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Climate Change, Carbon Footprint, Fisheries: Türkiye

İklim Değişikliği, Karbon ayak izi, Balıkçılık: Türkiye

Türk Denizcilik ve Deniz Bilimleri Dergisi

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ABSTRACT

This review provides a comprehensive assessment of the effects of climate change, the concept of carbon footprint, and the Turkish fisheries sector in the context of environmental sustainability. Fossil fuel-based production and consumption models, which have gained momentum since the industrial revolution, have increased greenhouse gas emissions and caused severe disruptions in the global climate system. In this process, carbon footprint has emerged as an important indicator that enables the quantitative monitoring of environmental impacts and serves as a critical tool in developing environmental sustainability policies by measuring individual or sectoral greenhouse gas emissions. As of 2020, the global annual CO_2 equivalent greenhouse gas emissions from fisheries activities amounted to 64 million tonnes, while the emissions from the fisheries sector in Türkiye, which includes fisheries and aquaculture activities, were estimated at 59,000 tonnes of CO_2 equivalent. The fisheries sector in Türkiye is among the sectors vulnerable to climate change. However, there are only a limited number of scientific studies on carbon footprint, which is an essential tool for monitoring environmental impacts. The "Climate Law" was published in the Official Gazette on July 9, 2025, in Türkiye. The law introduces the obligation for businesses that carry out activities that directly cause greenhouse gas emissions, and therefore for the fisheries sector, to obtain greenhouse gas emission permits in order to carry out these activities. In this study, the effects of international strategies developed within the framework of the European Green Deal and the Paris Agreement on the Turkish fisheries sector were discussed, and it was concluded that strategies should be developed to monitor and reduce emissions, emphasising the need to transition to sustainable and low-emission production models.

Keywords: Climate change, Greenhouse gases, Carbon footprint, Fisheries

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ÖZET

Bu derleme çalışması, iklim değişikliğinin etkilerini, karbon ayak izi kavramı ve Türkiye balıkçılık sektörü özelinde ele alarak çevresel sürdürülebilirlik bağlamında bütüncül bir değerlendirme sunmaktadır. Sanayi devrimi sonrası dönemde hız kazanan fosil yakıt temelli üretim ve tüketim modelleri, sera gazı emisyonlarını artırarak küresel iklim sisteminde ciddi bozulmalara yol açmıştır. Bu süreçte karbon ayak izi, çevresel etkilerin nicel olarak izlenebilmesini sağlayan önemli bir gösterge niteliğinde olup bireysel veya sektörel sera gazı salımlarının ölçülmesiyle çevresel sürdürülebilirliğe yönelik politikaların geliştirilmesinde kritik bir araç olarak öne çıkmaktadır. 2020 yılı itibariyle küresel ölçekte balıkçılık faaliyetleri için hesaplanan 64 milyon ton yıllık CO_2 eşdeğeri sera gazı salımına karşılık Türkiye'de balıkçılık ve su ürünleri yetiştiriciliği faaliyetlerini kapsayan su ürünleri sektörü için tespit edilen emisyon miktarı 59 bin ton CO_2 eşdeğeridir. Türkiye'de balıkçılık sektörü, iklim değişikliğine karşı kırılgan sektörler arasında yer almakta; buna rağmen çevresel etkilerin izlenmesinde önemli bir araç olan karbon ayak izi konusunda ülkede sınırlı sayıda bilimsel çalışma bulunmaktadır. Türkiye'de "İklim Kanunu" 9 Temmuz 2025 tarihinde Resmi Gazete'de yayımlandı. Yasa ile doğrudan sera gazı salımına neden olan faaliyetler yürüten işletmelere, dolayısıyla balıkçılık sektörü için de bu faaliyetleri yürütebilmek için sera gazı emisyon izni alma zorunluluğu getirilmektedir. Bu çalışmada, Avrupa Yeşil Mutabakatı ve Paris Anlaşması çerçevesinde geliştirilen uluslararası stratejilerin, Türkiye balıkçılık sektörüne etkileri tartışılmış, sürdürülebilir ve düşük emisyonlu üretim modellerine geçişin gerekliliği vurgulanarak, emisyonlarının izlenmesi ve azaltılmasına yönelik stratejiler geliştirilmesi gerektiği sonucuna varılmıştır.

Anahtar sözcükler: İklim değişikliği, Sera gazları, Karbon ayak izi, Balıkçılık

1. INTRODUCTION

Extreme weather events, which we can no longer ignore, are making themselves felt strongly in the atmosphere and oceans. Natural phenomena such as violent storms, rainfall, floods, melting glaciers, warming oceans and increasing acidity have reached a visible level in frequency and intensity.

While climate changes before the industrial revolution were generally associated with solar radiation and volcanic activity, the rapid warming at the end of the 20th century is linked to the increase in greenhouse gases (Huang *et al.*, 2013). Atmospheric gases such as water vapour, carbon dioxide (CO_2), methane (CH_4), nitrogen oxide (NO), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), nitrogen trifluoride (NF_3) (Brander and Davis, 2012), act as an insulating blanket for the earth under normal conditions. By making it difficult for heat to escape into space, they warm the earth in the same way that the walls of a greenhouse help keep the air inside warmer than the surrounding air. This effect is known as the greenhouse effect and is a natural process that makes earth habitable for humans. Without the natural greenhouse effect, global average temperatures are estimated at approximately 33°C (59°F) cooler (IPCC, 2021a). On the other hand, since the 19th century, human activitiesprimarily the burning of fossil fuels (coal, oil, and gas), industrial processes, agricultural activities, and deforestation have led to the release of increasing amounts of greenhouse gases into the atmosphere. These actions have increased the greenhouse effect, leading to global warming and positive radiative forcing (IPCC, 2021a).

Radiative forcing is one factor that alters the Earth's energy balance and hence influences the climate. This concept describes how much the balance between the solar energy reaching the Earth and the energy reflected into space changes due to alterations in the atmosphere or the Earth's surface. If radiative forcing is positive, the system gains energy and warms up; if negative, the system loses energy and cools down. Approximately 79% of the increase in radiative forcing over the past decade and approximately

77% of the increase over the past five years is attributable to CO_2. CO_2 is the most important human-caused greenhouse gas in the atmosphere and accounts for approximately 66% of the radiative forcing of long-lived greenhouse gases. (Montzka, 2024; WMO, 2024). Current atmospheric CO_2 concentrations are higher than in 2 million years (IPCC, 2021b).
The increase in human-caused greenhouse gas emissions has significantly increased global warming and the severity of extreme events in the climate. This disrupts the energy balance in the atmosphere, warming the climate system through radiative forcing and leading to CO_2 accumulation. Therefore, limiting the use of fossil fuels and urgently reducing carbon emissions to mitigate the effects of the climate crisis must be a priority for decision-makers (IPCC, 2021b).
This review aims to provide a comprehensive assessment of the effects of climate change in the context of environmental sustainability, focusing on the concept of carbon footprint and the Turkish fisheries sector.

1.1. Climate Change

It is important to define climate change to understand, analyse and interpret its impacts. Different institutions and researchers have made different definitions with common points in recent years. In this context, the United Nations Framework Convention on Climate Change defines climate change as a change in climate as a result of human activities that directly or indirectly disrupt the composition of the global atmosphere, in addition to natural climate changes observed over comparable time periods (URL-1, 2025).
As a result of energy use, transportation, industry, agriculture, and excessive use of fossil fuels, natural and industrial greenhouse gas rates have increased day by day. Climate change, which manifests itself as an important problem of the world, refers to "the changes in the global climate system and consequently in ecosystems due to the excessive increase in the accumulation of greenhouse gases in the atmosphere with anthropogenic effects" (Şahin and Avcıoğlu, 2016; Arıkan, 2016).
Global climate change, which is accepted as one of the most critical problems of our world, is defined as the change in climate due to the greenhouse effect of gases released into the atmosphere as a result of human activities. Global climate change is a multidimensional problem that affects socio-cultural and economic systems, especially ecological systems (aquatic and terrestrial ecosystems). For this reason, the issue of global climate change should be addressed with a holistic approach, and solutions should be produced (Binboğa and Ünal, 2018).
According to the Organization for Economic Cooperation and Development (OECD, 2024a), climate change directly and indirectly affects human welfare through food, health, housing and the environment. It is not only an environmental issue, but also a political, economic and social one, posing a range of complex and interconnected policy challenges. Countries therefore need comprehensive information and indicators to understand the impacts on human and environmental systems and, above all, appropriate policy responses (OECD, 2024a).
On the other hand, it can be said that international cooperation to combat climate change started with the Vienna Convention adopted in 1985. This convention encouraged intergovernmental cooperation regarding research on ozone-depleting substances, systematic observations and information sharing, and provided a framework without binding provisions. Subsequently, the Montreal Protocol was adopted in 1987. This protocol aimed to reduce the production and consumption of ozone-depleting substances and became effective with the addition of new substances and revision of reduction timetables over time. In addition, a multilateral fund was established in 1990 to support developing countries. Subsequently, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992 to limit greenhouse gas emissions that cause climate change at the global level. With this convention, the "Principle of Common but Differentiated Responsibilities and Relative Competencies" was adopted and the party countries were divided into obligation groups according to their development levels. The Kyoto Protocol, the first binding extension of this convention, adopted in 1997, is the first

international agreement stipulating quantified emission reduction obligations for developed countries. It also facilitated the fulfilment of emission reduction obligations through flexibility mechanisms (T.C. Ministry of Environment, Urbanization and Climate Change, Climate Change Presidency, 2025).

In the following process, the Paris Agreement was adopted in 2015, and the new climate regime was established, covering the post-2020 period following the expiry of the Kyoto Protocol. The Agreement aims to limit the global temperature increase to below 2°C and preferably 1.5°C. The Paris Agreement is based on the participation of all parties in the process through National Contribution Declarations (NDCs), and differs from Kyoto in this respect. On the other hand, the member states of the European Union adopted the European Green Deal in 2019 to achieve the goals of the Paris Agreement (Anonymous, 2021). The Compact provides a comprehensive strategy aiming to achieve zero greenhouse gas emissions by 2050. It envisages holistic regulations on topics such as clean energy, sustainable agriculture, circular economy and carbon limit mechanisms (T.C. Ministry of Environment, Urbanization and Climate Change, Climate Change Presidency, 2025).

The Green Deal is a holistic strategy that aims to make EU countries climate neutral by 2050 and prioritises reducing the carbon footprint. Within the scope of this strategy, carbon leakage is tried to be prevented through regulations such as the 'Carbon Border Adjustment Mechanism' and countries with intensive trade relations with the EU, such as Türkiye, are expected to be integrated into this process (Mirici and Berberoğlu, 2022).

The greenhouse gas reduction targets set by European Union (EU) member states and other countries in Europe (Norway, Sweden and the United Kingdom) are presented in Table 1. EU member states and the United Kingdom in 2019, Switzerland in 2020, and Norway in 2022 set a target of no net greenhouse gas emissions in 2050 (URL-3, 2019; Dragomir *et al.*, 2023). The United Kingdom envisages a reduction target of 68% in 2030 compared to 1990 levels (Dragomir *et al.*, 2023).

Table 1. Greenhouse gas emission reduction targets (Dragomir *et al.*, 2023)

Countries	2030 (compared to 1990 level)	2050
AB	At least 55% Target set for 2020	Net zero, target set for 2019
AB	New fully electric vehicles, starting with 2035	-
Norway	At least 55% target set for 2022.	Low emissions, target set for 2022.
Switzerland	At least 50% target set in 2020.	Net zero, target set in 2020
United Kingdom	At least 68% target set in 2020.	Net zero, target set in 2019

Nationally Determined Contributions (NDCs) prepared in the post-Paris Agreement period have started to make the role of marine and coastal ecosystems in combating climate change more visible. It was revealed that 70% of the 161 NDCs submitted by the countries included marine issues and that these contents were mostly adaptation-oriented. In particular, coastal impacts (95), ocean warming (77), fisheries impacts (72), and marine ecosystem impacts (62) were among the top issues mentioned in the NDCs (numbers in parentheses indicate the number of NDCs.) (Gallo *et al.*, 2017). This shows that the majority of countries are aware that climate impacts have a strong relationship with marine ecosystems, and they emphasise the need to take mitigating actions in their contribution declarations.

1.2. Carbon Footprint

Carbon footprint calculations are one of the most widely used environmental indicators. Since its introduction as a measurable concept for monitoring impacts on our environment, carbon footprinting has become a widely used term and concept in the public debate on responsibility and mitigation actions against the threat of global climate change (East, 2008; Kumar *et al.*, 2014). Among the many ways proposed to measure the contribution of companies to the greenhouse effect, the carbon footprint is by far the most widely used indicator (De Grosbois and Fennell

2011).

Bekiroğlu (2011) defines carbon footprint as "a measure of the damage caused by human activities to the environment in terms of the amount of greenhouse gases produced and measured in terms of CO_2". Its unit is "kg.CO_2-equivalent" or "ton.CO_2-equivalent". Carbon footprint is calculated by organisations for legal obligations, corporate social responsibility, customer or investor demands, marketing and corporate image, mandatory or voluntary greenhouse gas emission reduction and participation in emission trading mechanisms (Bekiroğlu, 2011).

Carbon footprint is the sum of greenhouse gases in the atmosphere. CO_2, nitrous oxide, methane and other industrial gases are called greenhouse gases. The carbon footprint gives us the full presence of these gases (Wadke *et al.*, 2023).

The carbon footprint of a product refers to the greenhouse gases emissions of a product throughout its life cycle, from raw materials to production (or service provision), distribution, consumer use and disposal/recycling (Anonymous, 2008).

Another definition is "a measure of the total CO_2 and other greenhouse gas emissions directly or indirectly generated by an activity or accumulated over the lifetime of a product, a person, an organisation, or even a city or state Carbon footprint is a measure by which a company or an individual can calculate how much carbon emissions a company or individual generates over a project or time period" (Goodier, 2010).

In line with all the scientific and grey literature, Wiedmann and Minx (2007) proposed the definition of "carbon footprint" as "a measure of the specific total amount of CO_2 emissions directly and indirectly caused by an activity or accumulated over the life cycle of a product".

Measuring carbon footprint is recognised by the UN Framework Convention on Climate Change as an important way to contribute to achieving international climate action targets. It allows organisations to see more accurately where the main impacts on their carbon footprint occur and thus take appropriate measures to reduce it (Gabrielii and Jafarzadeh, 2020). Many approaches, methodologies and tools for carbon footprinting have been developed and are available for estimation, ranging from simplified online calculators to more scientific and complex life cycle-based methods (Scrucca *et al.*, 2021).

Since carbon footprint is now one of the most widely used environmental indicators for measuring greenhouse gas emissions from human activities and primarily aims to calculate the emissions that occur throughout the entire life cycle of products or activities, carbon footprint calculations of fisheries activities are of critical importance in terms of monitoring and mitigating environmental impacts in the sector and developing sustainability policies.

1.3. Fisheries in the World and Türkiye

From 1950 to 2023, world fisheries production has undergone a radical transformation quantity and production structure. In 1950, global fisheries production was around 20 million tons, but this figure reached 185.4 million tons by 2022 and even higher in 2023, reaching the highest levels in history (FAO, 2025). The source of this growth has changed over time, with the aquaculture sector becoming more prominent, especially since the early 21st century.

In the past 20 years, global fisheries production has shown significant changes in capture and aquaculture. During this period, capture fisheries production declined from approximately 93.6 million tons in 2000 to 90.4 million tons in 2023. This decline was observed especially in marine fisheries, while inland fisheries followed a more stable course. This horizontal-vertical catch production trend can be considered a natural consequence of global fish stocks approaching their sustainable limits and limiting fishing pressure. On the other hand, aquaculture production showed a remarkable increase in the same period. From 32.4 million tons in 2000, aquaculture production reached approximately 98.5 million tons by 2023. While capture fisheries now have limited growth capacity, the aquaculture sector has started to assume a central role in the global protein supply through technological developments, investment incentives and policy directions (FAO, 2025).

Türkiye's total fisheries production between 1950 and 2023 has shown a remarkable increase, gaining momentum especially after the 1980s.

The production amount below 100 thousand tons in the 1950s reached approximately 300 thousand tons in the early 1980s, and a production standard of more than 500 thousand tons per year has been achieved since the 2000s (Figure 1). This growth trend is associated with both the expansion of marine fisheries capacity and the acceleration of aquaculture activities.

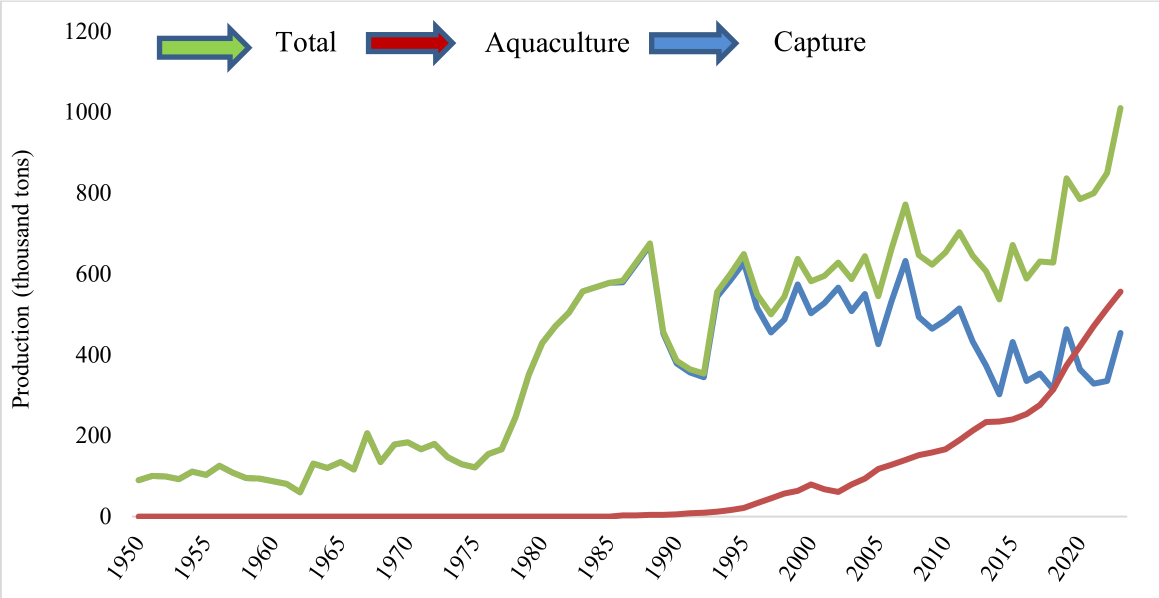

Figure 1. Türkiye's total fisheries production 1950-2023 (TurkStat, 2025)

The total fisheries production in Türkiye between 2015-2023 varied between 314 thousand tons and 454 thousand tons (BSGM, 2024). Between 2015 and 2023, fisheries in the seas constituted the majority of the total amount in Türkiye. More than 90% of the catch was obtained from the seas, while the amount received from inland waters remained relatively constant. Approximately 10-22% of the marine catch was composed of other species, while this ratio was around 5% in inland waters. This shows that Türkiye's fisheries are diversifying not only towards fish species but also towards species such as molluscs and crustaceans. Anchovy, sprat, bonito, horse mackerel, whiting, white sand mussel and periwinkle, which are the most commonly fished species in Türkiye, are mostly caught in the Black Sea. Between 62-81 percent of the total seafood catch in the 2015-2023 period was obtained from the Black Sea (BSGM, 2024). When we review the data on Türkiye's fleet of fishing vessels, the difference between marine and inland waters stands out. In 2000, the total number of fishing vessels operating at sea was 14975, while this number was 15219 by 2023. This increase was quite limited (1.6%). This is because the Ministry of Agriculture and Forestry has not issued licenses to fishing vessels in the seas since 2002. In addition, the number of fishing vessels less than 12 meters in length decreased from 13701 to 13609, while the number of vessels of 12 meters or more increased from 1274 to 1610. This change is also related to the one-time 20% length extension right granted to fishing vessels. The inland water fleet grew both numerically and structurally. While in 2000 the total number of fishing vessels operating in inland waters was 2500, this number reached 3260 in 2023, an increase of approximately 30%. Overall, while the maritime fleet has evolved towards a larger and more commercially oriented structure, the inland water fleet has grown in number and become more widespread. Between 2000 and 2023, a general downward trend in the number of fishing vessels of 12 meters and above was observed in EU countries, while Türkiye's fleet capacity in this segment increased. While the EU had 18131 12+ m fishing vessels in 2000, this number decreased to 10412 by 2023. This represents a decrease of 42.5%. In the same period, the number of vessels in this class in Türkiye increased from 1274 to 1610, an increase of 26.4%. Italy, Spain and France have the highest number of vessels in the EU. Türkiye ranks third in the number of large-scale fishing vessel fleet after Italy and Spain (BSGM, 2024).

1.4. Carbon Footprint and Fisheries

The impacts of climate change on the oceans have direct consequences for fishing activities and seafood supply. The IPCC (2023) report emphasises that ocean warming, acidification, deoxygenation and sea level rise adversely affect both offshore fisheries and shore-based small-scale fisheries. These changes are decisive in the migration routes, reproductive cycles and stock productivity of fish stocks. In particular, temperature increase causes shifts in species distribution towards the poles and decreases potential catches in some regions (IPCC, 2023). These assessments of the IPCC reveal that under global warming scenarios ranging from 1.5°C to 4.3°C, maximum fishery yields will decline in many regions and this decline will be felt more severely in tropical and low latitude regions. In parallel, shellfish aquaculture is also highly sensitive to changes in ocean chemistry. In particular, ocean acidification threatens species that form calcareous shells, reducing production efficiency. These disruptions in fisheries and aquaculture not only cause economic losses but also have serious social impacts on the food security and livelihoods of coastal communities. Regions with high climate vulnerability, such as subsistence fishing communities and small island states, are particularly vulnerable to these impacts (IPCC, 2023).

According to FAO's technical assessment for 2024, the risks of climate change to marine fisheries production are serious at the global level. In particular, under a high emission scenario (3-4 °C global warming), catchable fish biomass is projected to decline by over 10% by 2050. By the end of the century, these losses are estimated to exceed 30% in 48 countries and regions. Among the countries most affected by these declines are leading fish producers such as China, where declines of over 30% are expected. In contrast, under the low emissions scenario (1.5-2°C global warming), biomass levels in 178 countries and regions are projected to remain unchanged or decline by less than 10%. Furthermore, losses in excess of 40% are estimated in seas outside national jurisdiction, and these are the marine areas with the highest FAO catch records. These findings concretely demonstrate the impact of emission reduction scenarios in combating climate change and emphasise the urgency of adaptive fisheries management (Blanchard and Novaglio, 2024).

Tyedmers (2004) stated that the most important energy consumption in fishing activities is during the catching of aquatic organisms, which is the main objective. However, this energy consumption is often less visible and therefore receives less attention compared to the direct impacts of fishing on target stocks and marine ecosystems. Yet, today, it is the abundant and continuous supply of energy based on fossil fuels that makes it possible for many industrial fishing systems to continue to operate despite declining stocks. Therefore, assessing the forms and quantities of energy used in fisheries can be an indirect indicator of the biophysical scarcity of fished populations, especially when considering changes over time. However, over the last half century, fossil fuel consumption has become the dominant element of the energy profile, especially in large-scale industrial fishing systems. Long-term data reveal a clear downward trend in energy efficiency in many fisheries systems. This is interpreted as an indicator of system efficiency and the increasing trend of stock scarcity. The size and technological power of the global fishing fleet supports this trend (Tyedmers, 2004).

In another study, Daw *et al.* (2009) revealed the relationship between climate change and fishing activities. They predicted that climate change will directly and indirectly impact marine and inland fisheries. It was stated that mitigation measures for using fossil fuels may create additional economic pressures on the fishing sector as they will increase fuel costs. It was emphasised that climate change may affect fishers and fishing activities in many different ways, including biophysical processes such as changes in the distribution or productivity of marine and freshwater fish stocks, ocean acidification, damage to habitats, changes in marine physical characteristics, disruption of rainfall patterns and reduction of freshwater resources. In addition, direct impacts such as damage to coastal infrastructure and communities due to sea level rise, increase in storm frequency and intensity, and indirect effects such as displacement and human migration are also in question. Global commitments to reduce greenhouse gas emissions to limit climate change are also vital for fisheries (Daw *et al*., 2009).

In another study comparing the greenhouse gas emission sources of aquaculture and capture seafood, Hognes *et al.* (2014) found that the most significant source of emissions in capture seafood is the fossil fuels used by fishing vessels and that fuel consumption accounts for the majority of total emissions, especially in fishing methods that require high engine power such as trawling. In aquaculture production, the main source of emissions is the production process of feeds used to feed the fish, and feeds with high fish meal and fish oil content attract attention with their high carbon footprint (Hognes *et al.*, 2014).

1.5. Carbon Footprint Measurement Methods

Measuring carbon footprint is recognised by the UN Framework Convention on Climate Change as an essential way to contribute to achieving international climate action goals. It enables organisations to see more accurately where the main impacts on their carbon footprint occur and thus take appropriate measures to reduce it (Gabrielii and Jafarzadeh, 2020).

In carbon footprinting studies, analysis and interpretation should be understandable by everyone and facilitated by introducing a certain standard. For this purpose, approaches to how greenhouse gas emissions should be calculated sectorally and the activities between which calculations will be made in emission emissions have been tried to be methodised.

The first process of assessment in carbon footprint calculations is based on the Life Cycle Assessment (LCA) methodology. LCA is an analytical approach that aims to systematically analyse the environmental impacts of a product or service throughout its entire life cycle, from raw material procurement to final disposal. The LCA method, structured in line with ISO 14040 and ISO 14044 standards, consists of four stages: purpose and scope definition, life cycle inventory, impact assessment and interpretation (Weidema *et al.*, 2013). Naranjo *et al.* (2021) used a life cycle assessment methodology based on the ISO 14040:2006 standard using a gate-to-gate approach (Figure 2).

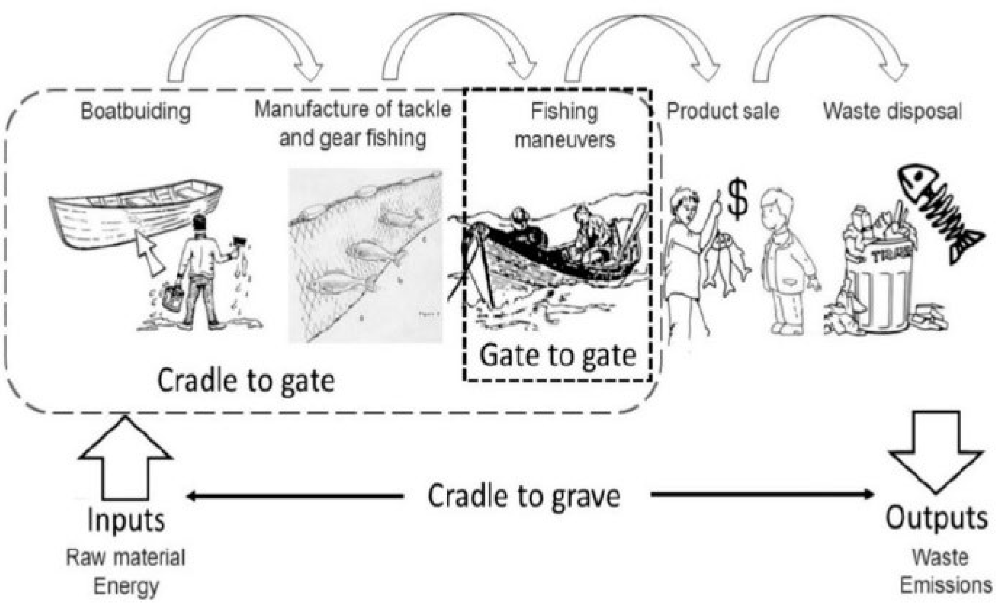

Figure 2. Terminology related to the scope of the life cycle assessment of hake gillnet fishing (Naranjo, 2021)

The LCA approach covers environmental impacts along the entire supply chain, including production, processing, transportation, retail, home use and disposal, especially in food production systems such as agricultural and aquaculture (Gabrielii and Jafarzadeh, 2020; Garnett, 2008). LCA-based calculations are generally carried out within the scope of GHG accounting, which aims to quantify greenhouse gas emissions. The main standards used in this framework are ISO 14067, PAS 2050 and GHG Protocol, and these methodologies provide a comprehensive assessment of GHG emissions from production to consumption (Pandey *et al.*, 2011). ISO 14067:2018 is an internationally recognised standard for calculating the carbon footprint of products. It stands out by allowing both full (cradle-to-grave) and partial (cradle-to-gate) life cycle calculations. This feature provides easy application, especially in sectors with limited data access (Gabrielii and Jafarzadeh, 2020).

PAS 2050 is a structured framework for calculating GHG emissions across the life cycle, developed by the British Standards Institute (BSI). This standard also forms the basis for carbon footprint calculations within the cradle-to-grave and cradle-to-exit boundaries. PAS 2050-2 was published in 2012 specifically for seafood and other aquatic foods and is a sectoral supplementary guideline that aims to identify GHG contributions at the capture, processing, transportation and cold chain stages (Gabrielii and Jafarzadeh, 2020).

Based on LCA, total greenhouse gas emissions are determined by calculating the energy and emission factors used in measuring greenhouse gas emissions. For this purpose, the guide prepared by IPCC (2006 IPCC Guidelines for National Greenhouse Gas Inventories) is used on a global scale (IPCC, 2006).

1.6. Carbon footprint from fishing industry in the World and Türkiye

In carbon footprint calculations, organisations such as WMO, IPCC and OECD make and publish reports and determinations. In this context, when the data obtained from the software environment created by the OECD were evaluated, the following results were reached.

The total carbon footprint in the world, which was 30153000000 tons of CO_2equivalent in 1995, increased by 43% to 43026000000 tons of CO_2 equivalent in 2020, while in Türkiye, which was 240000000 tons of CO_2 equivalent in 1995, increased by 118% to 523000000000 tons of CO_2 equivalent in 2020. Türkiye is responsible for 1.21% of the global total carbon footprint (OECD, 2024b).

The GHG emissions of the fisheries sector (capture and aquaculture together), which is one of the essential components of the agriculture sector, between 1995 and 2020 are presented in Figure 3 for the world and Türkiye. While it was 48.4 million tons in 1995 in the world, 64.0 million tons of CO_2equivalent were emitted in 2020. In Türkiye, the GHG emissions of the fisheries sector were 82000 tons of CO_2 equivalent in 1995 and reached the highest value of 120000 tons of CO_2equivalent in 2007. In the following years, a downward trend was observed until 2012 (26000 tons CO_2equivalent), and it was calculated as 59000 tons in 2020 (Figure 3) (OECD, 2024b).

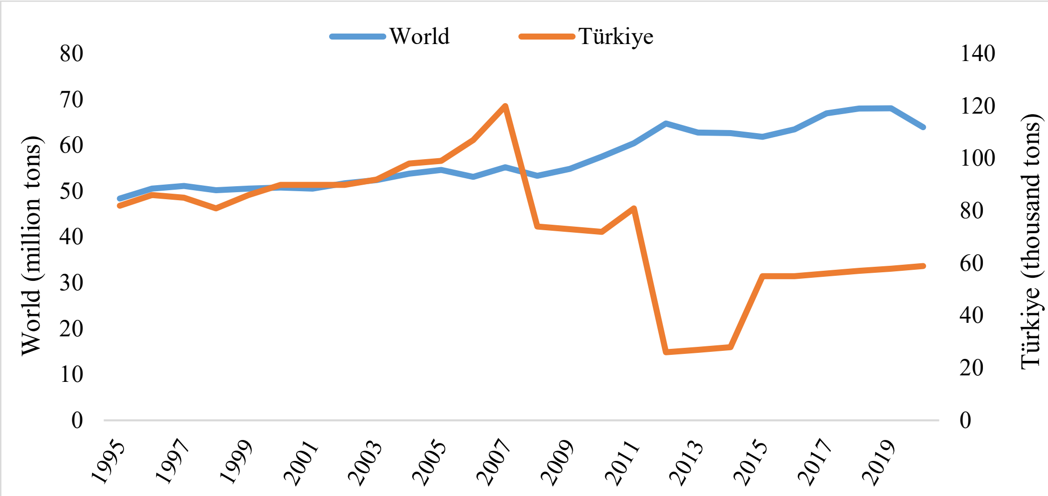

Figure 3. CO_2equivalent of the Fisheries sector in the World and Türkiye (tons) (OECD, 2024b)

On the other hand, studies on climate change and carbon footprint in fisheries have also been carried out by researchers outside of institutions: Tyedmers *et al.* (2005) combined FAO's spatially resolved catch statistics for 2000 with more than 250 fishery samples from around the world to assess the fossil fuel use and carbon emissions of global fisheries. They found that about 50 billion litres of fuel are burned annually, producing 80 million tons of seafood (fish and invertebrates). It is emphasised that this determination, which means an average fuel consumption of 620 litres per ton, results in the emission of approximately 134 million tons of CO_2. This amount corresponds to approximately 1.2% of world oil consumption. It is concluded that an average of 2.68 kg CO_2 carbon footprint is created for each litre of fuel.

Tyedmers and Parker (2012) reached an average emission value of 3.12 kg CO_2e/litre in their study conducted with the "well-to-tank" approach by covering the initial processes such as extraction, processing and transportation of fuel as well as direct fuel consumption. It was stated that purse seine fleets stand out as the most efficient segment with an average fuel use intensity (FUI) of 368 l/t, while longline, dragline and single line methods have FUI values of 1069, 1107 and 1485 L/t, respectively. In terms of species, it was stated that skipjack tuna (364 L/t) and yellowfin tuna (395 L/t) were caught most efficiently, while FUI values were relatively high for species such as albacore (1.303 L/t) and bluefin tuna (1.478 L/t). Geographically, the Pacific Ocean was found to have the lowest average FUI value (354 l/t). In terms of carbon footprint, it was estimated that the global tuna fleet consumed approximately 3 billion litres of fuel in 2009, resulting in approximately 9 million tons of CO_2-e emissions. Within the framework of LCA, it was stated that fuel consumption accounts for 60-90% of the total life cycle greenhouse gas emissions of tuna products (Tyedmers and Parker 2012).

In the study by Parker *et al.* (2015), the total carbon footprint from fuel was calculated as 3.1 kg CO_2e per litre. In the study, operational information obtained from 93 purse seine vessels with data from 2009 was analysed. The average fuel use intensity was determined as 368 litres/ton. While this value is 364 l/t for striped tuna, it is 395 l/t for yellowtail tuna. It was stated that the FUI in the Pacific Ocean was as low as 349 l/t, while in the Indian Ocean it was as high as 459 l/t, and that the difference was related to factors such as regional stock conditions, fisheries strategies and fleet structure. In terms of carbon footprint, it was determined that an average of 1140 kg CO_2e was emitted per tuna caught. The results of the study are evaluated on a global scale and it is estimated that the purse seine tuna fleet consumed approximately 1 billion litres of fuel and produced 3.14 million tons of CO_2e emissions in 2009. It is emphasised that this amount corresponds to 2.4% of global marine fisheries fuel consumption and 0.01% of total global greenhouse gas emissions (Parker *et al.*, 2015).

Park *et al.* (2015) calculated that the total GHG emissions from offshore fisheries in South Korea in 2013 were 1477279 tons CO_2e. It was explained that this amount corresponded to approximately 0.21% of South Korea's total national emissions in the same year, and it was also explained that although the number of fleet decreased by 2.3%, total fuel consumption and therefore emissions increased by 2.4% on average annually. In the conclusion part of the study, it was emphasised that small-scale but energy-intensive fisheries methods, such as jigging and longline fishing, have very high values in terms of GHG emissions per kg (7.28 $kgCO_2e/kg$ and 5.25 $kgCO_2e/kg$, respectively). In contrast, trawling, traditionally considered to have a high environmental impact, was more fuel and emission efficient (Park *et al.*, 2015).

A global study revealed that in 2011, the world's fisheries fleets consumed 40 billion litres of fuel and emitted a total of 179 million tons of CO_2-eq greenhouse gases to the atmosphere, of which 174 million tons were from motorised fishing vessels and 5 million tons from non-motorised fishing vessels (Parker *et al.*, 2018). Of this emission value, 152 million tons were determined to have occurred for human food production. Most of the total emissions (50 million tons of CO_2equivalent) are produced by China, and Asia is responsible for 78 million of the total emissions, while Europe ranks second with 20 million tons of CO_2equivalent. In the study, fuel utilisation intensity FUI (l t-1) was determined as 489. Based on 81 million tons of total landings, it was estimated that 2.2 kg of CO_2equivalent was emitted for each kilogram of fish and invertebrates landed (Parker *et al.*, 2018).

Naranjo *et al.* (2021) assessed the carbon footprint, focusing on small-scale fisheries targeting the hake (*Merluccius gayi*) species. During the data collection process, they calculated CO_2 equivalent emissions per activity based on fuel consumption in 2011 and 2012. According to the results, 0.47 $kgCO_2e$ was emitted per kilogram of hake product in 2011 and 0.58 $kgCO_2e$ in 2012. It is stated that almost all of these emissions are caused by the combustion of diesel fuel used in the fishing process.

Basurko *et al.* (2022) monitored the energy consumption patterns of a Spanish purse seine vessel operating in the Indian Ocean during ten consecutive fishing trips and also compared the fuel use intensity (FUI) of fish aggregating devices (FAD) and free-swimming schools (FSC) strategies over 14 additional trips conducted by different tropical tuna purse seiners. The average fishing trip lasted 33.1 ± 11 days, with 68.5% of the time spent cruising, 15.6% passive waiting at sea, 7.7% fishing and 8.1% port time. The average fuel consumption per voyage was 381 ± 113 tons, of which 90.4% was for cruising, 4.3% for fishing, 3.7% for passive period at night and 1.6% for port activities. It was stated that 75% of the total fuel was consumed by the main engine and 25% by the auxiliary engines. According to the analysis, the FAD strategy is a more fuel-intensive method with an average of 543.6 litres/ton of fish, while the FSC strategy has a lower FUI value with an average of 439.4 litres/ton. However, it is emphasised that the success rate of FAD catches (95.7% ± 3.8%) was higher than FSC (80.6% ± 5.8%) and this difference may be due not only to the strategy used but also to many external factors such as seasonality, FAD density in the region, vessel and equipment characteristics, and skipper experience. Moreover, FAD and FSC strategies were found to be more energy efficient than other methods used in Atlantic tuna fisheries such as longline (1069 L/t), trolling (1107 L/t) and pole-and-line (1490 L/t). However, this efficiency was similar or slightly lower compared to pole-and-line vessels in the Maldives (Basurko *et al.*, 2022).

Alma-Maris (2023) calculated that the global marine fisheries sector consumed approximately 12.86 million tons of fuel as of 2018, corresponding to approximately 14.953 billion litres of fossil fuel. As a result of this fuel consumption, the sector is estimated to emit 40.7 million tons of CO_2 equivalent greenhouse gas emissions. This value corresponds to approximately 4% of total emissions from maritime transport and 2.89% of global anthropogenic emissions in 2018. According to assessments of the European Union fishing fleet, it is reported that this fleet emits approximately 6.94 million tons of CO_2 equivalent greenhouse gas emissions with an average annual fuel consumption of 2.59 billion litres. This amount accounts for about 17% of global fisheries emissions. The majority of emissions come from fossil fuels consumed in operational activities such as vessel movement and fishing gear towing. Regarding energy efficiency, comparisons show that bottom contact fishing gear, such as bottom trawls, have high fuel use intensity (FUI, litres/kg) and daily fuel consumption (FUE, litres/day). This indicates that these fishing techniques have high energy and environmental costs. In contrast, passive fishing gears, with their lower FUI values, seem prominent in carbon footprint reduction strategies (Alma-Maris, 2023).

Limited studies were found in the literature on the carbon footprint of Turkish fisheries. In the first study, fuel data obtained from 34 purse seine, trawl and small-scale fishing vessels fishing in Iskenderun Bay were evaluated (Demirci and Karagüzel, 2018). In the second study, CO_2 emissions were calculated with the data obtained from a system that can display and record instantaneous and total fuel consumption, speed, position and engine speed on a research vessel on the determination and optimisation of fuel consumption in trawlers (Sarıca *et al.*, 2018). In the third study, CO_2 emissions of purse seine vessels engaged in anchovy fishing in the Black Sea were determined (Dağtekin *et al.*, 2022). In the last study, fuel use intensity (FUI) in Turkish trawl fisheries was evaluated in terms of energy efficiency and carbon footprint. In the study conducted by Fakıoğlu (2025), the data of 129 commercial voyages carried out by 13 trawlers were examined, and it was determined that an average of 1.22 litres of fuel was consumed for 1 kg of landed catch, which resulted in approximately 3.21 kg CO_2 emissions. The research shows that fuel consumption increases as engine power increases, but fuel use intensity decreases as the vessel length increases. In particular, it was emphasised that shrimp-targeted voyages consume more fuel than fish-targeted voyages. The findings reveal that factors such as vessel design, catch targets, and engine efficiency should be considered in the decarbonisation process of fisheries (Fakıoğlu, 2025).

The fact that very few studies have been conducted on the carbon footprint of Turkish fisheries points to a significant gap in the literature that needs to be filled. In this context, the lack of a holistic carbon footprint inventory of the Turkish fishing fleet makes sustainable resource management and integration into international climate policies such as the Paris Agreement and the European Green Deal difficult.

2. EVALUATION AND CONCLUSION

Recent scientific studies have shown that climate change is caused by man-made greenhouse gases (Ekici, 2019), and information on greenhouse gas emissions plays a key role in climate change statistics. Emissions data are essential for assessing the impact of policy interventions as well as mitigation efforts of countries. Given the wide range of possible analytical and policy objectives, the need to develop different approaches to collect, estimate and structure GHG emission data was emphasised (OECD, 2024a).

In the Report of the Parliamentary Investigation Commission No. 201, 28th legislative term, 3rd legislative year, Established to Investigate the Problems Experienced in the Fisheries and Aquaculture Sector and to Determine the Measures to be Taken, the need to reduce the carbon emissions of our fishing fleet has been emphasised many times and for this purpose, limiting the engine power of fishing vessels, It has been suggested to encourage the use of engines that consume less fuel, emit less carbon emissions and run on different fuel/energy types such as more efficient electric/hybrid engines (TBMM, 2025).

On the other hand, Türkiye's "Climate Law" was published in the Official Gazette on July 9, 2025 and entered into force. With the law, businesses that carry out activities that directly cause greenhouse gas emissions are obliged to obtain greenhouse gas emission permits to carry out these activities. The fisheries sector also faces this sanction.

In Türkiye, there are scarce studies on carbon footprint, which is an essential indicator in monitoring the environmental impacts of climate change in fisheries. It is important to increase these studies and evaluate their results. The effects of climate change and their mitigation are problem that requires all humanity to act with a common awareness. A decarbonisation approach should prevail in the activities of all energy-producing and energy-using sectors. Greenhouse gas emissions need to be reduced and eventually eliminated. Greenhouse gas emissions need to be reduced and eventually eliminated. Reducing the greenhouse gas emissions of the Turkish fisheries sector should be made a public obligation.

First it is necessary to conduct a greenhouse gas inventory study by all sectors and regularly monitor the data. Meanwhile, alternative fuel systems (e.g. electric, hybrid) should be supported, and public support should be directed not only towards fuel subsidies but also towards technical conversion. Regional restrictions and efficiency criteria should be established for energy-intensive fishing gear such as bottom trawls and purse seines, and a licensing system should be developed for this purpose. Support should be diversified and increased by developing a 'Support for Small-Scale Fisheries' model for the use of low-emission passive fishing gear. A digital recording system should be established to enable the annual monitoring of fuel consumption and carbon footprint at the fleet level, addressing data quality and gaps. An effort should be made to increase emission mitigation regulations in fishing ports. Energy efficiency and carbon footprint training should be provided to fisheries cooperatives, unions and sector representatives to enhance ecosystem literacy and environmental awareness. Vessel designs that increase fuel efficiency and fishing gear that reduces friction should be used. In addition to monitoring CF of fishing operations, the boundaries of sectoral distinctions should be more clearly defined by tracking all processes from cradle to grave through LCA. Of course, the most important thing is to protect aquatic ecosystems and biodiversity and create marine carbon sinks that increase oxygen production.

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Hüseyin AKBAŞ: Conceptualization, Investigation, Original Draft, Writing, Writing - Review and Editing. **Hakkı DERELİ:** Conceptualization, - Writing - Review and Editing.

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The authors declare that for this article they have no actual, potential or perceived conflict of interests.

ETHICS COMMITTEE PERMISSION

The authors declare that this study was conducted in accordance with with ethics committee procedures of human or animal experiments.

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