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Carbon Footprint Calculation Methods Used in the Textile Industry

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Abstract

Climate change is one of the most significant issues of our time. Therefore, reducing the factors causing climate change and replacing existing methods with new ones have become essential for the world.

The primary driver of climate change is greenhouse gas emissions. The use of fossil fuels to meet the increasing energy demand, especially after the Industrial Revolution, has led to an accumulation of greenhouse gases in the atmosphere. Turkey, closely following the measures taken globally and being a party to international agreements, continues its efforts to reduce greenhouse gases. In this context, the Ministry of Environment Urbanization and Climate Change submitted the 8th National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat in May 2023. As mentioned in this report, the textile sector is among the largest contributors to Turkey's manufacturing industry, with an 8.4% share in revenue. The directive, published to minimize the environmental impacts of waste generated by the activities of the textile sector—one of Turkey's leading industries—includes provisions related to reducing energy consumption, water consumption, pollutants in wastewater, and air pollutant emissions.

This study discusses how greenhouse gas emissions, which are among the leading air pollutants in the textile sector, can be calculated using three different methods: the Tier approach, Life Cycle Analysis (LCA), and the DEFRA method. These three calculation methods are compared using the SWOT analysis technique, offering options to the end-user. By highlighting the advantages and disadvantages of greenhouse gas emission calculation methods, this study aims to assist sector representatives or experts performing calculations in determining roadmaps for compliance with national and international standards.

Keywords: *SWOT, Tier, LCA, DEFRA*

1. Introduction

In this era where our natural resources are increasingly being destroyed, depleted, and the natural balance is progressively disrupted, it is evident that we are facing numerous disasters caused by this destruction. Hunger, water scarcity, changes in vegetation, floods, fires, natural disasters, extinction of species, global warming, and climate change are among the examples that can be given. Among these issues, the most significant ones that affect all living beings are climate change and global warming.

As defined in the United Nations Framework Convention on Climate Change (UNFCCC), climate change refers to *"a change in the climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods."*

To eliminate or reduce the harmful effects of climate change, legal frameworks such as the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and the Paris Agreement have been voluntarily established by countries. These regulations include measures aimed at reducing greenhouse gas emissions.

1.1. United Nations Framework Convention on Climate Change

The effects of greenhouse gas emissions caused by human activities on climate change have become a source of concern for countries. In an effort to address this problem, countries came together and opened the United Nations Framework Convention on Climate Change (UNFCCC) for signature at the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992. The

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UNFCCC represents the first international step taken in this area. The convention entered into force on March 21, 1994. A total of 196 countries, including the European Union, are parties to this agreement. Turkey became a party to the convention on May 24, 2004. This agreement encourages participating countries to reduce greenhouse gas emissions and collaborate on mitigation efforts [1,2].

The Climate Change Convention is implemented through two key instruments. The first is the Kyoto Protocol, which outlines the actions to be taken until 2020, and the second is the Paris Agreement, which defines the measures to be implemented after 2020.

1.2. Kyoto Protocol

The Kyoto Protocol, which serves as the first implementation agreement of the Climate Change Convention, is the first legally binding international treaty to set mandatory limits on greenhouse gas emissions. Countries that are parties to this protocol have agreed to provisions within the protocol to either reduce the emissions of gases that contribute to CO2 and greenhouse gas emissions or, if unable to meet reduction targets, to increase their rights through carbon trading.

Although the Kyoto Protocol was adopted in 1997, it did not come into force until 2005 because, at the time, the countries that were parties to the agreement did not collectively account for 55% of global emissions based on their 1990 levels. This condition was met only when Russia joined the protocol in 2005.

The Kyoto Protocol was planned in two commitment periods.
I. Commitment Period**:** This period covers the years 2008–2012. During the first period, countries listed in Annex I of the agreement were obligated to reduce their total emissions by at least 5% below their 1990 levels.
II. Commitment Period: This period spans from 2013 to 2020. Unlike the first commitment period, the second required a reduction of 18% in emissions compared to 1990 levels by 2020. However, the necessary number of party countries for the Second Commitment Period was only achieved in Doha in 2020. As the Paris Agreement, which is the second implementation instrument of the UNFCCC, outlines actions to be taken after 2020, the Second Commitment Period was largely formal and procedural in nature [3, 4].

Although Turkey became a party to the Kyoto Protocol in 2009, it was not included in Annex B, which lists countries with greenhouse gas emission limitation or reduction obligations, because Turkey was not a party to the UNFCCC at the time the protocol was adopted [5].

1.3. Paris Agreement

The Paris Agreement, adopted in 2015, represents the second implementation phase of the UNFCCC. It set a global goal of limiting human-induced greenhouse gas emissions to levels that keep the global temperature increase below 2°C compared to pre-industrial levels for the post-2020 period.

The Paris Agreement classified countries as developed or developing and emphasized that all nations must work toward the goal under the principle of "common but differentiated responsibilities." The agreement became operational in function in November 2021, following the completion of the Paris Agreement Work Program at the Conference of the Parties.

Turkey signed the Paris Agreement in 2016 as a developing country. However, its ratification, completion of domestic legal processes, and notification to the United Nations Secretariat occurred in October 2021 [6].

To fulfill its commitments under international agreements on climate change, minimize environmental problems, and ensure a more livable environment, Turkey needs to take various measures. These include controlling greenhouse gas emissions, reducing emissions through renewable energy sources, managing emissions at all stages of production, and utilizing resources effectively. The first essential step in implementing these measures is identifying the carbon footprint.

In this study, the methods for calculating the carbon footprint, which represents the first step in creating a roadmap for legal obligations for businesses, are discussed using the example of the textile industry. The calculation steps of these methods are explained, and a comparison of the methods is provided.

2. Method

In this study, the carbon footprint calculation methods in the textile sector were compared using the SWOT analysis method.

SWOT Analysis is a method used to understand the strengths and weaknesses of any situation and identify the opportunities and threats that may arise. The term "SWOT" is an acronym derived from the first letters of the English words Strengths, Weaknesses, Opportunities, and Threats.

This method is crucial for identifying how to utilize strengths effectively, addressing weaknesses with appropriate measures, evaluating opportunities arising from external factors, and mitigating potential threats. By providing a comprehensive view of both positive and negative internal and external factors, SWOT analysis acts as a strategic roadmap for decision-making.

For these reasons, SWOT analysis was chosen to compare the various methods used in carbon footprint calculation, highlighting their distinct features and offering a structured approach to understanding their applicability and limitations.

The carbon footprint resulting from processes and resource usage in the textile industry is typically calculated using three main methods. The first is the Tier Approaches developed by the Intergovernmental Panel on Climate Change (IPCC), the second is Life Cycle Assessment (LCA), and the third is the method of the United Kingdom's Department for Environment, Food and Rural Affairs (DEFRA).

When performing calculations, emissions are categorized based on their sources. This categorization is carried out in accordance with the international ISO 14064:2018 Greenhouse Gases – Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals standard. The definitions of the categories are as follows:

- Category 1: Direct greenhouse gas emissions
- Category 2: Indirect greenhouse gas emissions from imported energy sources
- Category 3: Indirect greenhouse gas emissions from transportation
- Category 4: Indirect greenhouse gas emissions from used products/services
- Category 5: Indirect greenhouse gas emissions associated with the use of products
- Category 6: Indirect greenhouse gas emissions from other sources

3. Findings

According to the literature review, the three different carbon footprint calculation methods used in the textile industry—Tier Approach, LCA, and DEFRA Method—are detailed in this section, including their calculation steps and a comparison of these methods.

3.1. Intergovernmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change (IPCC) was established by the United Nations in 1988 to conduct scientific studies on climate change caused by human activities [7].
In its research, the IPCC highlighted that greenhouse gas (GHG) emissions have the most significant impact on climate change and has published greenhouse gas inventories. Using these inventories, each country can perform calculations to determine its own emission values. The guidelines published by the IPCC also include formulas for conducting greenhouse gas calculations.

3.1.1. TIER Approach

The Tier approach, included in the guidelines published by the IPCC in 2006 to calculate and report greenhouse gas (GHG) emissions, is a classification system consisting of three levels: Tier 1, Tier 2, and Tier 3. The Tier approach progresses from simple to complex, where Tier 1 can be described as basic, Tier 2 as intermediate, and Tier 3 as advanced.

Tier 1 Approach

This calculation method, which requires less data, is performed using fuel consumption data and emission factors. The results of the calculation are expressed in CO2 values. This method does not take into account the manner in which the fuels are burned [8]. The data required for this approach include the amount of energy consumed and standard emission factors [9].

Tier 2 Approach

In this method, the data on burned fuels is used along with emission factors specific to each country's type of fuel to perform calculations. Since emission factors vary depending on the country, the accuracy of the calculated results is high [8]. The data required for this approach include the amount of energy consumed and country-specific emission factors for energy consumption [9].

Tier 3 Approach

This approach uses more data, resulting in more accurate and reliable outcomes; however, it is more complex to calculate. The calculations are carried out using data and emission factors specific to the sector or organization being evaluated. This approach requires various detailed and complex data such as fuel type, combustion, control and maintenance technology, and the age of fuel equipment, among others [9].

3.1.2. Fundamental Elements of the Method

Data Analysis : Data are determined according to categories, that is, direct and indirect emission sources.

Emission Factor : The emission factor for the relevant source is identified based on the IPCC 2006 guidelines.

Calculation : The total amount of emissions related to the process is determined using the relevant formulas.

3.1.3. Calculation Method

The first step is data analysis, which involves identifying all components that contribute to emissions. In its simplest form, the emission value is calculated using the formula shown in Equation (1). Here, the emission factor per unit of activity is obtained from the guideline and used for the calculation.

$$\text{Emission} = \text{Total Fuel Amount} \times \text{Emission Factor} \quad (1)$$

The emission calculation steps for Category 1 are as follows:

- Identify fuel types
- Calculate total consumption
- Find density values for liquid fuels

Equation (2) is used for this step.

$$\text{Fuel Amount (kg)} = \text{Fuel Amount} \times \text{Density } (kg/m^3) \quad (2)$$

- Calculate the energy content of fuels:To determine the energy content, the net calorific values of the fuels are required. Multiply the fuel amount by the net calorific value using Equation (3)

$$\text{Energy Content} = \text{Fuel Amount} \times \text{Conversion Factor} \times \text{Net Calorific Value} \quad (3)$$

- Calculate the total carbon dioxide content: Multiply the energy consumption by the carbon emission factor using Equation (4)

The emission factor is found in the IPCC 2006 Guidelines. [10].

$$\text{Emission Content (kg)} = \text{Emission Factor (kg/Tj)} \times \text{Energy Consumption} \quad (4)$$

- Equation (5) is used to calculate the total carbon value involved in combustion.

$$\text{Carbon Emission (kg } CO_2) = \text{Emission Content (kg } CO_2) \times (1 - \text{Biomass Fraction}) \times \text{Oxidation Factor} \quad (5)$$

The emission calculation steps for Category 2:

- The amount of electricity used is calculated in kWh.
- Carbon dioxide emissions are calculated using Equation (6).

$$CO_2 \text{ Emission (kg } CO_2) = \text{Electricity Consumption (kWh)} \times \text{Emission Factor (kg } CO_2 / kWh) \quad (6)$$

The emission factor is obtained from the information form titled "Turkey Electricity Generation and Electricity Consumption Point Emission Factors" prepared by the Republic of Turkey Ministry of Energy and Natural Resources, Directorate of Energy Efficiency and Environment [11].

The emission calculation steps for Category 3,4,5 and 6 ;

$$CO_2 \text{ Emission (kg } CO_2) = \text{Activity Data} \times \text{Emission Factor} \quad (7)$$

In Equation (7), the activity data for the relevant category is calculated and substituted accordingly.

3.1.4. TIER Approach SWOT Analysis

Strengths

1. Uses a standardized approach guided by IPCC guidelines.
2. Tier 1 approach is easier to use as it can be calculated with less data.
3. Tier 2 and Tier 3 approaches provide more detailed and accurate results.

Weaknesses

1. The Tier 1 approach has a lower accuracy rate as it is a general calculation.
2. Tier 2 and Tier 3 approaches require more data and are difficult to implement.

Opportunities

1. Software can be developed to simplify and accelerate calculations.
2. It can be used in emission reduction strategies.

Threats

1. Inconsistencies in results may arise as emission factors vary across countries.

3.2. Life Circle Assesment (LCA)

Life Cycle Assessment (LCA) is a system defined by the ISO 14040 and 14044 standards, used to evaluate, reduce, and manage the environmental impacts of a product, process, and/or service throughout its entire lifecycle—from cradle to grave. The purpose of LCA is also to analyze the interrelations of all lifecycle stages of a product, service, or process. In the context of a process, a lifecycle refers to all stages from the procurement of raw materials to disposal, assessing environmental impacts within these stages, including emissions, chemical usage, water consumption, and energy use [12,13].

The ISO 14040 standard defines the framework and principles of lifecycle assessment, while ISO 14044 provides the requirements and guidelines [12].

3.2.1. Fundamental Elements of the Method

According to the ISO 14044 standard, Life Cycle Assessment (LCA) consists of four stages:

Goal and Scope: The purpose and scope of the study are defined. Products, activities, and processes are identified, and the expected environmental impacts are outlined.

Inventory Analysis : Emissions resulting from the use of raw materials, water, and energy within the system are identified in this stage.

Impact Assessment : The effects of emissions on human health and the environment are evaluated.

Interpretation : The final stage where the results of the inventory analysis and impact assessment are assessed.

The interaction of these four phases are presented in Figure 1.

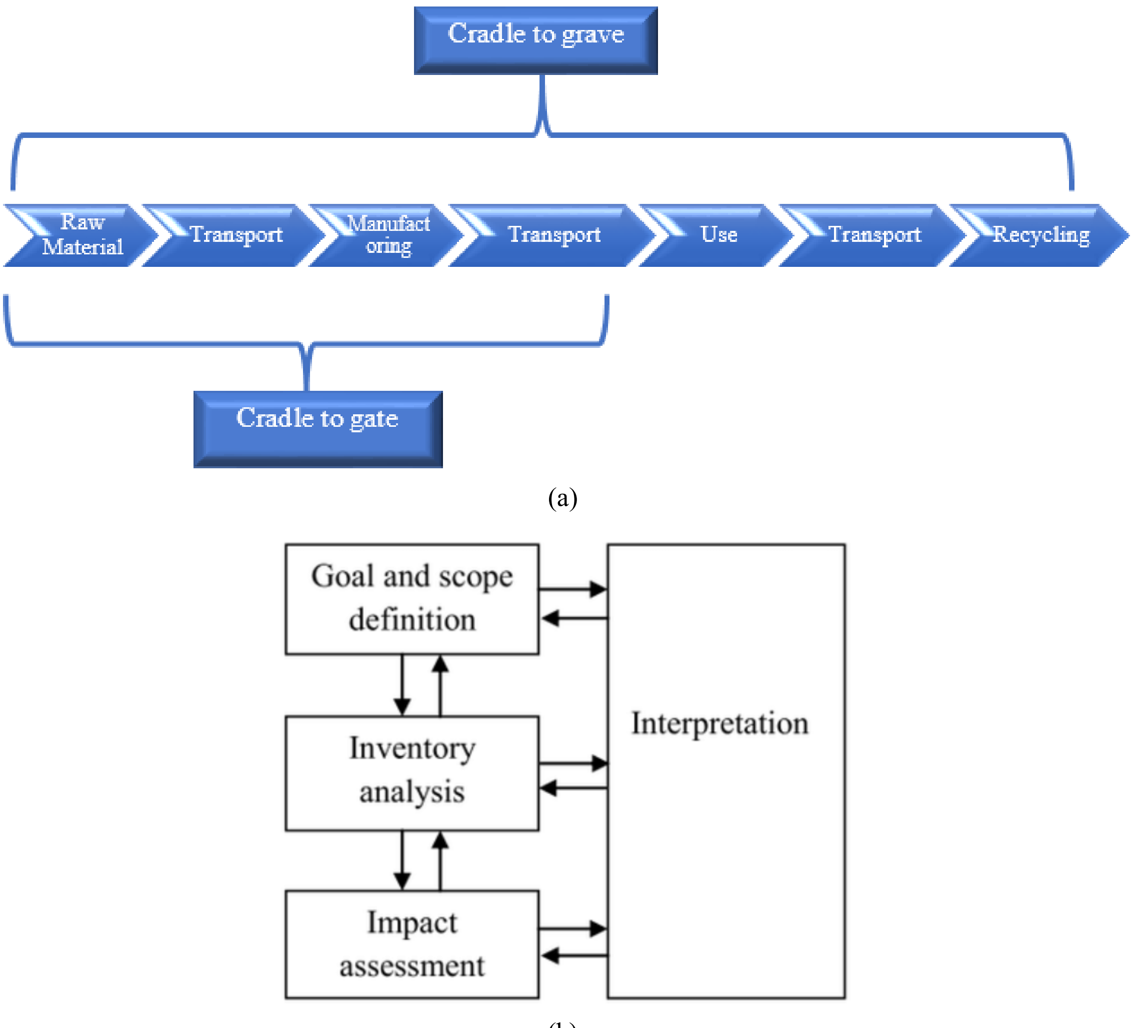

Figure 1. Phases of Life Circle Assesment [14]

3.2.2. Calculation Method

- The boundaries for calculating the carbon footprint are defined.
- All processes and emission sources within the defined boundaries are identified.
- Relevant emission factors are determined.
- Due to the complexity of the calculations, LCA software is often used.

$$CO_2 \text{ Emission} = \text{Resource Consumption Amount} \times \text{Emission Factor} \quad (8)$$

This calculation is performed for all processes to reach the total value.

3.2.3. LCA SWOT Analysis

Strengths

1. It encompasses all stages of a product's life cycle from cradle to grave.
2. It calculates emissions to include both direct and indirect emission sources.
3. It is implemented according to ISO 14040 and ISO 14044 standards.
4. Numerous software tools have been developed to enable calculations.

Weaknesses

1. Since it considers all processes from cradle to grave, analyses take a long time.
2. The cost of analysis is high.
3. It is difficult to understand and requires expertise.
4. Challenges may arise in obtaining data.

Opportunities

1. It helps businesses develop sustainable products.
2. Accurate measurements can create a competitive advantage in the industry.

Threats

1. Low-quality data negatively affects the reliability of the results.
2. It may be difficult to implement for small businesses but easier for large companies.

3.3. United Kingdom's Department for Environment, Food and Rural Affairs (DEFRA)

The UK Department for Environment, Food and Rural Affairs (DEFRA) is actively involved in addressing global warming and greenhouse gas emissions. To protect the environment and promote sustainability, DEFRA publishes annual emission factors. These factors include various carbon emission coefficients for activities such as transportation, energy consumption, and food consumption [1,15].

3.3.1. Fundamental Elements of the Method

Data Collection: All emission sources originating from activities are gathered.

Emission Factors : Method-specific emission factors are identified for sources such as electricity consumption, fuel usage and transportation vehicles.

Calculation : Calculations are performed using the relevant formula.

3.3.2. Calculation Method

Carbon Footprint = Consumption Data x DEFRA Emission Factor

Consumption data refers to the values of emission sources such as fuel consumption, energy consumption, transportation distance, and production quantity. The emission factor is the annual carbon dioxide equivalent (CO_2e) amount published by DEFRA.

3.3.3. DEFRA SWOT Analysis

Strengths

1. Emission factors are updated annually.
2. Emission factor values are provided for many categories, such as electricity, transportation, waste, and fuel consumption.
3. It is suitable for use in various sectors.

Weaknesses

1. Since emission factors are specific to the UK, their accuracy is lower for other countries.
2. The table may seem complex for individual use.

Opportunities

1. It can be digitized with software.

Threats

1. Other calculation methods are more commonly preferred

Tablei 1. Tier, LCA ve DEFRA SWOT analysis table

SWOT	TIER	LCA	DEFRA
Strengths	• Uses a standardized approach guided by IPCC guidelines. • Tier 1 approach is easier to use as it can be calculated with less data. • Tier 2 and Tier 3 approaches provide more detailed and accurate results.	• It encompasses all stages of a product's life cycle from cradle to grave. • It calculates emissions to include both direct and indirect emission sources. • It is implemented according to ISO 14040 and ISO 14044 standards. • Numerous software tools have been developed to enable calculations.	• Emission factors are updated annually. • Emission factor values are provided for many categories, such as electricity, transportation, waste, and fuel consumption. • It is suitable for use in various sectors.
Weaknesses	• The Tier 1 approach has a lower accuracy rate as it is a general calculation. • Tier 2 and Tier 3 approaches require more data and are difficult to implement.	• Since it considers all processes from cradle to grave, analyses take a long time. • The cost of analysis is high. • It is difficult to understand and requires expertise. • Challenges may arise in obtaining data.	• Since emission factors are specific to the UK, their accuracy is lower for other countries. • The table may seem complex for individual use.
Opportunities	• Software can be developed to simplify and accelerate calculations. • It can be used in emission reduction strategies.	• It helps businesses develop sustainable products. • Accurate measurements can create a competitive advantage in the industry.	• It can be digitized with software.
Threats	• Inconsistencies in results may arise as emission factors vary across countries.	• Low-quality data negatively affects the reliability of the results. • It may be difficult to implement for small businesses but easier for large companies.	• Other calculation methods are more commonly prefered.

4. Conclusion

In the textile industry, calculating the carbon footprint using all three methods will provide the most effective results for the enterprise in terms of comparison. A study where multiple methods are applied to evaluate each process individually, identify the processes with higher emissions, and prioritize them for implementing emission reduction measures will serve as a roadmap for environmental sustainability for the enterprise.

Although these evaluations may initially seem like a loss of time and money for businesses, they provide valuable data in the long term on measures to be taken.

This information can support various aspects of business operations, including quality management, risk management, and financial management.

Based on studies conducted on carbon footprint calculations within the sector, the general measures that should be taken can be summarized as follows:

- Using renewable energy sources instead of fossil fuels to meet energy needs.
- Preferring natural gas over coal in cases where fossil fuel use is unavoidable.
- Employing energy-efficient equipment to reduce energy consumption.
- Replanning transportation routes and keeping transportation distances short.
- Achieving carbon neutrality by increasing green areas.
- Reusing textile products at the end of their life cycles as raw materials.
- Ensuring proper insulation of buildings, both interior and exterior, for businesses.
- Implementing heat recovery techniques in necessary processes.
- Reducing waste quantities through effective management.
- Emphasizing the importance of recycling.
- Promoting the use of recycled products to foster sustainability.

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