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Carbon Footprint Assessment of Rose Oil Production

Gül Yağı Üretiminin Karbon Ayak İzi Değerlendirmesi

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Abstract
Greenhouse gas emissions in the atmosphere are a primary driver of climate change. As energy production and consumption rise rapidly globally, enterprises must quantify their environmental impacts. This study assesses the carbon footprint of a rose oil facility located in the Mediterranean Region, including its production and transportation activities to the export destination. The total carbon footprint of the facility was calculated as 14.63 $kgCO_2$-eq/kg; when the carbon sequestration effect of trees within the facility area was considered, this value was reduced to 14.08 $kgCO_2$-eq/kg. The product specific carbon footprint was determined to be 32.22 $kgCO_2$-eq/kg product. Natural gas was identified as the dominant emission source, accounting for 8.15 $kgCO_2$-eq/kg (55.71%). The combined carbon footprint from natural gas and diesel amounted to 8.93 $kgCO_2$-eq/kg, whereas electricity consumption contributed 0.15 $kgCO_2$-eq/kg. Other sources, excluding wastewater, CO_2 cylinders, transportation, and waste, were other carbon footprint contributions. To reduce emissions, the facility should adopt alternative renewable energy systems. Using rose residues in anaerobic reactors for electricity generation can also help with waste valorization and emission reduction. Minimizing indirect emissions from waste transportation and increasing the number of trees on-site are other recommended measures. Overall, carbon footprint mitigation is crucial for long-term sustainability strategies in the sector and mitigating climate change impacts.

Öz
Atmosferde biriken sera gazı emisyonları, iklim değişikliğinin başlıca etkenlerinden birini oluşturmaktadır. Enerji üretimi ve tüketimindeki küresel artışın hızı göz önüne alındığında, işletmelerin çevresel etkilerini nicel olarak değerlendirmeleri gerekmektedir. Bu çalışma, Akdeniz Bölgesi'nde bulunan bir gül yağı tesisinin üretim ve ihraç edilen ülkeye taşıma faaliyetleri dahil karbon ayak izini değerlendirmektedir. Tesisin toplam karbon ayak izi 14.63 $kgCO_2e/kg$ olarak hesaplanmıştır; tesis alanı içindeki ağaçların azaltıcı etkisi dikkate alındığında, bu değer 14.08 $kgCO_2e/kg$'a düşmüştür. Ürüne özgü karbon ayak izi ise 32.22 $kgCO_2e/kg$ olarak belirlenmiştir. Doğal gaz, 8.15 $kgCO_2e/kg$ (%55.71) ile baskın emisyon kaynağı olarak tespit edilmiştir. Doğal gaz ve dizelin toplam karbon ayak izi 8.93 $kgCO_2e/kg$ iken, elektrik tüketiminin katkısı 0.15 $kgCO_2e/kg$ olarak hesaplanmıştır. Atık su, CO_2 tüpleri, nakliye ve atıklar diğer karbon ayak izine neden olan başlıklardır. Tesisin karbon ayak izini azaltmaya yönelik temel öneri, alternatif yenilenebilir enerji sistemlerinin benimsenmesidir. Ayrıca, elektrik üretimi amacıyla anaerobik reaktörlerde gül artıkları kullanılması, atıkların değerlendirilmesini kolaylaştırırken emisyonları da azaltabilir. Atık nakliyesinden kaynaklanan dolaylı emisyonların en aza indirilmesi ve tesis alanı içindeki ağaç sayısının artırılması gibi ek önlemlerin de emisyon azaltımına katkıda bulunması beklenmektedir. Genel olarak, karbon ayak izinin azaltılması, sektördeki uzun vadeli sürdürülebilirlik stratejilerini güçlendirmek ve iklim değişikliğinin olumsuz etkilerini hafifletmek için temel bir ön koşul olarak görülmektedir.

INTRODUCTION

Driven by a burgeoning global population and rapid technological advancements, escalating energy consumption has led to significant environmental degradation. In the contemporary era, consumers are increasingly conscious of and concerned about the ecological consequences of their individual actions (Rondoni & Grasso, 2021). Notably, the relentless rise in atmospheric greenhouse gas emissions exerts a direct impact on ecological equilibrium, societal frameworks, and economic processes (Geneidy et al., 2021). Consequently, scientific inquiries into the role of greenhouse gas emissions in climate change have gained substantial momentum. Greenhouse gases generated through anthropogenic activities are identified as the principal drivers of climatic shifts (Zeng, 2009). In this context, formulating strategies to mitigate greenhouse gas emissions and fostering engagement in these initiatives have emerged as a critical imperative to alleviate the adverse effects of climate change (Gilles et al., 2021). The inaugural international treaty on this issue, the United Nations Framework Convention on Climate Change (UNFCCC), came into effect in 1994 (Turgut & Budak, 2022). Nevertheless, the Kyoto Protocol, signed in 2005, is recognized as the first legally binding instrument specifically designed to reduce climate-linked greenhouse gas emissions (Greenpeace, 2021). Building upon the foundation laid by the Kyoto Protocol, research on carbon footprint (CF) intensified following the signing of the Paris Agreement in 2016 (Mutlu et al., 2018). Adopted in December 2015, the Paris Agreement represents one of the most pivotal global initiatives to curb carbon emissions, with the primary objective of limiting the global average temperature increase to 1.5°C and maintaining it well below 2°C (Tas, 2022). Türkiye ratified the Paris Agreement on April 22, 2016; subsequently, the "Law on the Approval of the Paris Agreement" was published in the Official Gazette in 2021, and officially enacted (Tosun & Dede, 2024). These collective developments have bolstered global awareness and accelerated scientific research focused on calculating the CF of production processes across diverse industrial sectors (Ozsoy, 2014).

Rose oil production, as a fundamental source of raw materials for the pharmaceutical and cosmetic sectors, remains one of the world's most significant industries (Fereidani & Uctug, 2023). Turkey, particularly the region surrounding Isparta, is a leading global producer due to its high-quality rose oil output (Agaoglu, 2000). However, the distillation-based production of rose oil involves multi-stage processes such as fuel consumption, transportation, and waste management all of which led to substantial energy consumption and various greenhouse gas emissions (Kiss & Smith, 2020). By measuring, monitoring, and reporting the carbon footprint (CF) within the rose oil production sector and implementing necessary measures for activities with high carbon intensity, both the sector's contribution to the national economy and its overall sustainability can be enhanced.

CF Assessment to Global Warming Potential (GWP)

Anthropogenic activities, such as the combustion of fossil fuels, industrial development, and deforestation, lead to the accumulation of greenhouse gases in the atmosphere, thereby driving an increase in global temperatures. This phenomenon is considered the primary driver of the climatic shifts observed particularly since the mid 20th century (Altay et al., 2025). Such accumulation intensifies the natural greenhouse effect and when combined with urbanization, increases atmospheric temperatures and worsens the scarcity of agricultural water resources (Senturk et al., 2023). Broadly defined, the CF is a metric that quantifies the environmental damage caused by human activities in terms of carbon dioxide equivalent greenhouse gas emissions (Budak et al., 2025a; Cambazoglu et al., 2026a). Assessments regarding the fundamental causes of climate change and the concept of CF are directly linked to measures taken on a global scale. The rise in greenhouse gas emissions stemming from human activities has not only disrupted environmental equilibrium but has also necessitated collective international action (Fereidani & Uctug, 2023). Consequently, international agreements developed within the scope of combating climate change play a critical role in reducing carbon emissions and ensuring sustainable development (Tosun & Dede, 2024). A cornerstone of the sustainable environment approach is the necessity of sharing and managing carbon emissions (Wang et al., 2020; Budak et al., 2025b). The significance of environmental emissions is manifested not only through the tracking of gases released into the atmosphere by enterprises but also through the measurement, monitoring, reporting, and calculation of the CF (Durlu-Özkaya et al., 2024).

The most current method for identifying carbon emissions that may cause a greenhouse effect because of anthropogenic activities is the calculation of the 'CF' (Coskun & Dogan, 2021; Cambazoglu et al., 2025; Cambazoğlu et al., 2026b). CF calculation encompasses greenhouse gas emissions released throughout the stages of raw material extraction, product manufacturing, product utilization, and end-of-life waste disposal (Patel, 2006; Galli et al., 2012). These activities result in the emission of greenhouses gases such as CO2, CH_4, N_2O, HFCs, PFCs, and SF_6 (Igci & Cobanoglu, 2019; Coskun & Dogan, 2021). To determine the global warming potentials of these greenhouse gases, the impact of each gas is expressed in terms of CO_2 and is termed 'Carbon Dioxide Equivalent' (CO_2e) (Coskun & Dogan, 2021; Budak et al., 2025a; Budak et al., 2025b). Consequently, CF is defined as the amount of equivalent CO_2 released per unit of product because of the production phases (Patel, 2006). Based on the assumption that the atmospheric impact of CO_2 gas is 1 unit, the impact exerted by each greenhouse gas can create in the atmosphere over a 100-year period has been established in the literature as 'global warming potential' (Gunathilaka & Gunawardana, 2015). CO_2 is the most significant gas considered in CF calculations, and its global warming potential is specified as 1 according to the IPCC 5th Assessment Report (IPCC, 2013).

In - CF calculations, emission sources are reported across different categories as Scope 1, Scope 2, and Scope 3. Emissions originating from controlled chemical production and vehicle usage within the facility are classified under Scope 1; emissions resulting from the use of electricity generated within the facility during production or purchased from external sources are evaluated under Scope 2; and indirect emissions arising from sources not controlled by the company are categorized under Scope 3. The most prevalent practice for CF calculation involves estimations performed using documented emission factors (EF) and activity data (Matthews et al., 2008; Gunathilaka & Gunawardana, 2015; Inakollu et al., 2017).

A review of the existing literature reveals a limited number of environmental impact assessments concerning essential oil production, with CF studies specifically focusing on rose oil production facilities lacking sufficient detail. In this context, the present research was conducted to calculate CF within the scope of environmental emissions and to evaluate it from a sustainable environmental perspective. The study aims to contribute to the body of academic CF research in our country and to serve as a model for the industry.

Rose and Rose Oil Production in Türkiye and the World

The rose oil production industry remains a global locomotive sector due to its role in providing essential raw materials for the cosmetics, perfumery, pharmaceutical, and food industries (Gökdoğan, 2013). The most extensive producers of aromatic rose oil and rose water are Iran, Türkiye, Bulgaria, and India (Zamani-Farahani & Fox, 2018). Isparta province, which produces 80% of Türkiye's oil-bearing roses, possesses the potential to establish a 'cosmetics valley' for the growth of the national cosmetics and fragrance sectors (Giray & Omerci Kart, 2012; Gül & Celik, 2016). The remaining production is concentrated in several provinces, namely Burdur, Afyon, and Denizli (Ömerci Kart et al., 2012). Rose water can be produced using 1 to 3 kg of fresh rose petals and 3,500 to 6,000 kg of rose petals are needed to produce 1 kg of rose oil (Fereidani & Uctug, 2023). The production of rose oil and rose water contributes significantly to the national economy, and the export of most of the produced rose oil serves as a vital source of foreign exchange (Agaoglu, 2000). Rose oil accounts for a significant portion of Turkey's essential oil exports. Nearly all rose oil produced is exported. In 2010, rose oil exports totaled approximately $10.4 million (Ömerci Kart et al., 2012). The price per kilogram of rose oil was $6,384 in 2010 (Ömerci Kart et al., 2012) and €7,500 in 2018 (Dağlı, 2019). In 2018, 10,546 kg of rose oil was exported, generating $14,597,630 for the national economy (Dağlı, 2019). It is exported to various countries, primarily France, followed by Switzerland, Japan, and the USA (Demircan, 2005; Gül et al., 2015).

Sustainable Rose Oil Production and CF Studies

The sustainability of rose water and rose oil production, which are utilized in cosmetic and medicinal fields due to their high aromatic profiles and bioactive components, is of paramount importance (Jabbarzadeh & Khosh-Khui, 2005). Furthermore, the environmental impacts of this sector which requires intensive agricultural (Sellahewa and Martindale, 2010; Ghisellini et al., 2016) and processing practices must be analyzed due to its high consumption of energy and natural resources (Tilman & Clark, 2014). Ultimately, the sustainability of rose water and rose oil production is intrinsically linked to the sustainable utilization of natural resources.

Factors such as the types of fuel utilized in rose oil production conducted through traditional and semi-industrial methods, water consumption, energy requirements during the distillation process, and the management of organic waste are prominent elements regarding sustainable production. Simultaneously, these factors emerge as critical parameters in determining the CF. Therefore, evaluating the production process through an environmental perspective is significant for identifying emission sources and developing mitigation strategies (Dogan, 2023).

According to the research by Fereidani and Uçtug (2023), the life cycle of rose water, secondary rose water, and rose oil production in Iran was evaluated by considering both the cultivation and processing stages. When comparing the CF studies of these three products, rose oil was found to have the highest energy intensity based on the specific energy use of the final products. The CF value for traditionally produced rose oil was calculated at 1.01 kgCO_2-eq/kg. It was concluded that utilizing fresh rose flowers for oil production increases greenhouse gas emissions due to their low oil content (Fereidani & Uçtug, 2023). Furthermore, rose petal and natural gas consumption are the primary contributors to total energy consumption (Fereidani & Uçtug, 2023). In alignment with these findings, Moura et al. (2022) state that natural gas is the dominant energy source for the extraction process in distillation plants. As the production rate increases, energy consumption per unit of product decreases; thus, the significant differences between the impacts of products manufactured at industrial versus laboratory scales are understandable (Fereidani & Uctug, 2023).

MATERIALS AND METHODS

Facility Data

This study was conducted at a rose oil production facility operating in the Mediterranean Region. The facility operates on a seasonal basis (June and July) and is characterized as a small-scale enterprise with 15 employees and an annual production capacity of 437 kg of rose oil. The study assesses the carbon footprint associated with the operations of a rose oil facility, including the production stages and the transportation of the product to the point of sale in the export country. Data regarding product use and lifespan were not obtained and have therefore been omitted. This study is not a life-cycle assessment but includes cradle-to-gate carbon footprint calculations (Figure 1).

Data regarding product use and lifespan were not obtained and have therefore been omitted. This study is not a life-cycle assessment but includes cradle-to-gate carbon footprint calculations. In the rose oil production process, fresh rose flowers harvested in the early morning are transported to the facility on the same day and subjected to hydrodistillation in steam distillation boilers. Five hundred kilograms of fresh rose flowers, along with three tons of water, are added to the distillation boiler and heated for approximately 1.5 hours to facilitate steam generation. During the boiling process, the volatile oils released from the oil-bearing roses are drawn toward the condenser, where they are liquefied and collected in glass vessels within the Florentine tank. In the final stage, the residual wastewater and pulp in the boilers are discharged and transferred to a pulp pool. The calculations were based on 2021 data; Scope 1 and Scope 2 emissions were evaluated using primary facility data, whereas Scope 3 emissions were assessed within the context of waste management activities managed by third-party organizations.

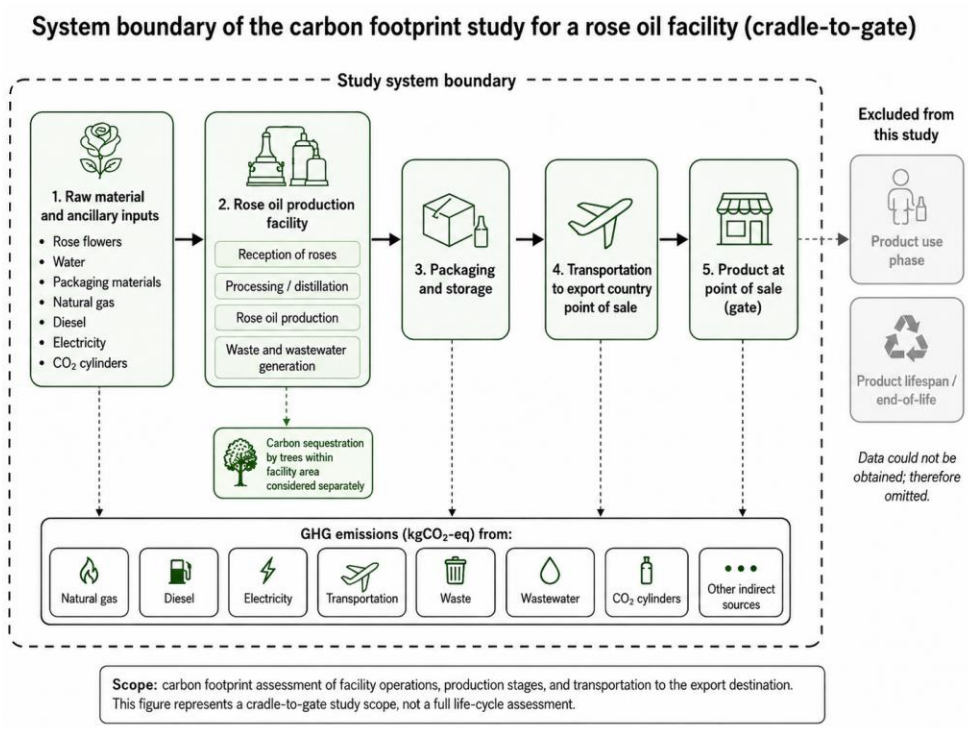

Figure 1. System boundary of the study

The scope of the rose oil production process was analyzed, considering natural gas and diesel consumption under Scope 1. Electricity consumption was included under Scope 2. Additionally, CO_2 cylinders, transportation, hazardous and non-hazardous wastes, and wastewater data were assessed under Scope 3. These detailed data are presented in Table 1.

Table 1. Facility data and emission sources

Scope	Sources	Consumption Amounts	Unit	Instructions
Scope 1	Natural Gas	4.190	m^3/year	Heating of production boilers, kitchen
	Diesel Fuel	290	L/year	Facility-owned vehicles and staff shuttle services
Scope 2	Electric	272.74	kWh/year	Facility lighting and machinery operation
Scope 3	CO_2 cylinders	84	kg	Four units of 12 kg and six units of 6 kg
	Hazardous Wastes	35	kg	Contaminated packaging, personal protective equipment (PPE), cleaning cloths, and batteries
	Non-Hazardous Wates	25.000	kg	Rose pulp and municipal waste
	Wastewater	3.900	m^3	Process, kitchen, and washbasin
	Transportation	11.156.5	L/year	Export of rose oil to France

Method

The scope of this study involved calculating the potential amounts of CF that could be generated from the rose oil production facility. These calculations were conducted within the framework of the 'Integrated Pollution Prevention and Control (IPPC) approach, using the formulas recommended by the IPCC for the Tier-1 level, as illustrated in Equations 1 and 2 (IPCC, 2019).

$$CF = AD * EF \quad (1)$$

$$CF = AD * EF * NCV \quad (2)$$

Carbon footprint (CF) refers to the amount of carbon dioxide equivalent (CO_2eq) of air pollutants emitted into the atmosphere from a facility due to activities like electricity consumption and heating. Activity data (AD) pertains to the fuel or materials consumed or produced by a process. Emission factor (EF) represents the average emission amount per unit of volume, mass, time, or quantity of a pollutant. Net calorific value (NCV) represents the energy content of a fuel or material.

Assuming a cargo aircraft cabin volume of 35 m³, the space occupied by the rose oil dispatched for export in 2021 was calculated as 0.58 m³, which represents 1.66% of the aircraft's total cargo volume. Consequently, 1.66% of the aircraft's total total carbon footprint (CF) is attributed to the rose oil shipment in question. The IPCC recommends using the Tier-2 method to calculate emissions from aircraft using jet fuel (IPCC, 2019). In this context, emission values were calculated via the Tier-2 approach, based on the emission factors and fuel consumption data provided by the IPCC.

$$CF_{transportation} = \left((FC * d * 10^{-3}) * CF * 10^{-3}\right) * EF * 10^{-3} * fox * GWP \quad (3)$$

Here, FC represents fuel consumption in liters (L), d denotes density in kilograms per liter (kg/L), CF refers to the conversion factor in terajoules per gigagram (TJ/Gg); EF stands for the emission factor kilograms per terajoule (kg/TJ); fox represents the fraction of carbon oxidized (1% for CO_2) (IPCC, 2019); and GWP indicates the global warming potential (1 for CO_2) (IPCC, 2019). The emission factors and net calorific values (NCV) were sourced from IPCC publications (IPCC, 2019). The relevant emission factors and NCVs are presented in Table 2. Using these data, the tCO_2eq values were calculated, which in turn enabled the determination of the total CF of the facility.

Table 2. Emission factors and net calorific values

Emission sources	Emission factors (CO_2/CH_4/N_2O)	Emission factors units	Net calorific values (NCV) (Ti/Gg)
Tree count	11	kgCO_2-eq/year	
Natural gas	56.100/5/0.1	kgCO_2-eq/Tj	48
Diesel fuel	74.100/3.9/3.9	kgCO_2-eq/Tj	43
Electric	0.555	kg/kWh	
CO_2 cylinders	-		
Hazardous wastes	3.59	kgCO_2-eq/t waste	
Non-Hazardous wastes	0.021	kgCO_2-eq/t waste	
Wastewater	0.0014	kgCO_2-eq/L	
Transportation	71.500	kg/Tj	44.1

RESULTS

In the rose oil production process, the CF was calculated using the Tier-1 method. This method accounted for natural gas and diesel consumption in production boilers and the kitchens, as well as fuel consumption per kilometer and for shuttle and private vehicles. It is also included electricity consumption, CO_2 cylinders, hazardous and non-hazardous waste and wastewater data. Emissions originating from transportation were evaluated within the scope of exporting the rose oil produced at the facility to France. These emissions were calculated using the Tier-2 method. Additionally, the emission sequestration effect of the trees located on the facility grounds was estimated using the Tier-1 method. The source-based CF results are presented in Table 3.

Table 3. Distribution of CF by emission sources

Scope	Emission sources	Consumption amounts
Scope 1	Natural Gas	4.190
	Diesel Fuel	290
Scope 2	Electric	272.74
Scope 3	CO_2 cylinders	84
	Hazardous Wastes	35
	Non-Hazardous Wates	25.000
	Wastewater	3.900
	Transportation	11.156.5
Tree Count		**-0.005**
TOTAL CF		**14.08**

Figure 2 illustrates the distribution of carbon emission scopes. Within Scope 1, natural gas consumption is the primary source of carbon emissions accounting for 61.04%. Scope 2 emissions contribute 1.03% of the total CF, while Scope 3 emissions make up 37.94%. Scope 1, the largest contributor to carbon emissions, is dominated by natural gas consumption, accounting for 91.27%. Diesel consumption accounts for the remaining 8.73% of emissions within this scope. In Scope 3, the emission-contributing factors are ranked by magnitude. Wastewater treatment activities are the largest contributor, accounting for 98.38% of the total emissionsin this category. Other factors include CO_2 cylinders, transportation, non-hazardous waste, and hazardous waste.

The highest carbon emissions originate from the natural gas used in the production process, accounting for 55.71% (Figure 3). Wastewater treatment activities follow, contributing 37.32% of the total emissions. To determine the facility's net carbon emissions and their impacting on the atmosphere, we must consider the carbon sequestration provided by the trees on the facility grounds. When this sequestration effect is factored in, the facility's annual CF is calculated to be 14.08 kgCO_2-eq/kg. Given the facility's annual production capacity of 437 kg of rose oil, the CF per unit of product is determined to be 32.22 kgCO_2-eq/kg product.

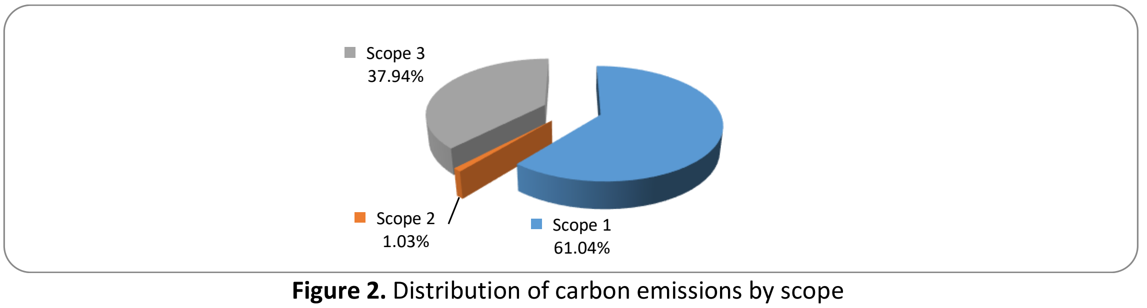

Figure 2. Distribution of carbon emissions by scope

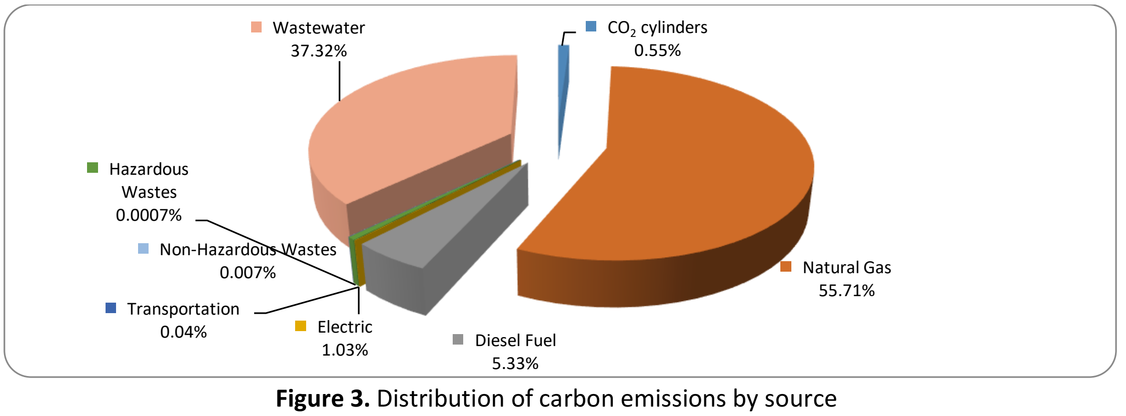

Figure 3. Distribution of carbon emissions by source

DISCUSSION

Within the scope of this study, the total CF of the rose oil production facility was calculated to be 14.63 kgCO_2-eq/kg. The primary source of emissions is the natural gas used during production, which falls under Scope 1 and accounts for 8.15 kgCO_2-eq/kg (55.71%). Interestingly, the literature consistently reports that natural gas consumption during the hydrodistillation process in rose water production can reach up to 66.4% of the total CF (Fereidani & Uctug, 2023).

In the study, Scope 2 emissions from electricity consumption were found to be 0.15 kgCO_2-eq/kg. Wastewater treatment activities were the largest source of emissions under Scope 3, accounting for 5.46 kgCO_2-eq/kg. In contrast, CO_2 cylinders, transportation, and hazardous and non-hazardous wastes generated lower emission levels. The significant contribution of wastewater treatment processes to the total CF is supported by existing literature (Fereidani & Uctug, 2023). Reducing natural gas and electricity consumption is the primary solution for lowering CO_2 emissions. For instance, Helmes et al. (2021) evaluated CF processes in greenhouse rose cultivation categorizing them based on the contributions of natural gas, electricity, transportation, and waste. They recommended investing in temperate and sheltered regions to reduce energy consumption. To mitigate environmental impacts, Moncada et al. (2016) suggest using more profitable and cleaner extraction technologies in essential oil production. Additionally, converting non-hazardous waste into fertilizer through composting on factory premises can help reduce waste disposal costs (Işık et al., 2025). Reducing the amount of waste that needs to be removed from the facility is one of the measures that can be taken to reduce the carbon footprint.

In a study conducted in Colombia, Moncada et al. (2016) determined the CF of thyme and rosemary oils based on electricity consumption. The CF values were 0.73 kgCO_2-eq/kg for thyme oil and 0.68 kgCO_2-eq/kg for rosemary oil. In this study, the CF per unit of rose oil was calculated for a facility with an annual production capacity of 437 kg of rose oil was found to be 32.22 kgCO_2-eq/kg. The higher CF value for rose oil compared to other essential oils, can be attributed to several factors. Firstly, the oil yield from rose petals is relatively low compared to the weight of the raw material. Secondly, the facility's production capacity is smaller, which contributes to the higher CF. Additionally, the inherently low oil content of fresh rose petals is a significant factor in the elevated CF of rose oil production (Fereidani & Uctug, 2023). Existing literature supports these findings with similar CF values per kilogram of product. For example, studies have reported CF values of 43.8 kgCO_2-eq/kg for lemon oil (Beccali et al., 2009), 74.4 kgCO_2-eq/kg for orange oil (Beccali et al., 2009), and 70.58 kgCO_2-eq/kg /750 mg for terpene oil (Pérez-López et al., 2016). These studies corroborate the CF values calculated for rose oil in this research.

CONCLUSION

This study compherensively assesses the carbon footprint of rose oil production by analysing emissions across all operational stages. The findings reveal that energy consumption, particularly from natural gas, significantly contributes to the plant's carbon footprint. When combined with diesel fuel, fossil fuel usage accounts for the majority of total emissions. While electricity consumption has a limited impact, it still adds to the overall carbon footprint. Carbon sequestration from trees within the facility area partially mitigates total emissions. Given the relatively low contribution of other emissions, the primary focus should be on transforming energy use to reduce emissions. In this regard, transitioning to renewable energy systems emerges as the most effective solution. Additionally, reusing condensed water from the steam boiler is a noteworthy measure that can save water and reduce energy costs within the current practices of the rose oil production plant. Furthermore, broader strategies aimed at reducing the carbon footprint are summarized below:

(1) To reduce natural gas consumption, its advisable to encourage the installation of solar energy systems to meet hot water demands during the summer months. This practice will help lower the CF by reducing reliance on fossil fuels,

(2) Mitigation Indirect Emissions from Waste Transportation: Optimizing logistical processes in waste management can significantly reduce emissions associated with transportation,

(3) Enhancing Energy Efficiency: Implementing energy efficiency initiatives in commercial buildings and industrial facilities can lead to substantial savings. For instance, processing rose pulp, a byproduct of rose oil production in biogas plants, to generate electricity offers a sustainable solution,

(4) Fuel Selection in Transportation: Prioritizing hybrid or electric vehicles over fossil-fuel-powered alternatives can effectively reduce transport-related emissions,

(5) Afforestation Activities: Existing trees within the facility grounds contribute to emission reduction by sequestering 0.55 kgCO2-eq/kg of tree. Further lowering the carbon footprint can be achieved by implementing new landscaping projects with broad-leaved species such as Maple, Hornbeam, Linden, Poplar or Chestnut, which enhance CO_2 sequestration.

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