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Carbon Footprint Calculations of Processing in Aquaculture: A case study of Turkish Salmon from Sinop Province in Türkiye[M1]

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Abstract: The rapid increase in the world population and human needs lead into the gradual depletion of existing resources and increased food production. Today, intensive farming systems, which allow for greater production per unit area, have become widespread. As a result, many environmental problems such as climate change and global warming have arisen. The effects of climate change are increasingly noticable, and as a result, the environmental sustainability of food systems has become a critical priority. Aquaculture is an important food source worldwide. However, aquaculture production processes can cause various environmental impacts. This study was conducted to determine the carbon footprint of Turkish salmon processed at the aquaculture processing facility located in the Sinop Organized Industrial Zone during its journey from sea to table. The study calculated the CO_2 emissions from fossil fuels consumed during the transportation of the fish from farms located in the Black Sea to land and the processing facility. Furthermore, the fish arriving at the facility: CO_2 emissions from electricity were calculated as a result of tank tilting, buffer tank, laser head cutting, conveyor belt, hand slaughter line, grading, fish gutting, air compressor, waste disposal, treatment, ventilation, glazing, forklift charging, hydrophore, ice machine, refrigeration machine, and combi boiler use. In addition to greenhouse gas emissions from transportation (fossil fuel/diesel) and processing (electricity), CO_2 emissions from ice and water used in fish transportation and in the facility were also included in the calculations. As a result of the study, a total of 0.761 kg CO_2 emissions were found for one kg of salmon.

Keywords
- Black Sea
- Carbon Footprint
- Salmon
- Processing
- Sustainability

1. INTRODUCTION

Carbon footprint is a measure of the total greenhouse gas emissions directly and indirectly caused by a product, service, or activity. In the context of aquaculture, a carbon footprint refers to the amount of carbon dioxide equivalent (CO_2) released into the atmosphere at all stages, from fishing activities to aquaculture operations and other processes in the supply chain. These calculations allow us to identify concentrated emission sources, compare the environmental impacts of different production methods, and develop mitigation strategies (Kılıç & Amet, 2017; Li et al., 2025).

With the global population growing and dietary habits changing, the demand for aquaculture products is constantly increasing (FAO, 2022). However, ensuring environmental sustainability is crucial when meeting this demand. Greenhouse gas emissions from aquaculture production, particularly during energy consumption, feed production, and waste management, can contribute to climate change (Guan et al., 2022; Rifqi et al., 2022). Aquaculture is the fastest-growing food production industry, while preventing overexploitation of marine fish populations, it is emerging as a viable option for reducing the high amounts of greenhouse gas emissions caused by cattle production. Consuming approximately 200 g of beef results in 12 kg of CO_2 emissions, and 200 g of lamb results in 8.12 kg of CO_2 emissions. These values have been calculated as 1.58 kg for consuming 200 g of fish (salmon/tuna) and 2.36 kg for 200 g of shrimp (Anonymous, 2025a). Therefore, carbon footprint calculations have become a critical tool for understanding and reducing the environmental impacts of aquaculture.

International trade has been shown to benefit global economic growth; however, it also results in increased greenhouse gas emissions (Wu et al., 2021). In particular, analysis of national carbon footprints and their link to global trade has highlighted the energy costs associated with living and consumption habits (Hertwich & Peters, 2009). This fundamental understanding, particularly with the increasing public awareness of climate change, has paved the way for subsequent developments in estimating individual and family carbon footprints.

Turkish salmon (Oncorhynchus mykiss), produced by transferring rainbow trout from freshwater to marine environments, has become one of the most important aquaculture products in Türkiye. According to 2024 production data, Türkiye produced 60,686 tons of rainbow trout, of which 20,540 tons were produced in Sinop Province alone. This corresponds to approximately 33.8% of the national Turkish salmon production, positioning Sinop as the leading production center in Türkiye. Turkish salmon typically reaches a market size of 3.5–4.0 kg and has gained increasing demand in European Union markets due to its nutritional quality and competitive production costs. The dominance of Sinop in Turkish salmon production makes the region a critical hub not only for aquaculture farming but also for processing, employment and regional economic development (URL1).

Given the rapidly growing production volume and export-oriented structure of Turkish salmon, understanding the environmental impacts of processing activities in Sinop is essential for developing sustainable aquaculture strategies in Türkiye.

This research was conducted to determine the carbon footprint of Turkish salmon processed at the seafood processing facility in the Sinop Organized Industrial Zone during its journey from sea to table.

2. MATERIAL AND METHODS

2.1. Material

In this study, Turkish salmon raised in salmon farms in Sinop province of Türkiye on the Black Sea coast were selected as sample material. Because these fish are brought to the Black Sea from different provinces, the carbon footprint of the fish from hatching to transportation to the sea and growth was not included in the study. The study calculated CO_2 emissions from fossil fuels consumed during the transportation of fish from farms established in the Black Sea to land and processing facilities. Furthermore, CO_2 emission value were calculated from electricity used by as a result of tank tilting, buffer tanks, laser beheading, conveyor belts, hand-slaughtering lines, grading, gutting, freezing (-40°C), glazing, storage (-18°C), air compressors, waste disposal, treatment, ventilation, forklift charging, hydrophores, ice machines, refrigerators, and combi boilers. In addition to greenhouse gas emissions from transportation (fossil fuel-diesel) and processing (electricity), CO_2 emissions from the transportation of fish and the use of ice and water in the facility were also added to the calculations (Figure 1).

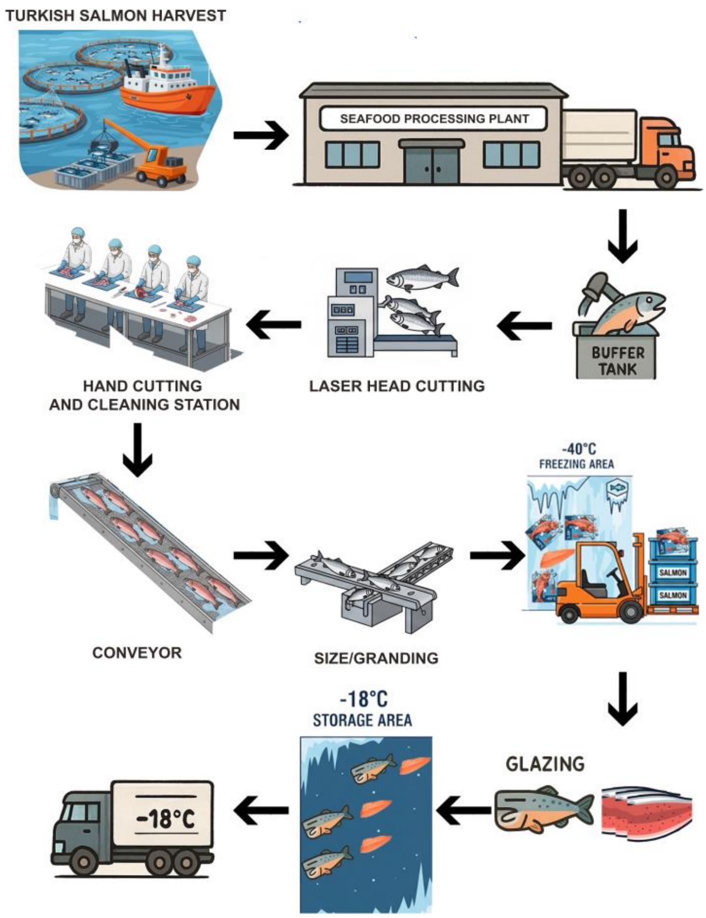

Figure 1. The Journey of Black Sea Salmon to Consumers.

The functional unit of this study was defined as 1 kg of processed Turkish salmon. All calculations were based on a reference production batch of 50 tons processed in a single shift at the seafood processing facility. Energy, fuel, water consumption and related greenhouse gas emissions were first calculated for the total batch (50 tons) and then normalized to one kilogram of product. The system boundary of the study covers the stages from fish harvesting at sea cages, transportation to land, transport to the processing facility, and processing operations including freezing, glazing and cold storage. Earlier life-cycle stages such as hatchery operations, grow-out phase and feed production were excluded from the system boundary.

The growth phase of salmon production was excluded from this study because the primary objective was to quantify greenhouse gas emissions associated with processing and post-harvest logistics. Turkish salmon is produced in different regions of Türkiye under varying farming conditions, feed formulations and management practices. Including the grow-out phase would introduce significant variability and uncertainty, reducing the comparability and clarity of the processing-stage assessment. Therefore, this study intentionally focuses on emissions generated from harvesting, transportation and processing stages, which are directly controlled by the processing facility.

In Türkiye, the establishment of marine aquaculture farms is regulated by environmental legislation aimed at protecting sensitive marine ecosystems. According to the national regulation, fish farms are prohibited in enclosed bays and gulfs, and offshore farms must be located at least 1,250 m from the coastline and in areas with a minimum water depth of 40 m. (URL2).

These legal requirements directly influence the distance between offshore cages and landing points, thereby affecting fuel consumption and greenhouse gas emissions associated with fish harvesting and transportation.

2.2. Method

2.2.1. IPCC Methodology and Tier Approaches

To address the problem of anthropogenic greenhouse gas emissions, the IPCC (International Panel on Climate Change) guide was developed to assist countries seeking to achieve their emission targets. Three methods are used to calculate emissions from fossil fuel use. These approaches, referred to as Tier 1, Tier 2, and Tier 3, increase the amount of data and detail used as the tier level increases (IPCC, 2006). Because factor values are generated from more detailed data on the carbon content of fuels, the Tier 2 calculation method provides more detailed information about the combustion technologies implemented in a country (Civelekoğlu & Bıyık, 2020).

2.2.2. Emission Factors Used in Calculations

In addition to electricity production in Türkiye, the electricity production emission factors calculated by fuel for power plants vary depending on the type of fuel used. For example, an electricity generation plant fueled by natural gas emits 0.379 tons of CO_2 equivalent greenhouse gas emissions per unit of gross electricity production. Finally, while electricity consumption point emission factors vary depending on the connection point, 0.445 tons of CO_2 equivalent greenhouse gas emissions are released per unit of electricity consumption for a consumption point connected to the transmission line, and 0.478 tons of CO_2 equivalent greenhouse gas emissions are released per unit of electricity consumption for a consumption point connected to the distribution line. According to calculations, an average of 0.442 tons of CO_2 equivalent greenhouse gas emissions are released per 1 MWh (unit) of gross electricity production across Turkey (Anonymous, 2025b). Furthermore, the percentages of loss and theft arising from electricity transmission and distribution are taken as 2% and 11%, respectively, or 13% in total (Anonymous, 2025c). In transportation-related calculations, a density value of 0.845 kg/L was used for marine diesel fuel, a density value of 0.833 kg/L for road diesel fuel (Anonymous, 2025d), a conversion factor of 43 TJ/Gg, and an emission factor of 74100 kg/TJ (IPCC, 2006). An emission factor of 0.0014 kgCO_2/L was used in water consumption-related emission calculations (Alagöz et al., 2022).

2.2.3. Emission Calculation Equation from Electricity Consumption

The expression given in equation (1) was used in the emission calculations from electricity consumption (Üreden & Özden, 2018).

$\sum CO_2 = A \times B \times (C+1)$ ……………… (1)

A = Electricity consumption (kWh)

B = Emission factor (kg/kWh)

C = Transmission and distribution loss and leakage percentage (total 13% = 0.13 according to the TEIAS 2025 report)

2.2.4. Emission Calculation Equation from Transportation

The Tier 2 formula given in equation (2) was used for the emission calculations from transportation (IPCC, 2006).

$\sum CO_2 = D \times d \times E \times F \times G$ ………….. (2)

D = Fuel consumption (L)

d = Density (kg/L)

E = Conversion factor (TJ/Gg)

F = Emission factor (kg/TJ)

G = Energy consumption (TJ) ; [$G = D \times E \times 10^{-3}$]

2.2.5. Emission calculation equation from water consumption

The expression given in equation (3) was used to calculate emissions from water consumption (Alagöz et al., 2022).

$\sum CO_2 = H \times I$………………………. (3)

H = Amount of water used (L)

I = Emission factor (kg CO_2/L)

2.2.6. The greenhouse gas emissions required to deliver one kilogram of Turkish salmon to the consumer are:

kg CO_2/kg salmon = A+B+C

A = CO_2 emissions from electricity

B = CO_2 emissions from fossil fuels

C = CO_2 emissions from water consumption

3. RESULTS AND DISCUSSION

3.1. Emission Values from Electricity Use

The total electricity consumption per kilogram of salmon at a seafood processing plant in the Sinop Organized Industrial Zone was 1.432 kWh. Technical data for this calculation is shown in Table 1. This figure includes all electrically driven processes, such as cleaning the heads and internal organs of incoming fish, washing, weighing, freezing (-40 °C), storing (-18 °C), labeling, charging forklifts, and lighting the facility.

Table 1. Electricity use at a Turkish salmon processing plant (50 tons/shift).

Purpose	Power used (kW)	Operating time (hours)	Total electricity consumed (kWh)
Tank Tilting	4	8	32
Buffer Tank	2	8	16
Laser Head Cutting	0.75	8	6
Konveyor Belt	1.5	8	12
Hand Cutting Line	3	8	24
Sizing	10	8	80
Spoon Vacuum	24	8	192
Air Compressor	14	8	112
Waste Removal	30	8	240
Treatment Total	40	8	320
Ventilation	10	8	80
Freezing	6250	8	50000
Glazing	5	8	40
Frozen Storage	1000	8	8000
Forklift Charging (620 Amp, 48 Volt)	30	4	120
Hydrophore	20	4	80
Ice Machine	100	36	3600
Cold Water Machine	80	8	640
Combi Boiler	4000	2	8000
Total	**10624.25**		**71594**

As shown in Table 1, the electricity consumption for processing one kg of Turkish salmon was found to be 71594/50000 = 1.432 kWh. This calculation resulted in the greenhouse gas emissions resulting from processing one kg of Turkish salmon (Table 2).

Table 2. Carbon emissions from electricity use (kg CO_2/one kg salmon).

Electricity consumption (kWh)	Emission factor (kg/kWh)	Loss-leakage (%)	Total CO_2 emission (kg)
1.432	0.442	0.13	**0.715**

As shown in Table 2, the greenhouse gas emission value from electricity consumption for processing one kg of Turkish salmon is calculated as 0.715 kg CO_2.

3.2. Transportation Emission Value

The distance from the cages to the Demirci village fishing harbor is 4 miles (7.41 km) (Figure 2).

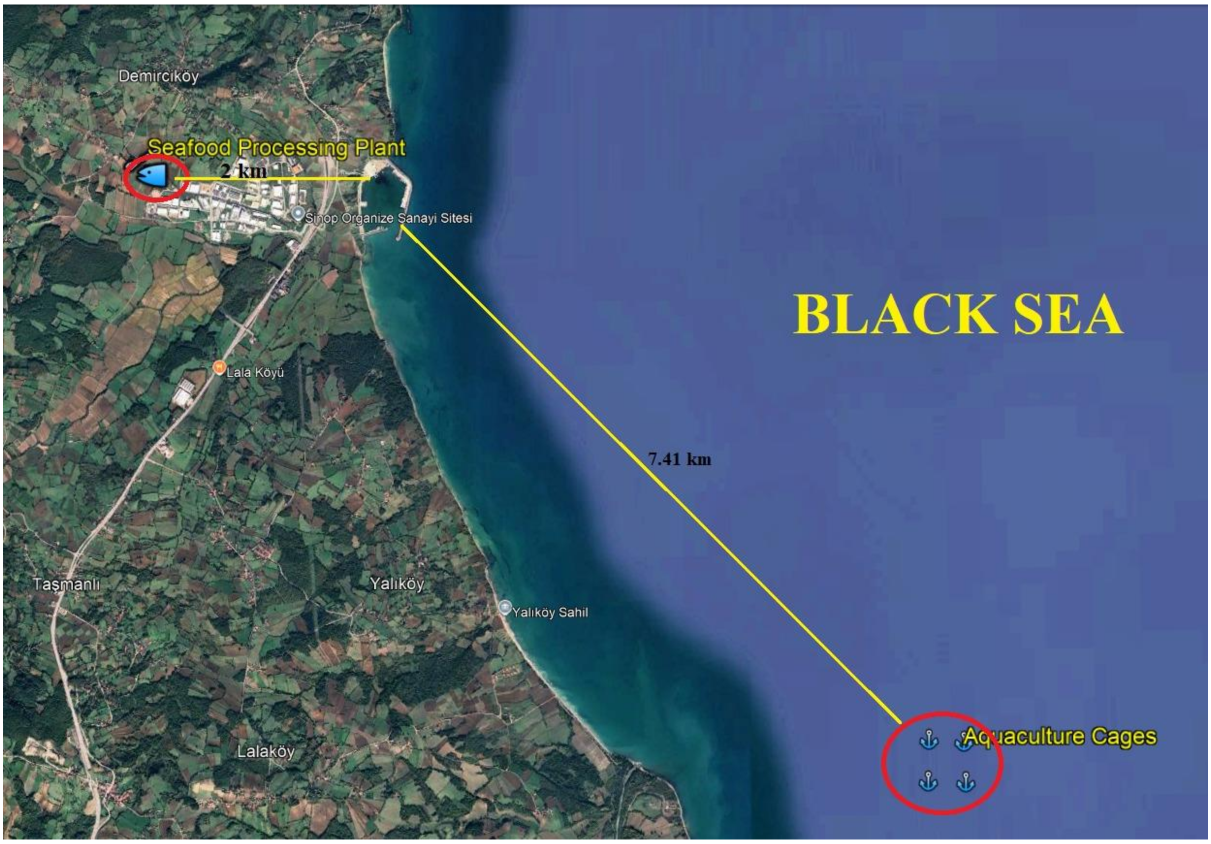

Figure 2. Study area.

The boat travels this distance empty and returns loaded. The salmon transport distance from the harbor to the aquaculture processing facility in the Sinop Organized Industrial Zone is 2 km. The transport trucks travel this distance empty and return loaded. In the fossil fuel calculations, data from both the boat and the trucks, including empty and loaded returns, are taken into account. Data on the transportation journey of Turkish salmon from the sea to the processing facility is given in Table 3.

Table 3. Fossil fuel consumption (diesel) of 25 tons of salmon from the sea to the processing facility.

Purpose	Transportation Distance (km)	Engine power (hp)	Fuel consumed (L)
Demirci-sea roundtrip + fish harvest	14.82	500	400
Demirci-processing facility round trip	4	470	3,30
Total			**403.30**

As shown in Table 3, transporting 1 kg of salmon from sea to shore consumes 400/25000 = 0.016 liters of diesel, while the diesel consumption of the fish by road to the processing plant is calculated as 3.30/25000 = 0.000132 liters.

The carbon footprint of the fossil fuel burned by the boat traveling from the Demirci village fishing harbor to the net cages and by the trucks used for land transport to the facility was calculated, and the results are presented in Table 4. Calculations were made assuming that there are 50 tanks with a volume of 1 m³ on a boat, and half of the tanks contain ice water and the other half contain fish. The fossil fuel consumed by the boat's auxiliary engine for fish harvesting was also included in the calculations.

Table 4. Fossil fuel consumption (diesel) emission value of salmon from sea to processing plant (kg CO_2 per kg of Turkish salmon).

Transportation	F.C. (L)	d (kg/L)	∑ F.C. (tons)	C.F. (TJ/Gg)	E.C. (TJ)	E.F. (kg/TJ)	CO_2 (kg)
Land transport	0.000132	0.833	$1.10x10^{-7}$	43	$4.73x10^{-9}$	74100	0.00035
Sea Transport	0.016	0.845	$1.352x10^{-5}$	43	$5.814x10^{-7}$	74100	0.0431

F.C. = Fuel consumption (L), d = Density (kg/L), ∑ F.C=Total Fuel consumption (tons), C.F.= Conversion factor. (TJ/Gg), E.C.=Energy consumption (TJ), E.F.=Emission factor (kg/TJ)

The total greenhouse gas emissions from fossil fuels used for the transportation of one kilogram of salmon from the sea to the aquaculture processing plant were found to be 0.0435 kg CO_2 (Table 4).

3.3. Emission Value from Water Consumption

The amount of water consumed to process 50 tons of salmon in the aquaculture processing plant (including ice and water used in transport tanks for fish transportation, personnel and factory hygiene, fish cleaning, crate cleaning, personnel consumption, etc.) totaled 94 tons, and the water consumption of one kilogram of salmon was found to be 1.88 liters (94000/50000). The CO_2 emission (kg) from this consumption was determined to be 0.0026 (Table 5).

Table 5. CO_2 emission (kg) related to water consumption of one kilogram of salmon.

Amount of water consumed (L)	Emission factor (kgCO_2/L)	**Total CO_2 emission (kg)**
1.88	0.0014	**0.0026**

To determine the total carbon footprint of one kilogram of Turkish salmon prepared for consumption at the facility, the CO_2 emissions (kg) resulting from transportation, electricity, and water consumption are given in Table 6.

Table 6. CO_2 emissions (kg) of one kilogram of processed salmon.

Emission sources	CO_2 emissions (kg)
Electricity	0.715
Fossil fuel (diesel)	0.0435
Water Use	0.0026
Total	**0.761**

As shown in Table 6, the CO_2 emissions from electricity (kg) for one kg of cleaned, frozen, and stored Turkish salmon were found to be 0.715, fossil fuel (diesel) CO_2 emissions (kg) = 0.0435, and water consumption CO_2 emissions (kg) = 0.0026. Total CO_2 emissions were determined to be 0.761 kg.

Due to the essential amino acids it contains, seafood is a food that should be consumed at every stage of life (such as childhood, adolescence, pregnancy, birth, and old age) for a healthy/balanced diet, growth, development, intelligence, judgment, healthy decision-making, and the development of intellectual thought. It is an undeniable fact that greenhouse gas emissions occur as a result of animal production, although not as much as is thought. However, it should not be forgotten that animal production, despite all its challenges, is a necessary activity for the continuation of the ever-increasing human existence (Sariözkan et al. 2024).

The study found that salmon's electricity-related greenhouse gas emissions were 0.715 kg CO_2. Studies on energy consumption during fish processing indicate that a significant amount of energy is required for various processes, including cooling and cooking. Energy audits in fish processing facilities have shown that advanced systems can optimize electricity use and efficiency, highlighting the need to integrate smart energy management technologies into fish processing operations (Alzahrani et al., 2019). Studies have shown that the carbon footprint associated with fish farming (including processing stages) contributes significantly to overall emissions (Sherry & Koester, 2020). Life cycle assessments, in particular, have shown that energy consumption and material use are significant factors affecting the greenhouse gas emissions of aquaculture systems, particularly for species such as salmon (Sherry & Koester, 2020; Ellis & Tiller, 2019). Furthermore, energy-intensive processes such as heat treatment have been found to contribute to higher emissions, indicating that methods that consume significant amounts of electricity for salmon processing can lead to significant CO_2 outputs (Park & Yoon, 2018). The relationship between energy use and CO_2 emissions is highlighted by research showing that inefficient heat treatment methods are associated with increased energy consumption and environmental impact (Indzere & Blumberga, 2020; Dreimanis et al., 2020). Understanding the efficiency of processing methods is crucial for assessing associated carbon emissions. Figures for electricity consumption and CO_2 emissions in Turkish salmon processing are supported by a comprehensive understanding of energy consumption patterns in aquaculture and the assessment of emissions through life cycle assessments. Such analyses demonstrate the interconnectedness of energy efficiency and environmental sustainability in the fish processing sector.

The study found that the greenhouse gas emissions from salmon transportation were 0.0435 kg CO_2. The Turkish salmon farm selected for the study is a 14,82 km round-trip distance from the port. The distance from the port to the seafood processing facility is only 4 km round-trip. Distance in maritime and land transport is crucial in greenhouse gas emissions. The research results are similar to those of other studies. The transportation of seafood, particularly from sea to land-based processing facilities, involves both maritime and land transport, each contributing individually to the carbon footprint. The use of fossil fuels for these transportation methods means that emissions are directly related to the distance traveled. Research shows that carbon emissions from transportation can vary significantly. Maritime transport generally has lower greenhouse gas emissions than land transport, despite significantly higher carbon dioxide levels per ton/km of goods transported (Mundaca et al., 2021). Furthermore, studies highlight that emissions from seafood transportation can be significant and can vary depending on logistics choices (MacLeod et al., 2020). To provide a comprehensive overview of the environmental impacts associated with seafood processing and distribution, it is crucial to analyze emissions from land and sea transportation collectively (Nguyen & Giao, 2024). The combination of these factors suggests that local processing units closer to aquaculture farms can increase sustainability by minimizing travel distances and thus reducing overall emissions. Carbon footprint assessments in aquaculture indicate that significant emissions arise not only from farming practices but also from the logistics used to distribute seafood from production to consumption points (Li et al., 2025). Furthermore, it is important to consider potential mitigation strategies in transportation logistics to further reduce emissions. Optimizing vehicle use, along with switching to alternative energy vehicles in land transportation, offers opportunities to reduce reliance on fossil fuels for transportation (Jayakumar et al., 2017). Furthermore, improving more efficient transportation methods and landing and processing practices can contribute to reducing emissions in the aquaculture sector (Rifqi et al., 2022; Wei et al., 2016).

Consequently, emissions associated with diesel consumption from salmon processing depend on geographical variables, effectively highlighting the importance of transportation methods and distances involved. Prioritizing efficient logistics and adopting cleaner technologies will be critical to reducing the carbon footprint of aquaculture operations.

In this study we found that a total of 94 tons of water is used to process 50 tons of fish at the facility. The greenhouse gas emissions from water used at each stage of salmon transportation and processing were found to be 0.0026 kg CO_2. Water use in seafood processing is essential for both operational efficiency and environmental sustainability. Excessive water use can lead to increased energy demand for heating and cooling, increasing greenhouse gas (GHG) emissions. A study on life-cycle assessments of seafood processing shows that inefficient water use during thermal processing contributes significantly to overall emissions (Nguyen & Giao, 2024). This correlation supports the claim that overuse of resources such as water can increase greenhouse gas emissions due to excessive energy consumption. Conversely, inadequate use of water can lead to inefficiencies that can indirectly increase emissions. When processing facilities use water inefficiently, for example, during cleaning or cooling, additional energy is often consumed to maintain operational efficiency. Research shows that optimizing water flow and recycling practices can lead to reduced energy consumption and, consequently, lower emissions (Naing et al., 2024). These findings align with broader discussions around the water-energy nexus, which emphasize that minimizing water use in energy-intensive processes is vital for reducing greenhouse gas emissions (Naing et al., 2024).

Furthermore, studies on the environmental impacts of various seafood processing methods reveal that the types of systems used and their associated water requirements (whether for cooling or heating) are directly related to greenhouse gas emissions (Pelletier et al., 2009). Efficient water management is vital not only to address emissions but also for overall resource sustainability. The balance of water use must be carefully managed; excessive water can lead to waste and increased energy use, while insufficient water can necessitate reliance on energy-intensive systems. The relationship between water use and greenhouse gas emissions in seafood processing presents a significant challenge. Both excessive and insufficient water use can negatively impact emission profiles, necessitating that processing facilities focus on efficiency and sustainability in their water management practices. Implementing optimized systems and recycling mechanisms not only promotes resource conservation but also increases overall efficiency by reducing greenhouse gas emissions. A total of 0.761 kg of CO_2 was found to be the greenhouse gas emissions from fossil fuels, electricity, and water during the journey of one kg of salmon from sea to table, from the sea to land, and from the landing point to the aquaculture processing facility and storage. In other studies, greenhouse gas emission values per kg of products are 47-65 kg CO_2 for steak (MacLeod et al. 2020); 9-129 kg CO_2 (Nijdam et al. 2012); 6,7 kg CO_2 for pork (MacLeod et al. 2020); 12,31 kg CO_2 (Poore & Nemecek, 2018); 9,87 kg CO_2 for poultry (Poore & Nemecek, 2018); 10-150 kg CO_2 for lamb and mutton (Nijdam et al. 2012); and 5,6 kg CO_2 for aquaculture (MacLeod et al. 2020). It was found to be 3-15 kg CO_2 (Nijdam et al. 2012). The low probability of the research result (0.761 kg CO_2) may be because the hatching, transportation, growth, and feeding of the fish were not included. Furthermore, transportation distances may affect this situation. These studies show that the carbon footprint of aquaculture products can vary significantly depending on the species, production method, geographical location, and technologies used.

Recent studies have highlighted the environmental impacts of various protein sources, particularly in aquaculture. For example, Li et al. (2025), calculating greenhouse gas emissions from livestock farming, stated that beef contributes significantly to these emissions and that methane emissions associated with enteric fermentation account for a significant portion of these emissions. In this context, emissions from salmon processing appear significantly lower, suggesting that salmon may be a more environmentally friendly protein option compared to conventional livestock farming. Similarly, comparing dietary greenhouse gas emissions from different protein sources in the UK, they highlighted that red meat has a significantly higher carbon footprint than fish and seafood (Scarborough et al., 2014). This suggests that carbon emissions from salmon processing are lower than those from livestock farming, while also positioning aquaculture as a more sustainable method of protein production.

Aquaculture, particularly salmon farming, has several advantages over terrestrial livestock farming. It typically has a significantly lower carbon footprint per kilogram of protein produced. The study highlights the need for efficiency in seafood processing facilities; improvements to these facilities could further reduce emissions associated with fossil fuel and electricity use (Nguyen & Giao, 2024). Furthermore, the 0.761 kg CO_2 figure cited does not account for the early life stages of fish, such as hatching, growth, and feeding. However, if these stages were included, the footprint would likely remain lower, even compared to emissions from other animal proteins. For example, while beef requires extensive resources for both grazing and feed production, aquaculture systems can utilize a variety of sustainable inputs, such as waste products from other industries (Bianchi et al., 2022).

Climate legislation increasingly holds industries accountable for their emissions. Initiatives such as the Paris Agreement aim to limit global warming by reducing greenhouse gas emissions (Retegi et al., 2023). Aquaculture also plays a critical role in food security and resilience, especially given the challenges posed by climate change and a growing global population.

Labor-related emissions were not included in the carbon footprint calculations due to the lack of precise data on individual commuting distances, modes of transport, and work schedules of personnel. Labor-related emissions in seafood processing plants are generally considered to contribute marginally compared to energy-intensive processes such as freezing, cold storage, and transportation. However, labor-related emissions are considered a limitation of the current study and may be considered in future assessments where detailed labor data are available.

4. CONCLUSION

In conclusion, the determination that processing one kilogram of salmon results in 0.761 kg of CO_2 emissions reflects a positive perspective on the sustainability of aquaculture compared to land-based animal protein sources. The data highlights the potential of aquaculture as a lower-emission alternative, particularly with globally changing diets. Given the increasing demands for favorable climate policies and sustainable food systems, investing in aquaculture offers both an immediate solution to protein production challenges and a long-term strategy for reducing greenhouse gas emissions. As the world grapples with the complexities of climate change, transitioning to sustainable practices in aquaculture will be vital to ensuring food security and reducing environmental impacts.

Aquaculture is one of the fastest-growing agricultural sectors globally and is becoming increasingly important for producing sustainable and healthy diets with relatively low climate impacts. Compared to livestock farming, particularly beef production, seafood production has lower carbon emissions. Furthermore, some species can contribute to a long carbon cycle by extracting carbon from aquatic environments. While animal food production sectors vary widely in terms of environmental performance, aquaculture and capture fisheries produce fewer greenhouse gases than red meat farming and poultry.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR CONTRIBUTIONS

Fiction: HAD; Literature: HAD, ÜÖ; Methodology: HAD, ÜÖ; Performing the experiment: HAD, ÜÖ; Data analysis: HAD, ÜÖ; Writing: HAD, ÜÖ, Supervision: HAD, ÜÖ. All authors approved the final draft.

ETHICAL STATEMENTS

Local Ethics Committee Approval was not obtained because experimental animals were not used in this study.

DATA AVAILABILITY STATEMENT

Data supporting the findings of the present study are available from the corresponding author upon reasonable request.

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