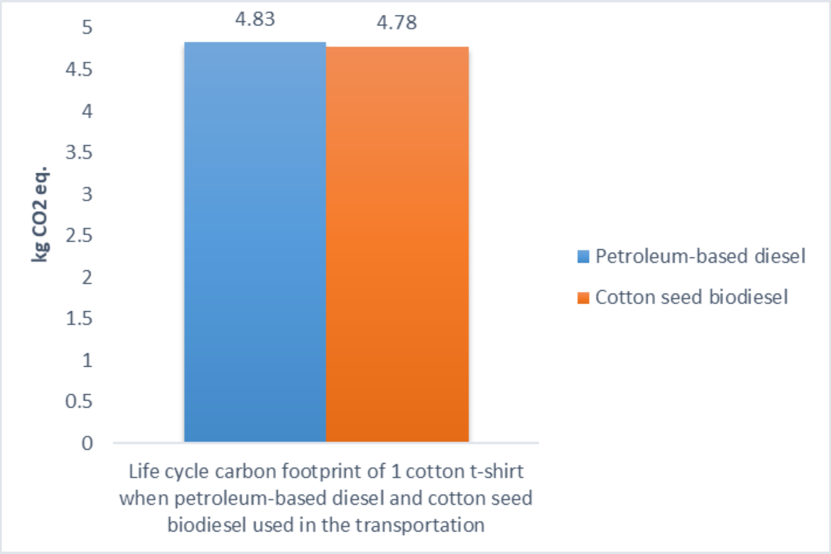


Figure 25. The impact of using biodiesel in the transportation of 1 cotton t-shirt on carbon footprint (kgCO_2eq).

As can be seen in Figure 25 above, the use of biodiesel from cottonseed in textile product transportation did not create a significant difference in the textile industry basis. However, this is specific to industries like the textile where the share of transportation in the life cycle is low. Therefore, it is foreseen that it can provide very significant benefits for products with very long transportation distances.

3.4.Comparison with the Literature

There are many biogenic diesels subjected to academic research on climate action. Table 9 lists the carbon footprint of cottonseed biodiesel, which is the subject of this thesis, and three biogenic diesels that are frequently encountered in the literature.

Table 9. Comparison of global warming potential of different biogenic diesels.

Biogenic diesels	**Global Warming Potential (kgCO_2 eq)**	**References**
Palm biodiesel	2.76	(Paminto, Karuniasa and Frimawaty, 2022)
Soybean biodiesel	2.48	(Coronado, De Carvalho and Silveira, 2009)

Table 9 (Continued). Comparison of global warming potential of different biogenic diesels.

Microalgae biodiesel	2.32	(Üçtuğ, Modi and Mavituna, 2017)
Cottonseed biodiesel	1.99	This study

According to Table 9 above, it is clearly seen that the biogenic diesel with the highest global warming potential is the one that produced from palm oil, followed by soybean, then microalgae and finally cottonseed biodiesel. Based on the table 9, it can be said that the use of cottonseed biodiesel having great importance than other biogenic diesels in terms of global warming potential within the framework of the EU's Green Deal and the upcoming CBAM.

3.5.Importance of Circular Economy Approach

In this study, a case study was conducted on the reuse of biodiesel obtained from cottonseed wastes, which are produced after the cotton is harvested for use in textile production, in the transportation of cotton textiles.

The circular economy, also referred to as circularity, is an economic model that focuses on minimizing waste and making the best use of available resources by making use of circular methods. The traditional linear economy, on the other hand, is characterized by the production, use, and discard of products after they reach their maximum useful life. As a result, there is a one-way flow between production and disposal. The circular economy, in contrast to the traditional linear economy, aims to create a closed-loop system of reusing, recycling, and renewing resources to extend their lifetime and reduce their ecological impact.

As the key principles of the circular economy include waste reduction, resource recovery and recycling, this study serves as a basis for businesses that want to transition to a circular economy model by using their waste for biodiesel production and re-directed use in the same business.

CHAPTER 4: CONCLUSION

This study proved that the use of biodiesel from cottonseed oil has the potential to reduce emissions from transportation of its life cycle compared to petroleum-based diesel by almost half.

In order to conduct a full feasibility study, analyses such as the establishment of a biodiesel production plant and its lifetime costs are required. This study does not include a detailed economic analysis. It only aims to determine whether the use of biodiesel would create a significant difference in the transportation of the end-product in the textile sector. At this point, considering that emissions from transportation have decreased by about 45.6%, it is seen that it could make a significant difference especially for textile manufacturers that produce on a large scale.

It is envisaged that investments to be made by textile companies for the conversion of agricultural production wastes into biofuels through biological methods and/or encouraging their suppliers to use biofuels will be beneficial within the scope of the Green Deal and Border Carbon Regulation.

For companies that produce their own agricultural products, such processes would be easy to integrate into their systems. However, it is known that the majority of purchases are made through external suppliers. At this point, raising awareness, training and incentivizing external suppliers on such processes will provide an advantage for both the producer and the supplier in terms of competitiveness in the market.

In light of the fact that transportation has a very small contribution to the environmental impacts of textile products, the amount of carbon footprint reduced by using biodiesel in transporting textile products is low. It is important to note that this study is based on a case study which is a textile product. Consequently, biodiesel is found to reduce carbon emissions by 45.6% if considered solely in terms of transportation using a life cycle approach. In this context, promoting biodiesel use in industries where transportation plays a significant role in the life cycle would be an invaluable effort. Moreover, biodiesel is expected to generate significant profits from taxes payable under the EU-ETS and the upcoming CBAM. Especially if the companies maintaining this transition are suppliers, they will be in compliance with international regulations in the future, increasing their chances of competing on the market.

For this study, CCaLC2 was used which is a free software. Although this software has many advantages, it also has some disadvantages. One of them is that the software only calculates 6 different environmental impacts. However, there are more than 40 environmental impacts to be evaluated, some of which may be significant for transportation or textiles. Therefore, this study does not address other environmental impacts that CCaLC2 does not account for. It is also a disadvantage of the software that it does not calculate end-point indicators, such as those relating to human health, biodiversity and resources scarcity, but only mid-point indicators, which refer to individual environmental issues, such as climate change and acidification potential. For this study, some end-point indicators could have been useful. Therefore, conducting a similar study with more professional software and more environmental impact analysis would provide more comprehensive results.

Additionally, being completely outside the scope of this study, it would be useful to compare biodiesel production from different agricultural crop wastes using a life cycle approach. This would provide a clearer indication of which sectors are worth investing in.

This study is a case study that demonstrates how an analysis should be done with a life cycle approach. Therefore, other industries can follow the methodology proposed in this thesis to calculate the environmental impacts of processing other wastes under various conditions to produce biofuel so that they can make investments in using this biofuel in their own processes.

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