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# Carbon Footprint Calculation: A Case Study from Textile Industry

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**Abstract**

This study investigates the carbon footprint (CFP) of a textile manufacturing plant located in Denizli province for the year 2021. The analysis employs the Tier Method to estimate greenhouse gas emissions across Scope 1, Scope 2, and Scope 3 categories, utilizing data on energy consumption, waste management, and transportation. The results reveal that Scope 2 emissions, primarily from electricity consumption, constitute the largest portion of the plant's CFP. In contrast, Scope 1 emissions are mainly driven by diesel and natural gas use, with negligible contributions from gasoline and fire extinguisher leakage. Scope 3 emissions are significantly influenced by wastewater treatment and water supply. The findings underscore the importance of focusing on electricity efficiency and renewable energy sources to mitigate emissions and highlight potential areas for improvement in water management and waste processing. The study provides a baseline for developing targeted strategies to reduce the plant's environmental impact and enhance sustainability practices in the textile industry.

**Keywords:** Carbon Footprint, Environmental Aspects, Global Warming, Greenhouse Gas Emissions, Sustainability, Textile Industry.

## 1. Introduction

The Earth's atmosphere contains various gases that regulate temperature, with carbon dioxide playing a crucial role in trapping heat through the greenhouse effect. This process helps maintain a stable temperature, preventing widespread freezing. Greenhouse gases (GHGs) can be both natural (like water vapor, carbon dioxide, methane, and ozone) and human-made (such as CFCs and HFCs). Since the Industrial Revolution, human activities like burning fossil fuels and deforestation have increased GHGs levels, significantly contributing to climate change [1]. There is overwhelming evidence that human activities are the primary cause of the rapid warming observed since the mid-20th century. Scientists are more than 95% certain that human actions—particularly the emission of greenhouse gases—are responsible for most of the climate change effects witnessed over the past few decades [2]. Given the overwhelming evidence linking human activities to climate change, it is critical to take proactive measures to reduce GHGs emissions and mitigate the damaging impacts of global warming.

Numerous organizations, institutions, countries, and other groups at both national and international levels are actively working to reduce emissions and achieve carbon neutrality. The awakening to climate change began with the Stockholm Conference in 1972 and has been reinforced by pivotal reports and agreements, including the Brundtland Commission Report, the Kyoto Protocol, and the Paris Climate Agreement, which is historically significant as the world's first comprehensive climate agreement. The Paris Agreement, signed by 175 countries responsible for at least 55% of global greenhouse gas emissions, aims to raise socioeconomic awareness about climate change and has prompted countries to adopt roadmaps for climate resilience [3].

In this context, the European Union (EU) launched the Green Deal in 2019, outlining a roadmap to ensure cooperation in mutual trade and economic goals while

fulfilling the requirements of the Paris Agreement. This initiative aims to reduce greenhouse gas emissions by 50% by 2030 and achieve zero carbon emissions by 2050. The EU has reshaped its entire economic policy to prevent carbon emissions and has designed the Carbon Border Adjustment Mechanism to impose additional customs duties at the consumption level for non-cooperative trading partners. This mechanism targets manufacturing sectors, such as iron and steel, aluminum, and fertilizer, establishing foreign connections parallel to the trading system for reducing emissions [3].

To reduce the negative environmental impact, a series of measures must be taken, including the adoption of cleaner energy sources, improved energy efficiency, and sustainable practices. Over the last two decades, software packages have been developed to estimate GHGs emissions, helping individuals and organizations track their environmental footprint [4]. One key tool in this effort is the carbon footprint (CFP) model, which helps identify the primary sources of greenhouse gas emissions. By serving as a baseline, this model is crucial for designing effective strategies to mitigate emissions. The Intergovernmental Panel on Climate Change's 2014 report highlights the importance of CFP analysis in guiding decisions to reduce emissions, and supporting policies for environmental impact reduction [5].

The CFP concept has garnered increased attention recently, particularly regarding global warming and environmental sustainability [6]. It represents the total GHGs emissions, either directly or indirectly, generated by individuals, organizations, events, or products. These emissions are measured in carbon dioxide equivalent ($CO_2e$), which standardizes the impact of various GHGs by converting them into an equivalent $CO_2$ amount [7].

Many organizations, including universities, fire brigades, food manufacturers, and hotels, have recently evaluated their CFP to understand their impact on global warming [8-10]. This growing awareness highlights the importance of addressing specific sectors, particularly the textile industry, which is a major contributor due to the high levels of emissions produced during manufacturing.

The textile industry accounts for 8–10% of worldwide carbon emissions, surpassing the total emissions of the aviation and shipping sectors combined [11, 12]. The significant carbon footprint is mainly caused by energy-intensive production processes, lengthy supply chains, and a strong dependence on fossil fuels in manufacturing centers like China, India, and Bangladesh. These emissions not only impact the environment and contribute to global warming but also affect various industries that rely on textile products.

This study analyzes energy use and carbon emissions in a textile factory from 2021. It assesses how energy is consumed and calculates the carbon emissions from different processes. The research identifies areas for improvement and suggests measures to reduce the factory's environmental impact, aiming to enhance sustainability and promote eco-friendly practices.

## 2. Materials and Methods

### 2.1. Study Area

The company is a textile manufacturing firm located in Denizli province, specializing in the production of home textile products through weaving, textile processing, and garment manufacturing. With a total facility area of 15,430 m², the company operates a medium-sized plant that produced 934,696 kg of textile products in 2021. The plant, employing 88 staff members, functions for 295 working days each year.

### 2.2. Carbon Calculation Model

In this study, carbon footprint calculations for Scope 1, Scope 2, and Scope 3 sources were performed using the Tier Method. The Tier approach to calculating carbon emissions follows the IPCC 2006 methodology and consists of three levels, each increasing in specificity and accuracy [13].

Tier 1 is the most basic emissions estimation method, using general average emission factors for different fuels and combustion processes without considering specific conditions or variations. Tier 2 improves upon this by applying country-specific emission factors, incorporating more detailed fuel statistics and local conditions for greater accuracy. Tier 3, the most detailed and precise method, uses a bottom-up approach that involves collecting specific data from individual sources, including direct measurements and thorough analysis, to provide the most accurate emissions estimates [13]. The Tier 1 approach was used for carbon footprint estimations due to the lack of available data to allow a more advanced degree of estimation. Tier 1 offers a comprehensive but dependable emissions estimate, ensuring sufficient accuracy considering the limitations of the available data.

For the calculation of greenhouse gas emissions, it is necessary to determine emission sources according to the following three scopes. Scope 1 emissions are direct greenhouse gas emissions from sources that are owned or controlled by the organization. Scope 2 emissions are indirect emissions resulting from the consumption of purchased electricity. These are emissions that occur at the power plants that generate the electricity the organization uses. Scope 3 emissions are the result of the organization's activities but come from sources not owned or controlled by the organization [13].

The general formula for the Tier Method is shown in Equation 2.1 [14].

$$CE = AD \times EF \quad (2.1)$$

Where CE represents the carbon emissions (tons $CO_{2e}$), AD is the activity data, and EF is the emission factor.

Direct greenhouse gas emissions from diesel and gasoline sources are calculated using Equation 2.2 [15].

$$CF = AD \times EF \times LHV \times D \times OF \times GWP \quad (2.2)$$

Direct greenhouse gas emissions from natural gas sources are calculated using Equation 2.3 [16].

$$CF = AD \times EF \times LHV \times OF \times GWP \quad (2.3)$$

Where LHV is the lower heating value, D is density, OF is the oxidation factor, and GWP is the global warming potential.

Direct greenhouse gas emissions from fire extinguishers are calculated using Equation 2.4 [15].

$$CF = \mathrm{WG} \times \mathrm{NN} \times \mathrm{LEO} \quad (2.4)$$

Where WG is the weight of the cylinder, NN stands for the number of cylinders, and LEO is the leakage emission rate.

### 2.3. Data

All data is based on information from the year 2021. Within the scope of this data, calculations have been performed for the total produced products, electricity consumption, natural gas usage, steam usage, water supply, wastewater treatment, hazardous and non-hazardous waste storage, fire extinguishers, and emissions resulting from transportation. The data for the year 2021 related to the business is provided in Table 1.

**Table 1.** Operational Data.

| Activity | Unit | Amount |
|---|---|---|
| Production | kg/year | 934,696 |
| Electricity consumption | kwh/year | 2,579,676 |
| Natural gas consumption | $m^3$/year | 7,009 |
| Steam consumption | ton/year | 2,214 |
| Diesel consumption | l/year | 7,226 |
| Gasoline consumption | l/year | 886 |
| Water supply | $m^3$/year | 14,200 |
| Water treatment | $m^3$/year | 9,236 |
| Employee shuttle diesel | km/year | 4,800 |
| Non-hazardous waste | kg/year | 44,440 |
| Hazardous waste | kg/year | 1,877 |
| Waste truck | km/year | 200 |
| Fire extinguishers | amount/year | 35 |

In this study, it is assumed that the vehicles use gasoline and diesel, due to those fuels are standard fuels with well-documented emission factors, allowing for reliable and consistent $CO_{2e}$ emissions estimates. This assumption ensures feasible and accurate calculations within the available data, providing a significant estimate of emissions from transportation activities. Table 2 contains the conversion factors that will be used to convert the "quantity" into the equivalent $CO_{2e}$ emissions.

**Table 2.** Emission Factor [16].

| Activity | Unit | Emission Factor |
|---|---|---|
| Electricity consumption | kg $CO_{2e}$/kwh | 0.447 |
| Steam consumption | kg $CO_{2e}$/kg | 0.054 |
| Water supply | kg $CO_{2e}$/$m^3$ | 0.149 |
| Water treatment | kg $CO_{2e}$/$m^3$ | 0.272 |
| Employee shuttle - diesel | kg $CO_{2e}$/km | 0.17 |
| Non-hazardous waste | kg $CO_{2e}$/ton | 21.294 |
| Hazardous waste | kg $CO_{2e}$/ton | 21.294 |
| Waste truck | kg $CO_{2e}$/km | 0.17 |

The density values for diesel and gasoline fuels are 0.830 kg/L and 0.735 kg/L, respectively [17].

The IPCC Global Warming Potential (GWP), used to convert greenhouse gases into $CO_2$ equivalents, is provided in Table 3 [5].

**Table 3.** Global warming potential values relative to $CO_2$.

| Greenhouse Gas | Global Warming Potential |
|---|---|
| $CO_2$ | 1 |
| $CH_4$ | 28 |
| $N_2O$ | 265 |

The lower heating values of fuel types are provided in Table 4 [15, 18].

**Table 4.** Lower heating values of different fuel types

| Fuel Type | Lower heating values |
|---|---|
| Natural gas | 8,100 kcal/$m^3$ |
| Diesel | 43 MJ/kg |
| Gasoline | 44.3 MJ/kg |

The emission factors for fuel types are provided in Table 5 [19].

**Table 5.** Fuel types emission factos

| Fuel Type | $CO_2$ (kg/TJ) | $CH_4$ (kg/TJ) | $N_2O$ (kg/TJ) |
|---|---|---|---|
| Natural gas | 56,100 | 5 | 0.1 |
| Diesel | 74,100 | 3.9 | 3.9 |
| Gasoline | 69,300 | 25 | 8 |

## 3. Results and Discussion

The results of the calculation are presented in Table 6 and Figure 1. The sources of carbon emissions from Scope 1 include natural gas consumption, gasoline consumption, diesel consumption, and leakage from fire extinguishers. Diesel consumption is the primary source of Scope 1 emissions, with natural gas coming in second. In comparison, the impact of gasoline and leakage from fire extinguishers is negligible.

The sources of carbon emissions from Scope 2 include electricity and steam consumption. Electricity consumption is the dominant contributor to Scope 2 emissions, indicating that improving the efficiency or switching to renewable energy sources for electricity could significantly reduce the carbon footprint.
The sources of carbon emissions from Scope 3 include water supply, wastewater treatment, diesel consumption in services, and diesel consumption in waste trucks. Wastewater treatment and water supply are the primary contributors to Scope 3 emissions. Addressing these areas, either by optimizing treatment processes or enhancing water management practices, could contribute to a reduction in Scope 3 emissions.

When considering Scope 1, Scope 2, and Scope 3 together, it is observed that the carbon footprint from Scope 2 sources is higher. Scope 2 emissions sources include electricity and steam. When comparing these two emission sources within the business, it is determined that electricity emits more than steam. Electricity consumption generally comes from heating, cooling, office equipment, and machinery used in production. Steam consumption, on the other hand, occurs in heating and the sizing process.

Studies conducted by Yan and Wang, et al. [8], reported carbon footprints for wool-based textiles, with emissions of 14.07 kg $CO_2e$/kg for pure wool compared to 5.34 kg $CO_2e$/kg for cotton, where electricity accounted for 87% of total emissions. Similarly, Başoğul and Göksu, et al. [20] identified electricity consumption as the largest contributor in a factory emitting 297.343 tons $CO_2$ annually over 300 working days. These findings align with our results, which also emphasize the dominant impact of electricity on overall emissions.

The textile sector can significantly reduce its carbon footprint and align with both Turkish environmental regulations and the EU Green Deal by adopting sustainable practices and utilizing effective carbon accounting tools. This can be achieved by addressing emissions in all three scopes through a variety of strategies.

For Scope 1 emissions, primarily from the consumption of diesel and natural gas, manufacturers can make substantial improvements by transitioning to electric or hybrid vehicles for transport and waste management. Additionally, investing in energy-efficient heating systems and utilizing cleaner energy sources like electricity or biomass can further reduce direct emissions. Scope 2 emissions, mainly from electricity consumption, can be mitigated by adopting renewable energy sources such as solar and wind power. By implementing energy-efficient technologies like LED lighting, automated systems, and energy management practices, manufacturers can reduce their carbon footprint and energy costs while improving resource efficiency. For Scope 3 emissions, particularly those associated with water supply, wastewater treatment, and waste, manufacturers can focus on water conservation and recycling efforts. Implementing advanced wastewater treatment systems, water-efficient technologies, and water recycling practices will ensure more sustainable water use while complying with regulations such as Turkey's Water Pollution Control Regulation and the EU

Water Framework Directive. Optimizing waste management processes and adhering to eco-labeling standards will further support environmental goals [21, 22].

To support these efforts, the use of carbon accounting tools like the Carbon Trust Footprinting Tool, C&A's Climate Strategy & Emission Tracker, and the Higg Index can provide valuable insights into emissions across the supply chain. Tools like GaBi Software and the Ecoinvent Database enable companies to track their emissions more precisely, allowing for better management and reduction of their environmental impact.

**Table 6.** Carbon footprint results.

| Scopes | Activity | Carbon Footprint (tons $CO_{2e}$/ton of product) | Total |
|---|---|---|---|
| **Scope 1** | Natural gas consumption | 0.014 | 0.038 |
| | Diesel consumption | 0.021 | |
| | Gasoline consumption | 0.0022 | |
| | Fire Extinguishers | 0.0000075 | |
| **Scope 2** | Electricity consumption | 1.23 | 1.38 |
| | Steam consumption | 0.15 | |
| **Scope 3** | Water supply | 0.0023 | 0.0071 |
| | Wastewater treatment | 0.0027 | |
| | Waste | 0.0011 | |
| | Waste truck | 0.00014 | |
| | Employee shuttle - diesel | 0.00088 | |
| | | | 1.43 |

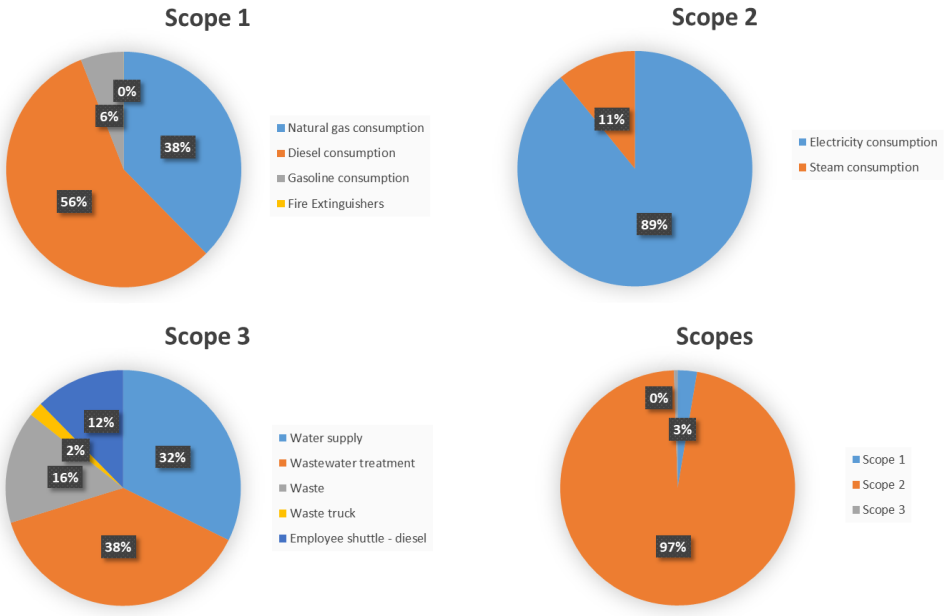



**Figure 1.** Carbon Footprint from Scope 1, Scope 2, and Scope 3 Sources.

## 4. Conclusion

This study provides a comprehensive analysis of the carbon footprint associated with a textile manufacturing plant in Denizli, emphasizing the significance of understanding and reducing greenhouse gas emissions. The primary purpose was to quantify emissions across Scope 1, Scope 2, and Scope 3 categories, thereby identifying key areas for improvement in the plant's sustainability practices.

The major findings indicate that Scope 2 emissions from electricity consumption are the largest contributor to the plant's carbon footprint, followed by Scope 1 emissions from diesel and natural gas. Scope 3 emissions, particularly from wastewater treatment and water supply, also play a significant role.

The textile sector can reduce its carbon footprint and align with environmental regulations like the EU Green Deal by addressing emissions across all three scopes. For Scope 1 emissions, companies can shift to electric or hybrid vehicles and adopt cleaner energy sources like electricity or biomass for production. For Scope 2 emissions, manufacturers can use renewable energy sources like solar and wind, and implement energy-efficient technologies such as LED lighting and automated systems. To tackle Scope 3 emissions, companies can focus on water conservation, efficient wastewater treatment, and waste reduction through recycling. Utilizing carbon accounting tools like the Higg Index and GaBi Software will help track emissions and guide reductions. By combining these strategies, the textile sector can reduce its environmental impact, meet regulations, and align with consumer expectations for sustainability.

### Author's Contributions

**Sümeyye Işık:** Investigation, Writing

**Mehmet Alperen Ergün:** Conceptualization, Methodology.

**Muath Njjar:** Writing – original draft.

**Ezgi Aktürk:** Validation

**Umut Başkurt:** Investigation, Methodology

**Abdullah Akdogan:** Writing - Review & Editing, Supervision

### Ethics

There are no ethical issues after the publication of this manuscript.

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