CMFRI Special Publication No. 149

Carbon Footprint of marine fisheries in India

National Innovations in
Climate Resilient Agriculture

Indian Council of Agricultural Research
Central Marine Fisheries Research Institute

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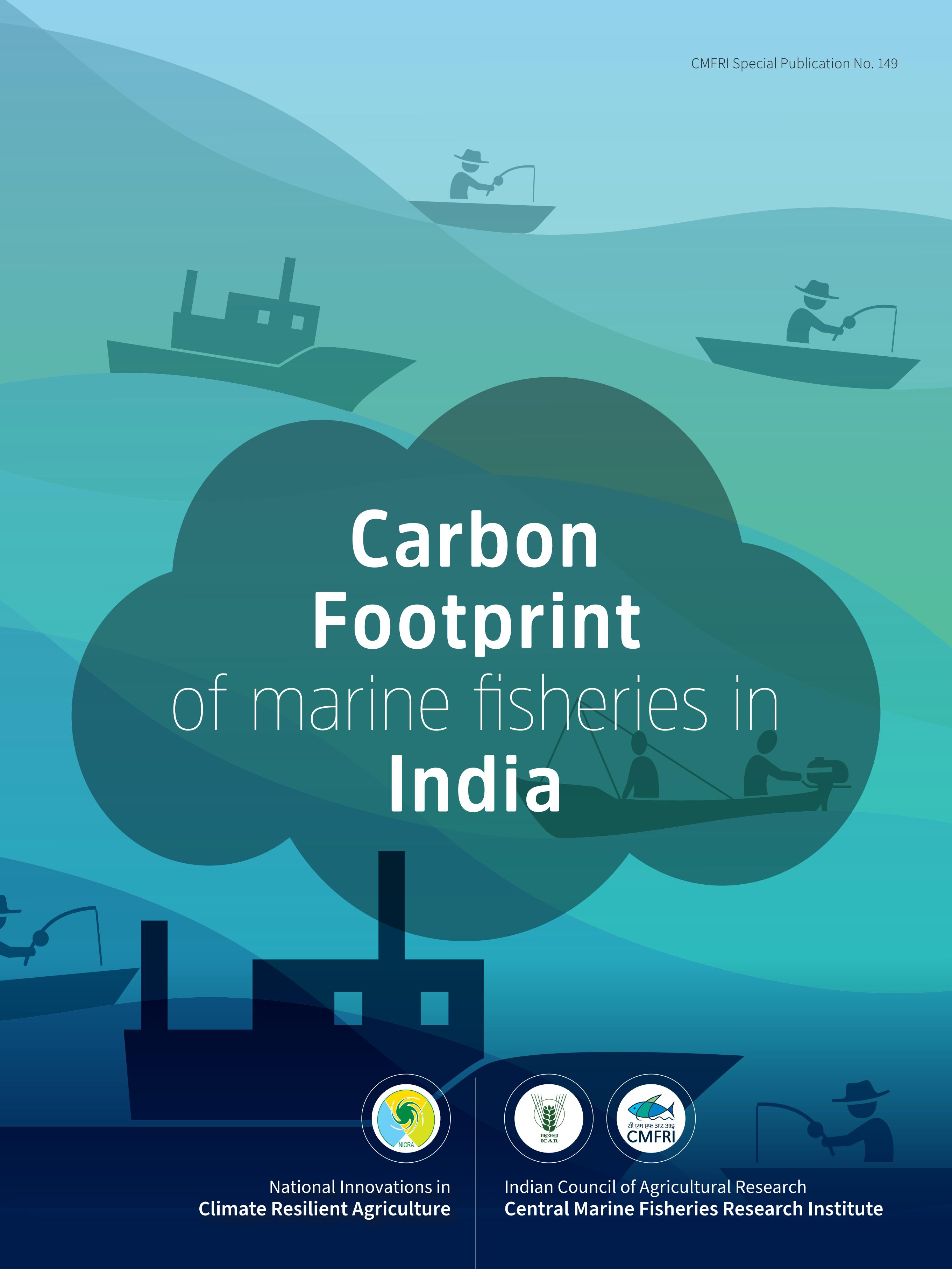

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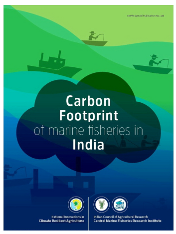

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Message

In the twenty-first century, the impact of human-induced climate change poses a significant challenge to humanity. Climate change-related impacts and associated challenges are evident in agricultural and allied sectors, including fisheries and marine ecosystems. For any nation to achieve net-zero emissions, the first step is to acquire information on carbon emissions across various sectors. In India, marine capture fisheries is a major contributor to both livelihood as well as nutritional security. Being a critical sector in the country's growth and development, a need was felt for a comprehensive assessment of greenhouse gas emissions from marine fishing activities.

I take great pride that, ICAR-CMFRI developed and standardized a comprehensive methodology under the National Innovations in Climate Resilient Agriculture (NICRA) project, for the holistic assessment of carbon emissions encompassing multi-sector, multi-gear marine fishing activities in India. The methodology was specially adapted to suit the small-scale tropical fishing sector contexts and could serve as a model for countries with diverse small-scale mechanized/motorized fishing sectors. I am delighted to learn that, as per the estimates of the study, the average emissions from the Indian fishing industry during 2023 were 1.52 kg CO_2e per kg of fish, which is 30% lower than corresponding global estimates. The relatively low carbon emission profile of Indian marine fisheries holds promise for a sustainable, environment friendly fishing scenario with timely and appropriate policy interventions.

Considering that the science-policy interface in India is strengthening over time, scientific documents like this play a great role in serving as guiding sources for policy planners. It is heartening that the ICAR-CMFRI team diligently worked on documenting emissions on a pan-India scale across different sectors of marine capture fisheries, resulting in a valuable publication. I extend my compliments to the ICAR-CMFRI and NICRA team for this significant output and wish them success in their future endeavours towards contributing to the sustainable development of India's fishing sector.

Himanshu Pathak

12th February, 2024
New Delhi

Secretary DARE & Director General
Indian Council of Agricultural Research (ICAR)

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Foreword

India's marine fisheries represent a dynamic and essential force, teeming with life and offering both sustenance and significant economic influence. This sector is anchored in a deep-seated relationship between humanity and the sea. This bond has not only endured but also flourished amidst modern technological advancements and innovative tools. The vitality of India's marine fisheries sector is evident in its successful integration of traditional practices with cutting-edge methodologies. In the global effort to combat climate change, carbon trading has emerged as a novel and promising tool. To effectively implement carbon trading in the marine fisheries sector, it is crucial to estimate the sector's emissions accurately. A comprehensive study conducted in 2018 on greenhouse gas (GHG) emissions in the fishing sector indicated that approximately 2.2 kg of CO_2 equivalent emissions are generated globally for every kilogram of marine fish captured.

In India, the ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI) developed a methodology to estimate CO_2 equivalent emissions per kilogram of fish caught, encompassing all activities of marine fishing from vessel construction to the final product. This methodology serves as a potential model for countries with diverse small-scale mechanized and motorized fishing sectors. When comparing India's total marine fish production with the global benchmark, it was found that GHG emissions per kilogram of marine fish produced in India were only 1.52 kg CO_2e. This indicates that the Indian marine fisheries sector emits 30% less CO_2 equivalent GHG per kilogram of fish produced, compared to the global average. Even with the updated global GHG emission data from 2018, Indian trawlers are estimated to emit 17.7% less, signifying a relatively slower increase in emissions compared to global estimates.

I extend my congratulations to ICAR-CMFRI for their diligent efforts in developing efficient methodologies for estimating emissions in the Indian marine fisheries sector and for their thorough examination of how these emissions align with global standards. I also express my appreciation for the NICRA team of ICAR-CMFRI. Special thanks to Dr. J.K. Jena, DDG (Fisheries Science), for his proactive role in addressing emission-related challenges in marine fishing. I am pleased to note that my suggestions during the last NICRA review meeting at CMFRI Kochi, regarding the publication of a document to elucidate the scientific methodologies for estimating carbon emissions associated with marine fisheries, were well-received. I am confident that this comprehensive scientific document on the carbon footprint of marine fisheries in India will serve as a valuable resource for policy advisories focused on sustainable and green fishing practices.

Suresh Kumar Chaudhari
DDG (Natural Resources Management), ICAR

10th February, 2024
New Delhi

Preface

The dynamic nature of India's marine fisheries and the complexities therein, derived from the diversity of resources, grounds, craft-gear combinations, operation modes and communities involved, make any assessment of its components challenging. More so when global methodologies for such assessments are still in infancy. As a team of researchers engaged for a decade in the estimation of carbon footprint in marine fisheries of India, we feel extremely glad at the outcome of a massive team-effort which paved way for this publication. Accessibility to information, compilation of datasets, analysis and final estimation happened in a coherent manner despite several changes in the constitution of the team during the study.

The importance of the marine fisheries sector in India prompted us to generate a baseline data to be compared with the latest changes and technological advancements in fishing operations to prove that our datasets remained scientifically robust for a pan-India estimation. The financial and conceptual support received from the Indian Council of Agricultural Research through National Innovations in Climate Resilient Agriculture project (Marine Fisheries component) helped us in coming up with this scientific document. The support received from Dr. J.K. Jena, Deputy Director General (Fisheries Science), Dr. S.K. Chaudhari, Deputy Director General (Natural Resource Management), Indian Council of Agricultural Research (ICAR); Dr. V.K. Singh, Director, ICAR-CRIDA; and Dr M. Prabhakar, National Principal Investigator, NICRA, ICAR-CRIDA throughout the study period was instrumental in the completion of this mammoth effort. As the nation looks forward towards 'net-zero emissions' as per the agreement of the Conference of the Parties (COP), we as part of the team dealing with climate resilience feel delighted to understand that Indian marine fisheries remain greener, sustainable, and resilient in comparison to our global counterparts. The small-scale nature of the fishery with a large volume of fisher participation moved us in a way that we believe that our realization will be a step forward in recognizing the hard labour of fishers who emit less when their industrial trawling counterparts elsewhere continue to use more fossil fuels.

The result of our study on carbon footprint of marine fisheries in India seems like a silver lining for this sector which is otherwise facing serious climate related challenges being in a vulnerable geographical setting. We strongly believe that our policy planners will be able to use this document in evolving fishery management measures to mitigate the challenges posed by climate change.

Dineshbabu A.P. et al.

ICAR-CMFRI

Executive summary

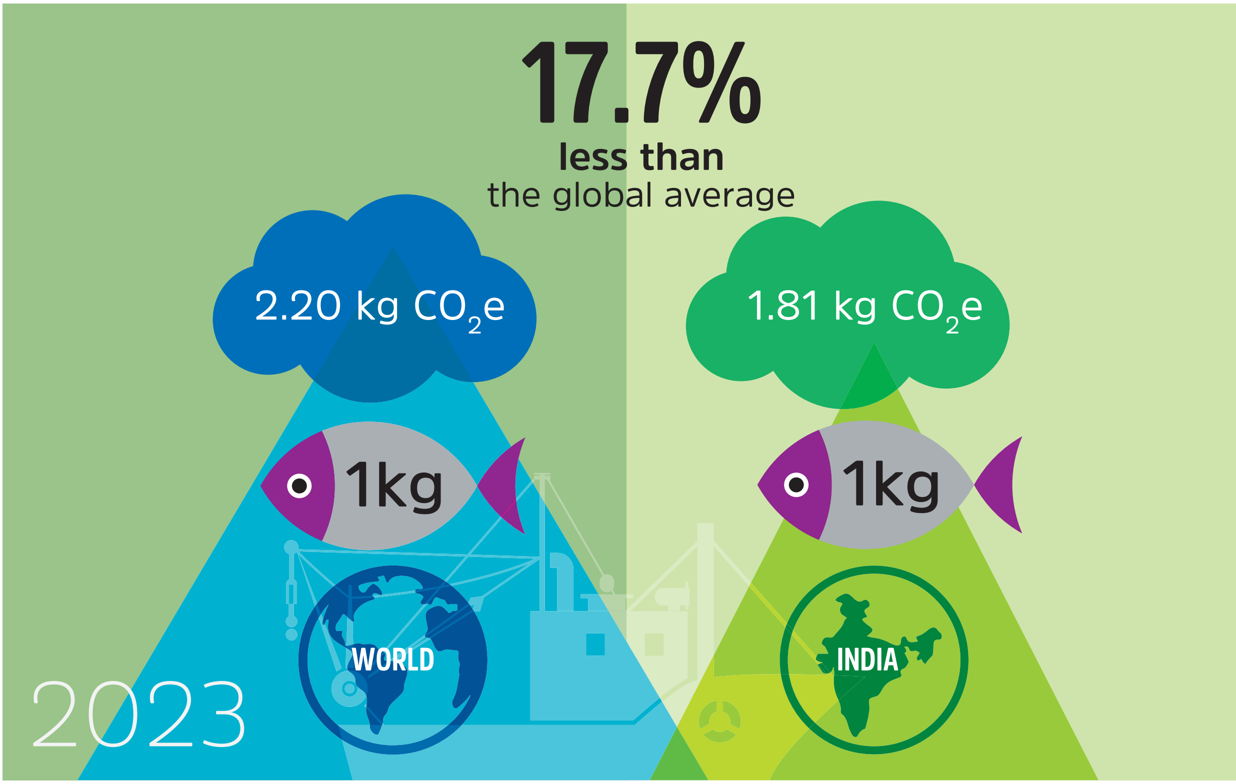
- Assessment of the carbon footprint of Indian marine fisheries involved a specific examination of the green-house gas equivalent (GHG) emissions produced by fishing activities.
- ICAR-CMFRI developed a unique, standardized methodology for the holistic assessment of multi-sector, multi-gear marine fishing activities of India, including construction and fabrication which integrated standard processes with indigenous modifications during the period 2012-2022.
- This methodology can be a model for countries with diverse small-scale mechanized/motorized fishing sectors.
- A global study (Parker et al., 2018) found that 2.20 kg of CO_2 equivalent emissions (CO_2e) are released to catch one kg of fish, with variations based on targeted fish type.
- Average emission was estimated at 1.47 kg CO_2e per kg of fish from India's mechanized fishery sector (pre-harvest, harvest & post-harvest scenarios), which includes trawlers, gillnetters, dol-netters, long-liners, purse seines, and ring seines. This is 33% lower than the global estimate.
- Average emission was estimated at 1.52 kg CO_2e per kg of fish caught from fishing operations in India (including mechanized, motorized and indigenous sectors), and this is 30% lower than the global estimate.
- When we initiated the study in India one decade ago, the estimates showed that GHG emissions from Indian trawlers were 16.3% less than the global average. With the increased emissions globally, the emissions are now 17.7% less than global average, which indicates that the Indian marine fisheries is greener.
- Environment-friendly methods with less carbon footprints are mechanized ring seines in Kerala (0.93 kg) and purse seines in Karnataka (0.68 kg).
- Most eco-friendly methods in marine fisheries are dol-netters in Gujarat (0.34 kg) and Maharashtra (0.39 kg) due to minimum fuel usage.
- Overall, Indian fishing units have lower emission profiles compared to the global figures.
- The relatively low carbon emission profile of Indian marine fisheries holds promise for a sustained green fishing scenario with timely and suitable policy interventions.

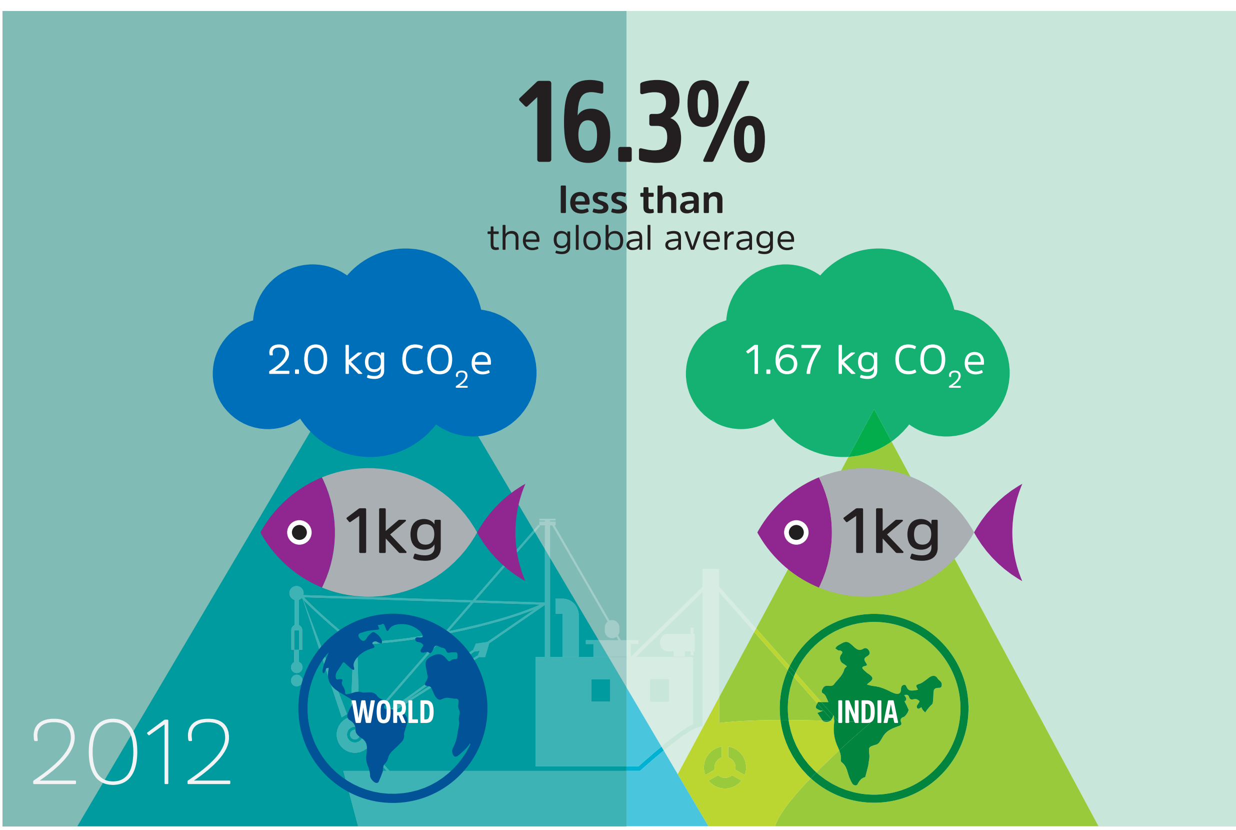
Indian marine fisheries emit **30% less than** the global average

Abbreviations

CO_2	:	Carbon dioxide
IPCC	:	Intergovernmental panel on climate change
ppm	:	Parts per million
EEZ	:	Exclusive economic zone
IMTA	:	Integrated multi-trophic aquaculture
NPACC	:	National plan of action on climate change
LCA	:	Life cycle assessment
ISO	:	International standards organization
SETAC	:	Society of environmental toxicology and chemistry
GWP	:	Global warming potential
CF	:	Carbon footprinting
SO_2	:	Sulphur dioxide
PO_4	:	Phosphate
NPPU	:	Net primary product use
EU	:	Energy use
EP	:	Eutrophication potential
AP	:	Acidification potential
FU	:	Functional unit
CO_2e	:	Carbon dioxide equivalent
$CO_2e\ kg^{-1}$	:	Carbon dioxide equivalent per kg.
FRP	:	Fibre-reinforced plastic
HDPE	:	High-density polyethylene
PP	:	Polypropylene
PA	:	Poly-amide
Defra	:	Department of food and rural affairs
DECC	:	Department of energy and climate change
GHG	:	Greenhouse gases
LPG	:	Liquified petroleum gas
CH_4	:	Methane
N_2O	:	Nitrous oxide
kWh	:	Kilowatt hour
CMFRI	:	Central Marine Fisheries Research Institute
ICAR	:	Indian Council of Agricultural Research
NICRA	:	National Innovations in Climate Resilient Agriculture

Carbon Footprint in Trawl Fisheries





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Introduction

Climate Change

Climate change has had widespread effects on the globe, from precipitating an increased frequency in extreme weather events to long-term downstream effects on the physiology of animals. As the world's oceans act as a heatsink for the globe, this has great effects such as rising sea levels, melting ice caps and slow but inexorable destruction of coastal communities. There are few industries that are as greatly impacted by this wide array of changes as marine fisheries. It is evident that greater efforts must be taken in order to prevent or mitigate the effects of climate change in this sector. Since the beginning of the industrial era, the global average concentration of carbon dioxide (CO_2) in Earth's atmosphere has been climbing at an alarming rate, going from ~210 ppm in 1850 to its current level at >415 ppm. Due to the nature of CO_2 and other greenhouse gases, this has resulted in a rapid and alarming shift in global climate patterns, which is colloquially referred to as climate change. Mitigating or limiting the impacts of climate change requires knowledge of the practices and products that produce the most emissions, which can therefore allow amendment of production methods or shifts to less resource and emission intensive methods.

Climate change adaptation is an urgent and indispensable call to safeguard development gains and to address the needs of the vulnerable. Healthy systems that are resilient to disruptions, shocks, and stressors are critical in achieving not only environmental benefits but also serve as a foundation for economic and human development. Climate resilience is a key component of any healthy system, particularly in vulnerable countries that depend heavily on climate-sensitive natural resources and traditional agricultural practices for subsistence and livelihoods. Adaptation and mitigation for climate change are issues of global concern and equity. Well-defined and well-implemented mitigation policies can substantially reduce the risks associated with human-induced global warming.

With global research on climate change events, mitigation and adaptation fast tracking in the last 50 years, there has been increasing evidence of many destructive and usually irreversible changes happening in the world around us, particularly in the oceans. Mitigating climate change is mostly about reducing the release of greenhouse gas emissions. Mitigation is defined by the IPCC as

human intervention to reduce the sources or enhance the sinks of greenhouse gases. It involves reducing our "carbon footprint" by using less energy, consuming fewer materials, and appropriately altering natural resource management practices. Carbon dioxide is created by burning fossil fuels like oil, natural gas, diesel. Carbon dioxide emission is a continuous process arising from a variety of human activities, but especially from electricity generation, energy use in the functioning and maintenance of buildings, fuel-powered transportation, industrial processes, agricultural processes, land use and deforestation. The emitted carbon dioxide remains in the atmosphere for 80 to 200 years. The total amount of greenhouse gases produced to support human activities directly and indirectly, usually expressed in equivalent tonnes of carbon dioxide is taken as a measure of the carbon footprint, i.e., the amount of carbon dioxide released into the atmosphere because of the activities of a particular individual, organization, or community. The best way is to calculate the carbon dioxide emissions based on fuel consumption from start to end of a process, including all the sub-processes involved in the chain.

Through limiting the carbon footprint of an industry as a whole, this will likely provide a small but not insignificant amelioration in terms of carbon output.

Fisheries and Climate Change

Fisheries form a major source of animal protein to nearly 20% of the world's population of ~7.2 billion people (FAO, 2017; FAO SOFIA, 2018), and is thus a vital industry contributing to achieving the UN's Sustainable Development Goals of global food security. While the impact of climate change can be felt in aquatic ecosystems and the fisheries sectors that thrive on them, the industry itself contributes towards aggravating climate change through its carbon dioxide emissions at various stages of its performance. The nutritional and economic value of fisheries remain uncontended, but their carbon footprints are a downside, and fishing is considered to be the most energy-intensive food production methods in the world (Wilson, 1999). The most dynamic and complex industry in the fisheries sector due to the diversity of craft and gear employed and the species harvested, marine fisheries pose a challenge to mitigating carbon dioxide emissions due to its high dependency on fossil fuels (Tyedmers et al., 2005). Greer et al. (2019) emphasized the potential importance of marine fishing as a part of the global CO_2e reduction strategy by estimating the total carbon dioxide emissions and carbon emission intensity from global marine fishing fuel combustion from 1950 to 2016. Carbon emission from fisheries is primarily based on fossil fuel combustion and secondarily as provision of craft, gear, engine, fuel, ice, and other necessities (Ziegler et al. 2003; Hospido and Tyedmers, 2005; Thrane, 2006; Sayana and Ramesan, 2020).

The State of Indian Fisheries

Home to several critical ecosystems and biodiversity, the challenges of mitigating and coping with climate change for India are many. With a great part of the country being bounded by seas (India has a coastline of >7500 km and a continental shelf of half a million sq. km), the Indian sub-continent is a hotspot warranting effective interventions to combat the consequences of climate change. India's Exclusive Economic Zone (EEZ) is spread over a total area of 2.02 million sq. km, i.e., 0.86 million sq. km on the west coast including the Lakshadweep Islands and 1.16 million sq. km on the east coast, including the Andaman and Nicobar Islands.

India is one of the major fish producing countries in the world, occupying the third position in capture fish production. This sector holds high potential for strengthening rural development, domestic nutritional security, employment generation, gender mainstreaming as well as export earnings.

India is a rich marine fishery resource-base with a continental shelf area extending to 0.53 million square kilometers. The marine fisheries industry has exhibited an impressive growth over the past six decades with a six-fold increase in landings from just 0.53 million tonnes in 1950-51 to about 3.49 million metric tonnes in 2022 (CMFRI, 2023). Recent assessments suggest that through proper implementation of sustainable management options, it is possible to enhance the production potential in the Indian exclusive economic zone (EEZ) to the extent of 5 million tonnes per annum or more. Mariculture and aquaculture are also areas with great potential for growth including open sea cage farming, seaweed farming, integrated multi-trophic aquaculture (IMTA), mussel and oyster culture, ornamental fish production and pearl culture.

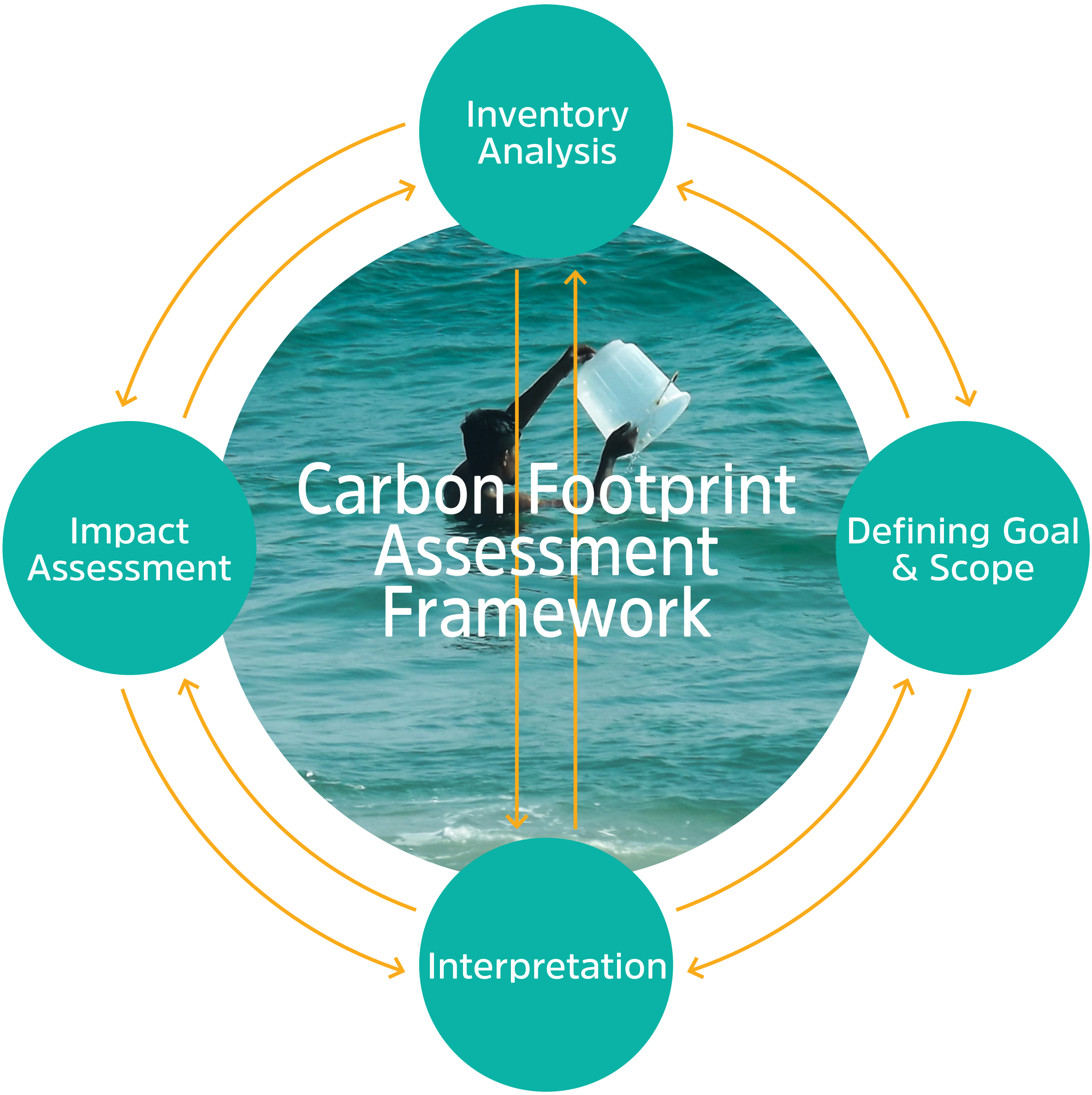
India's marine fisheries will take a major share of the impending impacts of climate change. According to the World Bank, climate change will take away nearly 3% of India's GDP and depress living standards of half its population by 2050. The National Plan of Action on Climate Change (NPACC), published by the Prime Minister's Council on Climate Change (Government of India) and adapted on 30th June, 2008, aims at creating awareness among the representatives of the public, different agencies of the government, scientists, industry and the community as a whole, on the threat posed by climate change and directs India towards sustainable development on ecological, social and economic fronts.

Carbon Footprint of Marine Fisheries

Fossil energy combustion of marine fishing vessels is an important source of carbon emissions from the marine fishing industry. Fossil-fuel burning by global fisheries was reported to be around 42.4 million tonnes (mt), representing 1.2–3.5% of global oil consumption, releasing approximately 134 mt of CO_2 into the atmosphere at an average of 1.7 t of CO_2 per tonne of live weight landed product (Tyedmers et al., 2005; World Bank and FAO, 2009). A more recent study (Parker et al., 2018) reported that 2.2 kg of CO_2 equivalent emissions (CO_2e) are released to catch one kg of fish, with variations based on targeted fish type, indicating intensification of fishing operations leading to higher carbon emission. For trawling operations which constitute roughly 50% of all mechanized fishing boats across the country, direct energy inputs for fishing operations, i.e., fuel costs, typically

account for 75-90% of the total energy consumption compared to allied activities such as vessel construction and maintenance (Watanabe and Okubo, 1989). This may be due to insufficient effort being directed towards recycling and appropriate dismantling of fishing vessels. Trawl and gillnet fishing form the mainstay of India's marine fisheries, both of which are known to be fuel intensive and hence, high-emission fishing methods (Yue et al., 2013; Kristofferson et al., 2021). All the mechanized and motorized fishing vessels in India use diesel for propulsion (Vivekanandan et al., 2013).

However, it is notable that fishing operations in India, being less intensive in scope, typically utilize less energy per unit of catch. Vivekanandan et al. (2013) reported that enhanced fishing effort and efficiency in the previous five decades had resulted in substantial increase in diesel consumption, equivalent to CO_2e of 0.30 mt in the year 1961 to 3.60 mt in 2010, and that for every tonne of fish caught, the CO_2e had increased from 0.50 to 1.02 t during the period. They found that among the mechanized crafts, the trawlers emitted more CO_2 (1.43 t CO_2/t of fish) than the gillnetters, bagnetters, seiners, liners and dolnetters (0.56–1.07 t CO_2/t of fish). However, they noted that by implementing fuel efficiency norms for fishing vessels, there is scope for reducing CO_2e in India as fuel efficiency, though defined primarily by boat engine, propulsion and gear characteristics, is substantially affected by fisheries management and practice.



Life Cycle Assessment (LCA)

LCA is a methodological framework that dates back to the 1960s and 70s, originating in attempts by corporate and non-governmental bodies to quantify the effects of production and industry on the environment. As awareness regarding the anthropogenic effects on the environment grew along with corresponding public outcry, these techniques were developed, broadening to include resource requirements, emission loadings and generated waste. In the late 1990s and early 2000s, as a result of efforts by the International Standards Organization (ISO) and Society of Environmental Toxicology and Chemistry (SETAC), a formal standardization of the methods and procedures used in Life Cycle Assessment took place. LCA is now a broadly accepted tool for the assessment of anthropogenic emissions.

The key benefit of LCA is that it allows decision makers and policy planners choose the product process or technology that results in the least impact on the environment. Through the use of LCA, we can gain better understanding of the overall sustainability and utilize that information as criteria for selection of the best practices from an environmental perspective. Essentially, LCA is the primary tool utilized in decision making for sustainable development. One of the key advantages of the cradle to grave approach taken by LCA is that it allows consideration of significant environmental impacts that are overlooked by other methods.

LCA in Fisheries

Internationally, in fisheries, LCA has been utilized not only for the assessment of the environmental impacts of gears and crafts but also as a method to assess the impacts of fishing on specific fisheries such as flatfish or cod fisheries. Additionally, LCA has also been extended to aquaculture concerns.

At its core, LCA analysis follows three stages – Goal definition, Inventory analysis and Impact assessment that feed into an interpretation stage. As the information regarding these are collected, the recursive approach favoured for LCA methodologies allows these three stages or steps to be redefined or re-contextualized as the assessment proceeds.

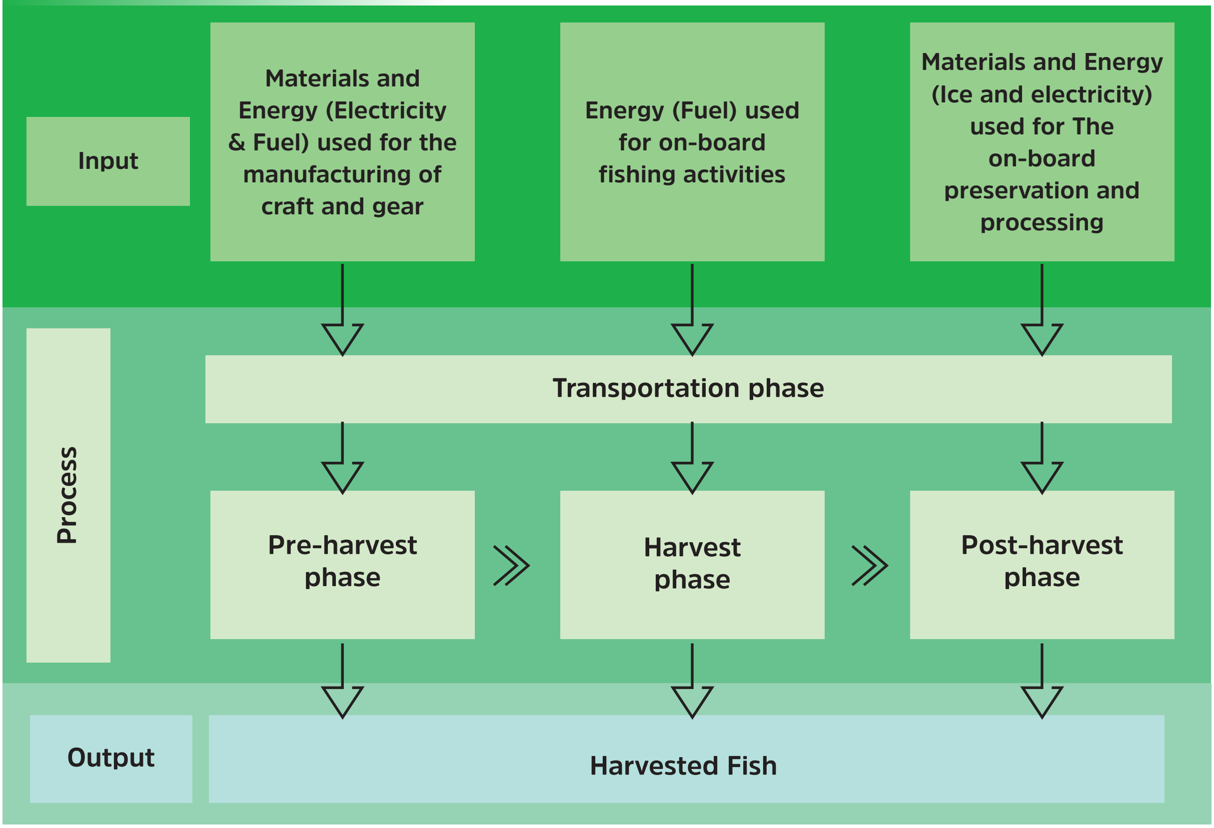
As LCA is considered a ‘cradle to grave’ approach for the assessment of the environmental impact of goods and their production, all stages of the manufacture, usage and disposal must be considered.

On a more concrete level, in order to calculate these emissions concomitant to these stages, three main sectors are considered – inputs, processes and outputs. With regards to fisheries, as considered for the present study, this is diagrammatically represented in fig. 1.

LCA vs Carbon Footprint

LCA and carbon footprint differ on the basis of the impact categories studied. While carbon footprint is focused on one environmental impact category–greenhouse gas (particularly CO_2) emissions, an LCA considers more impact categories, such as land use, water use and ocean acidification. Carbon footprint analysis is a subset of a complete life cycle assessment of a product, activity, or process (ICAEW, 2021). Thus, assessing the carbon footprint forms an integral part of an LCA framework. Excessive carbon emissions pose serious threats to the environment, necessitating a shift towards carbon neutrality for sustainable progress (Li et al., 2022). The marine fishing industry has a huge carbon sink potential and is also an important source of carbon emissions (Guan et al., 2022). To effectively pursue carbon neutrality, a comprehensive evaluation of carbon emissions from marine fisheries is imperative (Li et al., 2022).

There are several studies where environmental impact has been assessed through LCA approach in aquaculture production systems (Papatryphon et al., 2004, Aubin et al., 2006; Gronroos et al., 2006; Pelletier and Tyedmers, 2007; Pelletier et al., 2009; Ayer and Tyedmers, 2009; Pelletier and Tyedmers, 2010; d'Orbcastel et al., 2009; Aubin et al.,



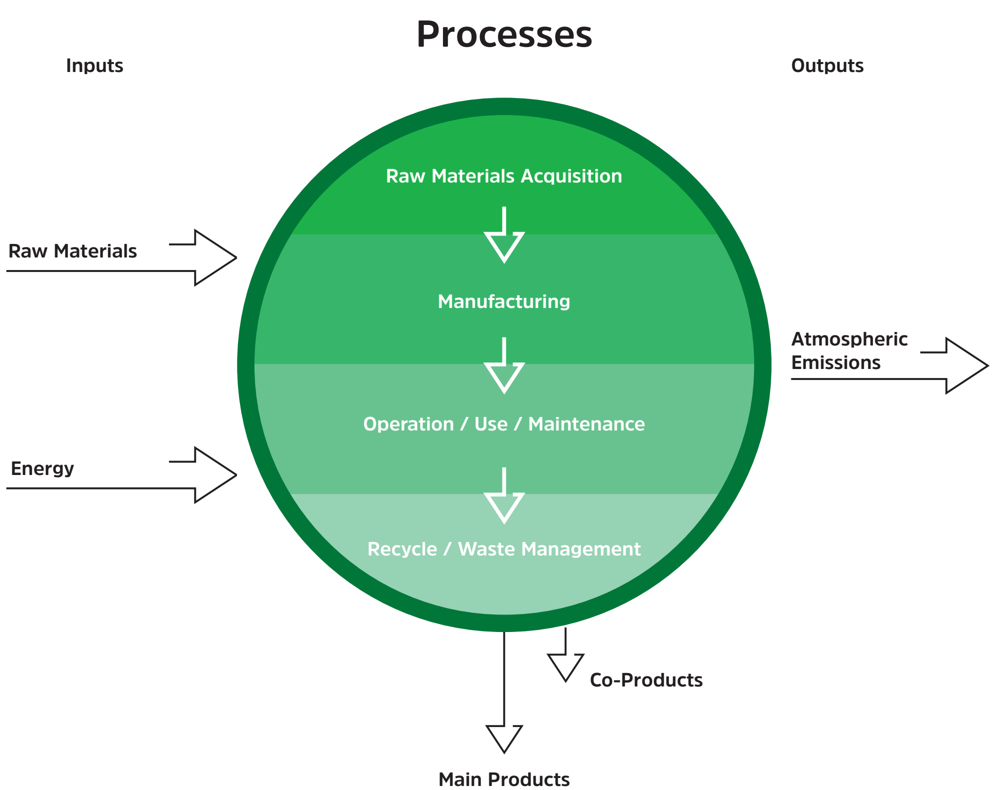


Fig.1. Defining the input, process, output and system boundary for the present carbon footprint study

2009; Iribarren et al., 2010; Phong et al., 2011; Jerbi et al., 2012; Samuel-Fitwi et al., 2013; Smárason et al., 2017; Abdou et al., 2017; Kallitsis et al., 2020; Sherry and Koester, 2020), and in capture fishery production systems (Ziegler et al., 2003; Hospido and Tyedmers, 2005; Thrane, 2006; Ziegler and Valentinsson, 2008; Ziegler et al., 2009, 2011; Ramos et al., 2010, 2011; Vázquez-Rowe et al., 2010, 2011 & 2012; Svanes et al., 2011; Ghosh et al., 2014; Ravi et al., 2020; Li et al., 2022). There are also studies where the LCA in seafood production systems have been compared across the different production systems (Ellingsen and Aanondsen, 2006; Ellingsen et al., 2009; Ziegler and Hilborn, 2023) and has been well reviewed (Ayer et al., 2006; Pelletier et al., 2006; Henriksson et al., 2012; Nijdam et al., 2012; Avadí and Fréon, 2013; Bohnes et al., 2018; Philis et al., 2019; Ghamkhar et al., 2020).

In this book, we present a detailed account of the carbon footprint assessment of India's marine fisheries based on fuel consumption data gathered from trawl, gillnet and purse seine operations from major harbours and landing centres in all the maritime states of the country. We hope that the results of this study will help in decoding the carbon footprint of India's marine fisheries across the different operational sectors and enable implementation of suitable mitigation measures related to management and to alleviate the role of the industry in furthering climate change.

Approach

The environmental impact of marine capture fisheries in India was assessed using an ISO standardized Life Cycle Assessment (LCA) approach (ISO 14040: 2006) following the specific guidelines updated for the carbon footprint study (ISO 14067: 2018). The term 'life cycle assessment' implies the identification and environmental impact assessment of all the different phases required for or caused by a product or process which include raw material, energy used and emissions produced during production, transportation, use and waste disposal (Jerbi et al., 2012). Often, the LCA study is conducted only to assess the global warming potential (GWP) by quantifying the greenhouse gases, and in such a situation the method is often referred to as carbon footprinting (CF) which is conducted following the LCA-specific guidelines (BSI, 2008; Nijdam et al., 2012). The study is conducted in four interrelated steps: (1) definition of the goal and scope of the study which defines the purpose, audiences and system boundaries of the study; (2) life cycle inventory which is the collection of data that defines all relevant inputs and outputs of energy, mass and emission flow for each unit process; (3) life cycle impact assessment consisting of three mandatory elements, i.e., (a) categorization which is the selection of appropriate impact categories (e.g. global warming potential and/or acidification potential and/or eutrophication potential etc.) according to the objective of the study, (b) classifications which is the assignment of life cycle inventory data to the selected impact category according to the available scientific knowledge on the cause-effect relationship between environmental interventions and the effect of impact categories (release of CO_2

to global warming potential, release of SO_2 to acidification potential, release of PO_4 to eutrophication potential etc.) and (c) characterization which is the assessment of impact by multiplying the inventory data by a characterization factor; and (4) the final step, i.e., result analysis, interpretation and recommendation that identifies significant issues based on analysis, evaluates the results to formulate recommendations so that the issues can be addressed (d'Orbcastel et al., 2009; Finnveden et al., 2009; Phong et al., 2011; Jerbi et al., 2012; Samuel-Fitwi et al., 2013).

Definition of the Goal and Scope of the Study

The present study was conducted to get an estimate of the carbon footprint of marine capture fisheries in India. The study was conducted with the following objectives, i.e., (1) to assess the carbon footprint of dominant fish capture (production or harvesting) methods; (2) to assess the carbon footprint of different phases of fish capture production; (3) to assess the carbon footprint of all the maritime states of India; and (4) to compare different categories of classification for identifying the most contributing input and process for the carbon footprint and exploring the possibilities of mitigation. The study was envisaged to create awareness among the stakeholders (fishermen, fisheries managers, seafood exporters, researchers and policymakers *etc.*) about the probable environmental impact of various fisheries activities.

To define the goal, scope, assumption and limitations of the study which include system boundary, impact categories, functional unit(s) and the method of allocation, it was assumed that different fishing methods produce different amounts of carbon footprints depending on the efficiency of production or harvesting method. Therefore, the study was conducted for four dominant categories of fish capture (production or harvesting) methods prevalent in the region, i.e. mechanized single day trawling, mechanized multiday trawling, mechanized multiday gillnetting and mechanized multiday bagnetting (locally known as 'Dolnet'). Each of these fish capture methods was sub-categorized into three main phases, i.e., (1) the pre-harvest phase, (2) the harvest phase and (3) the post-harvest phase all of which had an integrated (4) transportation phase.

Although the LCA study should cover activities from "cradle to grave", in the present study, the carbon footprint during offshore transportation as well as consumption of the produce (captured fish) was not included in the assessment and therefore, the system boundary for the present study is a typical "cradle to gate" approach (Guinée et al., 2001; Ramos et al., 2011). Only one indicator of the global level impact category, i.e., the global warming potential (GWP) of marine capture fisheries-related activities has been used for the present study. Other global-level indicators such as net primary product use (NPPU) and energy use (EU) have not been considered in the present analysis. None of the regional-level impact categories such as eutrophication potential (EP), acidification potential (AP), land use (occupation) etc. have been assessed in the present analysis. The functional unit (FU) relates the environmental impact to the production system and helps in the comparison of impacts across the different systems. In the present study, the '1 kg wet weight' of harvested fish has been used as a functional unit (FU) to assess and compare the environmental impact of marine capture fisheries-related activities from different fishing methods. The global warming potential (GWP), i.e., 'CO_2e' for each of the sub-categories was assessed by multiplying the inputs (material and/or energy) of every unit process inside the system boundary with the appropriate emission and conversion factors and finally adding them together to arrive at the total CO_2e for each of the harvesting methods which is subsequently divided with the system output, i.e., biomass (in kg) of fish harvested to express the carbon footprint of the product (fish) from the process (harvesting methodology) as CO_2e per kg of fish. The carbon footprint from the transportation phase was considered an integral but variable input phase as it varies depending on the distance of transportation. It is also important to mention the components that have not been included in the system boundary of the present study. The fugitive emission, i.e., emission of the greenhouse gas produced from the coolant during the production of ice for onboard preservation as well as during the frozen preparation of the produce in the processing plant was beyond the scope of the present study. Similarly, the carbon footprint from the discarded fish catch was ignored in the study due to the operational difficulties in arriving at the actual quantity discarded. The other input parameters such as the metallic assembly components, machinery for propulsion, ice and processing plant equipment, anti-fouling agents, marine lubricant oil and other chemicals utilized inside and outside the fishing vessels, utilization of freshwater during various harvest phases, waste treatment and disposal along with domestic transportation of the inputs and outputs between places were also not included in the study.

Inventory Preparation

One of the fundamental requirements of the LCA or carbon footprint study is to collect the required input and output data of the activities/processes involved in the fishery. To estimate the fishing effort and fuel usage by different fishing units, the units were categorized into single day operating trawlers, multiday operating trawlers, single day gillnetters, multiday gillnetters, single day dolnetters and longliners, multiday dolnetters and longliners, purse seines, ring seines, other motorized crafts and non-mechanized crafts. The entire marine capture fisheries activities for the four dominant fish harvesting methods, i.e. mechanized single day trawling, mechanized multiday trawling, mechanized multiday gillnetting and mechanized multiday bagnetting (locally known as 'dolnet') were categorized into the following four phases of production with differential amounts of material and energy requirements which are summarized as follows:

Phase-1: The carbon in the pre-harvest phase is mainly contributed by the input materials such as fishing craft and gear required for the fishing activity. The craft or boat building materials include wood, steel, fibre-reinforced plastic (FRP), iron and other metal accessories. The energy usage such as electricity and fossil fuel (diesel and petrol) consumption during craft building was meticulously recorded. The annual consumption (for both new and repair) of commonly used gear and rope building materials such as high density poly-ethylene (HDPE), poly-propylene (PP) and poly-amide (PA) was recorded.

Phase-2: The carbon emission in the harvest phase is mainly contributed by the combustion of fossil fuels (mainly diesel) for both cruising activity to reach the fishing ground and onboard fishing activities.

Phase-3: The carbon emission in the post-harvest phase is mainly contributed by the energy (electricity) used for the production of ice for the onboard preservation of output (fish catch) as well as for the subsequent frozen processing of the catch by the processing plants.

Phase-4: The transportation phase was identified as an integral variable phase involved in each phase of the above mentioned three production phases. It changes according to the distance of transportation and the carbon emission in this phase is mainly contributed by the combustion of fossil fuels (mainly diesel) for transportation.

The data inventory was prepared through on-site monitoring, questionnaires and interviews with different stakeholders. The amount of materials required for the construction of fishing crafts and gears was inquired from the manufacturers. The fish catch potential of different crafts and gears used in the analysis were the annual averages of the last 10 years' catch information acquired through multi-stage stratified random sampling. The information about the quantity of ice and fuel used by different crafts for onboard storage and fishing was obtained from the boat manager and the ice consumption was validated with the ice manufacturers and suppliers. Information on power consumption for post-harvest storage and processing was obtained from Ice plants and processing plants. Similarly, drivers from different categories of transportation vehicles were interviewed to collect the data on transportation phase.

Impact Assessment

According to Aubin et al. (2009), the environmental impact at the global level can be categorized as global warming potential (GWP), net primary production use (NPPU) and energy use (EU) whereas, the impact at the regional level is estimated as eutrophication potential (EP), acidification potential (AP), water dependence (WD) and surface use (SU). The process inputs involved in different phases of marine fisheries activity produce a certain amount of greenhouse gases (GHGs) and thus contribute to global warming. The greenhouse effect is a process by which thermal radiation from a planetary surface is absorbed by atmospheric greenhouse gases (GHGs), resulting in an elevation of the average surface temperature (Claussen et al., 2001). The global warming potential (GWP) of all the GHGs is not equal, rather it depends on radiative forcing and the average time for which that gas molecule stays in the atmosphere. Therefore, the GWP of GHGs in a 100 year time frame was calculated as a relative measure of the warming effect they can produce in comparison to a functionally equivalent amount or concentration of carbon dioxide (Goedkoop and Oele, 2003). In the present study, carbon dioxide equivalent (CO_2e) has been used as a unit to express the GWP of marine capture fisheries for a 100 year time frame (Gerber et al., 2010; Buchspies et al., 2011). In this step, the system input data such as craft and gear construction materials and fuel used for fishing, energy used for ice during onboard storage and electricity used for frozen processing of the harvested fish (Fig. 2) were converted to an environmental indicator, i.e. 'CO_2e' using standard conversion factors following the guidelines specified by the Department for Environment, Food and Rural Affairs (Defra) and the Department of Energy and Climate Change (DECC), UK (Defra-DECC, 2012) consistent with the Kyoto Protocol and the assessment report of

the Intergovernmental Panel on Climate Change (IPCC). However, a negative carbon footprint of 1.2 kg of CO_2e per kg of wood was used following the recommendations of Abbott (2008). Wood acts like a carbon sink as trees accumulate carbon during photosynthesis and therefore shows a negative carbon footprint when used as a construction material in place of other materials like FRP, PVC or concrete etc. Though it releases a huge amount of carbon during combustion, it is considered as a carbon sink when used as a building material due to its carbon sequestration history. To determine the environmental impact, the environmental indicator was divided by the system output, i.e. total fish catch (kg) and expressed as 'kg CO_2e kg^{-1} fish' produced.

Analysis and Interpretation

This is the final step in which general conclusions about the environmental impact categories and the system processes that contributed the most are drawn from the results of the impact assessment. In this step, the environmental impact (carbon footprint) of the different phases of production was compared to assess the most carbon contributing phase in the production system. Similarly, the carbon footprints from different fishing methods as well as from different maritime states were also compared. The Indian carbon footprint was also compared with internationally reported values to assess the GWP status of Indian marine fisheries compared to the global fisheries.

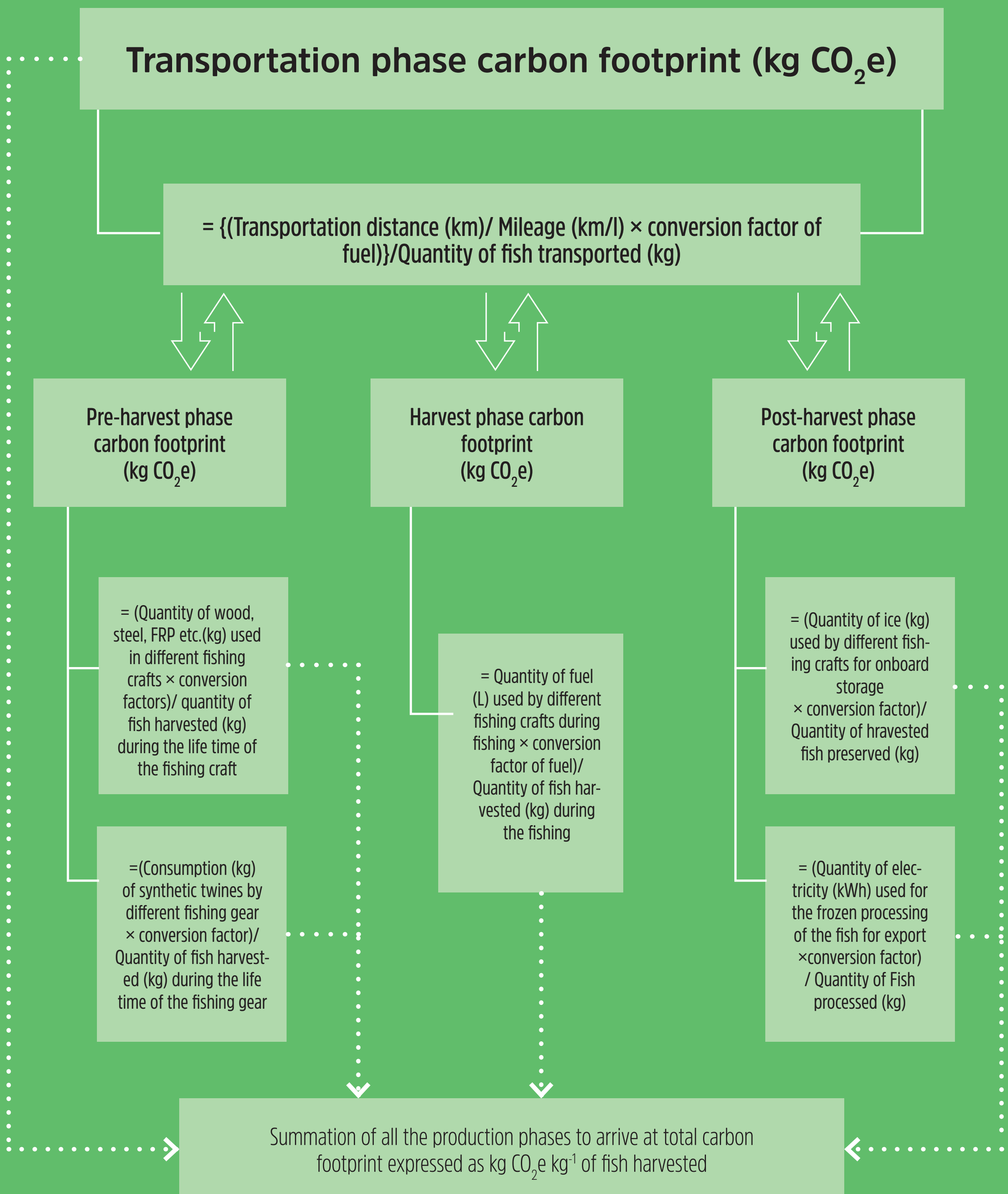


Fig.2. Schematic diagram showing the assessment framework used to calculate the carbon footprint from marine capture fisheries of India

Results

The carbon footprint of capture fisheries refers to the total amount of greenhouse gases (GHG) emitted in the process of harvesting one kilogram of fish, expressed in terms of carbon dioxide equivalent (CO_2e). This includes GHG emissions from various stages such as boat building, net fabrication, fish catch, processing, ice plants, and even fish consumption. To conduct this study, GHG emissions were mapped across various fishing harbours in all maritime states for the period between 2012 and 2022. The study relied on survey schedules developed at the national level to collect data for analysis.

The data schedule used for the analysis is attached as an annexure. Veraval in Gujarat, Mumbai in Maharashtra, Panaji in Goa, Mangalore and Malpe in Karnataka, Kochi in Kerala, Karaikal in Puducherry, Chennai in Tamilnadu, Visakhapatnam and Nizampatnam in Andhra Pradesh, Puri in Odisha and Digha in West Bengal were selected for the survey.

Multiday trawl life cycle

Pre-harvest studies were conducted by surveying boat-building yards and net fabrication yards. To determine the diesel consumption by boat building yards, data were collected on the materials used, the transportation of the material from the source, as well as the electricity and fuel required for the manufacturing of boat building materials such as steel and net materials such as nylon or HDPE. The estimated diesel consumption for mechanized boat building yards was collected, and the resulting carbon footprint for fuel combustion was calculated. This value was then extrapolated to the total number of manufacturing units.

To calculate the fuel used to construct new boats and the replacements made, data were gathered from the Marine Fisheries Census 2016 to determine the actual number of fishing units in operation within the state. The survey recorded many fishing nets used for different types of fishing, including trawlers, gillnetters, motorized crafts, and non-mechanized crafts. Additionally, the electricity consumption per kilogram of net fabrication for different categories of fishing operations was recorded. The carbon footprints for the electricity consumed and the diesel consumption were estimated.

The calculation used for the conversion of energy consumption and carbon footprint in boat building yards in Chennai Fishing Harbour and the estimation of the carbon footprint of fishing nets in Veraval, Gujarat, are given as examples (Table 1 and 2)

In the harvest phase, ice was found to be an essential component for the fishing activities. The survey helped in understanding and quantifying the ice requirements for each fishing vessel based on their specific operation. Additionally, data were collected on the number of ice plants that cater to the needs of fishing vessels in the state. In most fishing harbours, an agreement exists among ice plant owners and fishermen associations to supply ice only to the fishers of a particular harbor. Data on ice requirements were collected from well-documented registers wherever such agreements were in place.

Table.1. Energy consumption and carbon footprint calculated for the boat building yards in Chennai Fishing Harbour

Sector	Energy consumed		Carbon footprint (Milllion kg CO_2e)		
	Electricity consumption (lakh kWh)	Diesel consumption (lakh l)	By electricity	By diesel	Total emitted
Trawler	1.98	0.43	0.1	0.11	0.21
Gillnetter	0.34	0.32	0.018	0.085	0.103
Mechanized	2.32	0.75	0.12	0.2	0.32
Motorized	0.3	0.33	0.015	0.089	0.104
Total	2.62	1.08	0.14	0.29	0.43

Table.2. Estimated carbon footprint of fishing net manufacturing in Veraval, Gujarat

Net type	Netting material	Weight/net	Annual consumption (Net)	kg CO_2y^{-1}	Catch (kg)/boat	kg CO_2 emitted/kg fish
Trawl net-single day	HDPE & PP	70-90	3-6	1143.35 ± 216.07	114433.56	0.010 ± 0.002
Trawl net-single day	PA & PP	70-90	3-6	1672.37 ± 49.07	114433.56	0.015 ± 0.003
Trawl net-multi day	HDPE & PP	110-140	5-9	2522.33 ± 415.98	120967.65	0.021 ± 0.004
Trawl net-multi day	PA & PP	110-140	5-9	3481.84 ± 93.98	120967.65	0.029 ± 0.001
Dolnet	HDPE & PP	80-110	4-6	1369.14 ± 158.19	109576.38	0.012 ± 0.002
Dolnet	PA & PP	80-110	4-6	1890.12 ± 35.71	109576.38	0.017 ± 0.003

The conversion of HDPE, PP and PA to carbon dioxide equivalent is done by multiplying with the standard conversion factor viz. 2.789, 3.256 and 4.16 kg CO_2e kg^{-1} material consumed)

To estimate the carbon footprint, the electricity consumption for manufacturing ice blocks used for fishing voyages was converted to equivalent carbon emissions in kg CO_2e. Diesel consumption for water transportation during ice production and transportation to the harbor was calculated to account for their contribution to carbon emissions.

As an example, the method used to estimate the carbon footprint of ice for onboard fish preservation in Veraval, Gujarat is given in Table 3.

The COVID-19 pandemic caused significant disruptions in the fishing industry, resulting in several units becoming non-operational due to various factors. Hence, in this study, the fishery data for the fishing phase during the pre-COVID period of 2017 served as the baseline for catch data. Gear-wise data on fish landed in 2017 was used to calculate the carbon emission per kg of fish.

Table 3. Estimated carbon footprint of Ice due to onboard fish preservation in Veraval, Gujarat

Boat type	Mean CPH	Fishing duration (H)	Catch (kg)/ day	Ice (kg)/day	kg Ice consumed/kg Fish for onboard preservation	kg CO_2e due to Ice/kg Fish onboard preservation
Trawler-single day	59.60	8	476.81	240.00	0.503	0.230
Trawler-multiday	63.00	8	504.03	425.00	0.843	0.384
Gillnetter-single day	12.46	8	99.70	25.00	0.251	0.114
Dolnetter	76.09	6	456.57	400.00	0.876	0.400

Conversion of ice to Carbon dioxide equivalent is achieved by multiplying with conversion factor (0.562) as given in the methodology

Multiday vessels typically use LPG cylinders for cooking food during fishing trips. The estimated carbon footprint for gas consumption by multiday units, especially trawlers, was also calculated and added to the carbon footprint of the harvest phase in the respective multiday units.

In the post-harvest phase, the study was done on the total number of wholesale, retail, and terminal facilities at each fishing harbour, to estimate the carbon footprint associated with fish distribution. Transportation of catch to other states was also accounted for in the present study.

Calculation of the post-harvest phase's carbon footprint involved the carbon emissions resulting from the combustion of diesel used for fish distribution to various markets, as well as the electricity consumed across multiple fish markets. An example of the carbon footprint for fish distribution to different markets in Chennai is provided in Table 4.

The carbon footprint of fishing refers to the total amount of greenhouse gases (GHG) emitted, measured in carbon dioxide equivalent (CO_2e) per kilogram of fish harvested. This calculation involves a life cycle assessment that takes into account only the emissions that contribute to climate change. Typically, the use of fuels in fishing boats results in the release of carbon dioxide (CO_2) as well as small amounts of other GHGs like methane (CH_4) and nitrous oxide (N_2O). To determine the CO_2e of these emissions, their "global warming potential" is used to calculate the equivalent amount of CO_2 needed to produce the same greenhouse effect. This is measured in kilograms of carbon dioxide equivalent (kg CO_2e) units. Standard conversion factors were used for fuel and electricity as described in the methodology. In the case of diesel, the conversion factor used is 2.6676 kg CO_2e for using one liter of diesel adapted from Defra (2012). In the case of petrol, the emission factor is 2.3117 kg CO_2e for one liter of petrol. In the case of electricity, it is 0.5246 kg CO_2e for one unit (1 kWh) of electricity consumed (Defra 2012).

Table 4. Carbon footprint for fish distribution to different markets in Chennai

	Diesel consumption (lakh litres)					Electricity consumption (Lakh kWh)	Carbon footprint (Milllion kg CO_2e)		
Particulars	Local	Outside Chennai	Dry fish	Processed	Total		by diesel	by electricity	Total
Trawl fish marketing	14.70	1.28	0.40	8.28	24.66	1.01	0.66	0.05	0.71
Gillnet fishes marketing	0.27	12.16	0.21	0.00	12.65	0.39	0.34	0.02	0.34
Mechanized fish distribution	14.97	13.44	0.61	8.28	37.31	1.40	1.00	0.07	1.05
Motorized fish distribution	2.06	0.25	0.00	0.00	2.31	0.022	0.06	0.0012	0.06
Total	17.03	13.70	0.61	8.28	39.62	2.82	1.06	0.07	1.11

The emission in the case of the ice bar was calculated based on the average consumption of electricity for the production of a fixed quantity of ice per month, and this electricity was converted into carbon dioxide equivalent using the conversion factor of 0.5246 kg CO_2e for one unit of electricity. The average requirement of electricity for producing an ice bar of 50 kg was worked out as 2.147 kWh and 1 kWh. Unit of electricity releases 0.5246 kg CO_2e, and the release of GHGs due to the production of one ice bar was worked out as 1.126 kg CO_2e. In the case of vehicles, the quantity of fuel used by a vehicle was converted into GHGs using the conversion factors. It was then multiplied by the total number of vehicles. The emissions from pre-harvest, harvest, and post-harvest phases were summed up for total carbon footprint estimation. Overall analysis showed that more than 90% of the fuel consumption and GHC emission is in the harvest phase (Fig. 3 and 4).

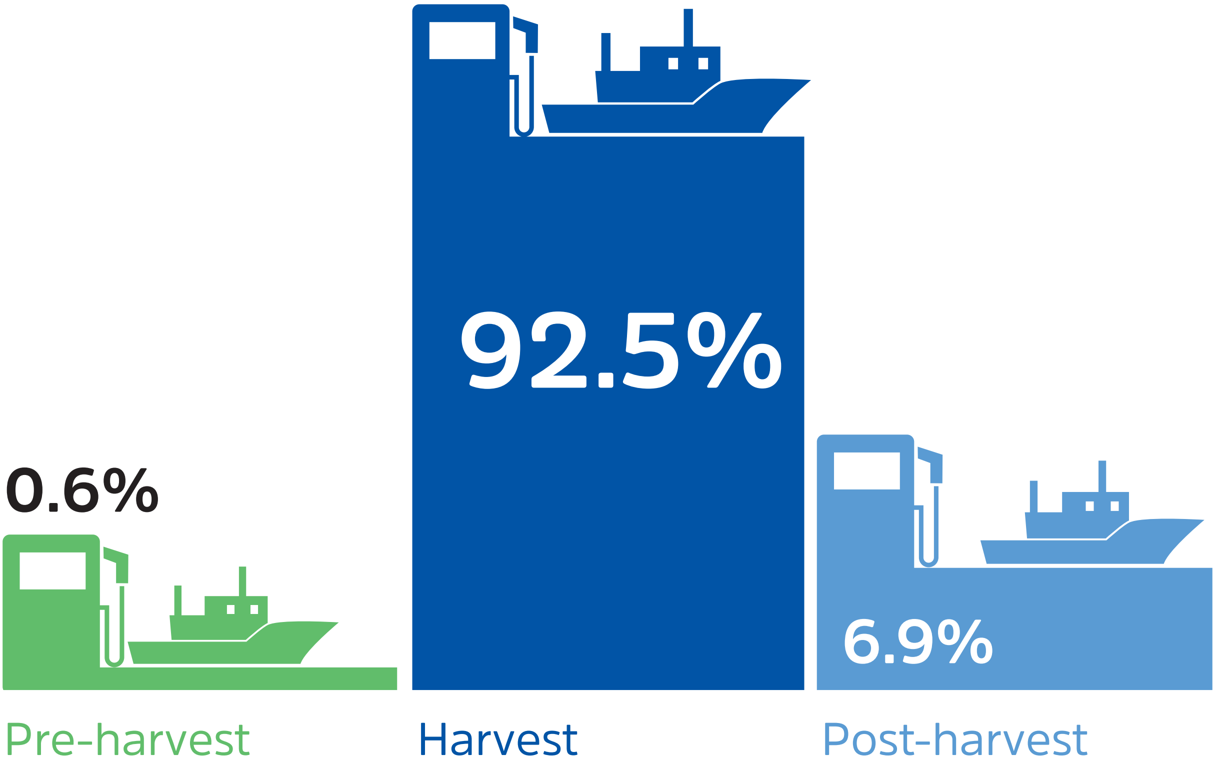


Fig.3. Fuel consumption in different phases of fishery.

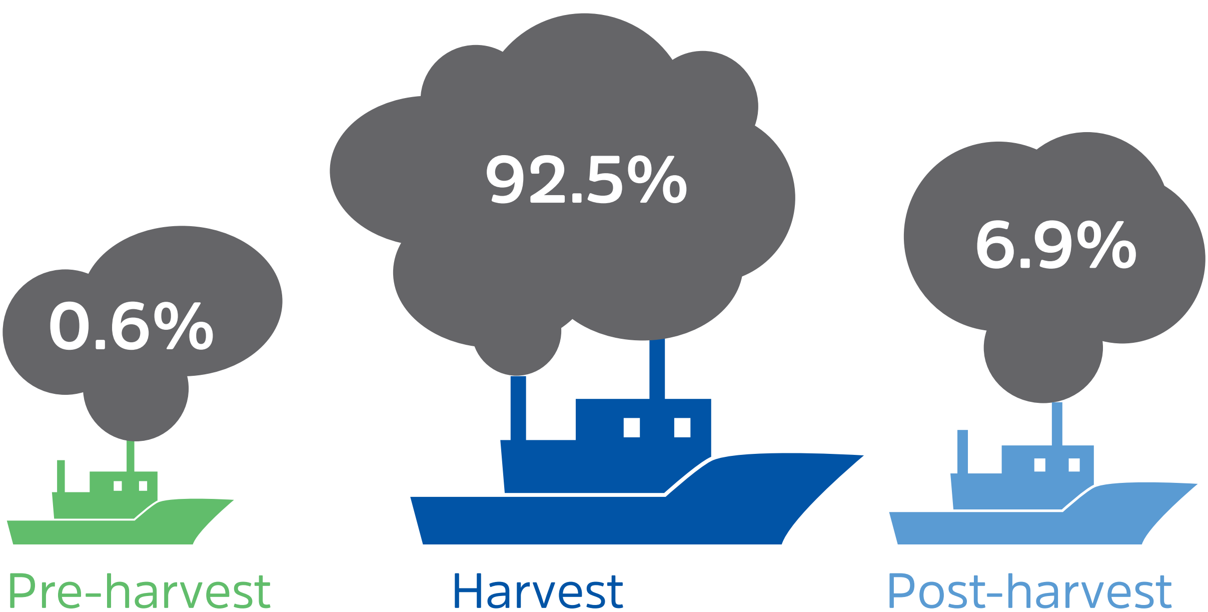


Fig.4. GHG emission in different phases of fishery.

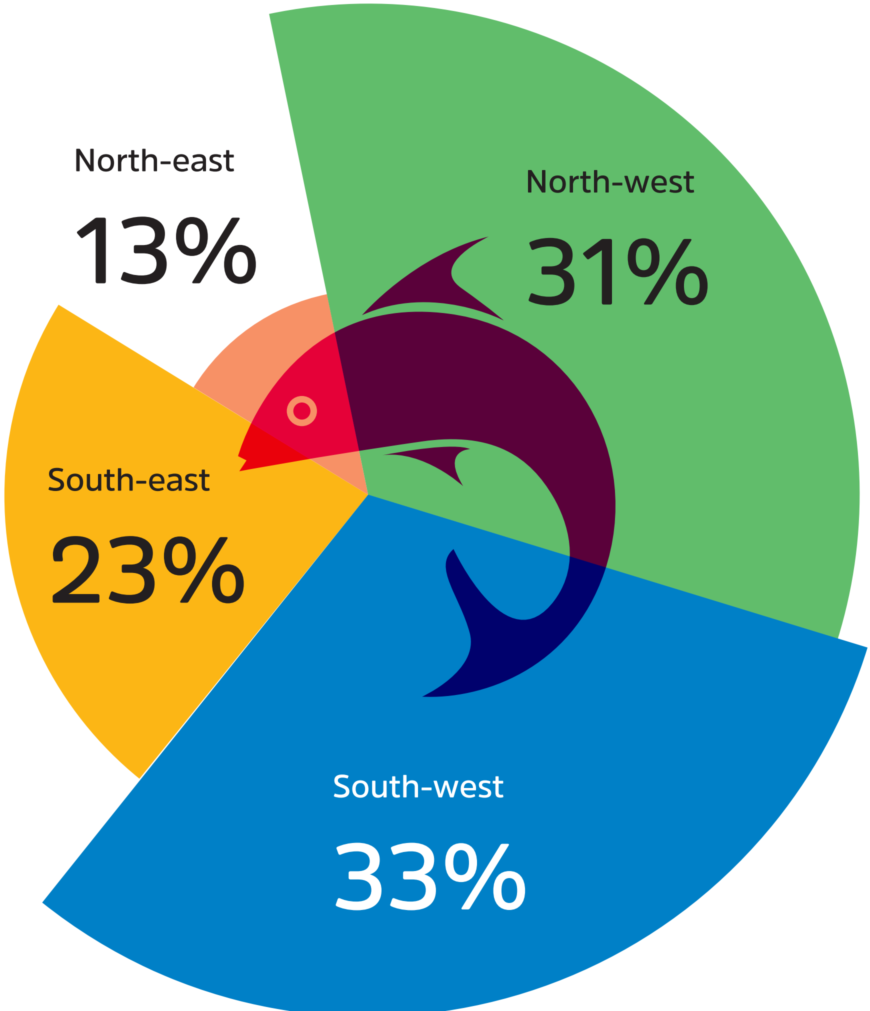


Fig.5. Region-wise proportion of marine fish landings in India

Zonal Analysis

Since fishery operations were extended horizontally and vertically, multiday operating fishing vessels carry out fishing operations far and wide. Hence, the landings in a state is not necessarily the fish caught in the waters of that state. Spatial studies of Indian marine fisheries (Dineshbabu et al, 2017, Mohammed et al, 2018) also emphasized need for zonal fishery regulation bodies to effectively implement the fishery regulations in India. In light of these recommendations, detailed zone-wise emission status was derived in the present study. For getting a zonal figure following the agro-climatic classification detailed by Vivekanandan (2011), Gujarat and Maharashtra were classified as North-west (NW); Kerala, Karnataka and Goa were as South-west (SW); Tamilnadu, Puducherry and Andhra Pradesh as South-east (SE), and Odisha and West Bengal as North-east (NE). The results of the zonal analysis are given in Table 5-8.

Table 5. Performance of the marine fisheries sector from the North-west coast of India, in terms of carbon dioxide equivalent gas emission

	Gujarat		Maharashtra		North-west coast of India	
	Mechanized sector	Total marine fishery sector	Mechanized sector	Total marine fishery sector	Mechanized sector	Total marine fishery sector
Fishing units	14601	27642	4681	12657	19282	40299
Total catch (t)	738544	786494	379201	383427	1117745	1169921
Pre-harvest CO_2(t)	14005	35012	10263	12828	24267	47840
Harvest CO_2(t)	839715	990850	474878	509826	1314592	1500676
Post-harvest CO_2 (t)	1185	11852	6336	7586	7521	19437
Total CO_2(t)	854905	1037714	491476	530240	1346381	1567953
CO_2e emission per kg of fish caught	1.16	1.32	1.30	1.38	1.20	1.34

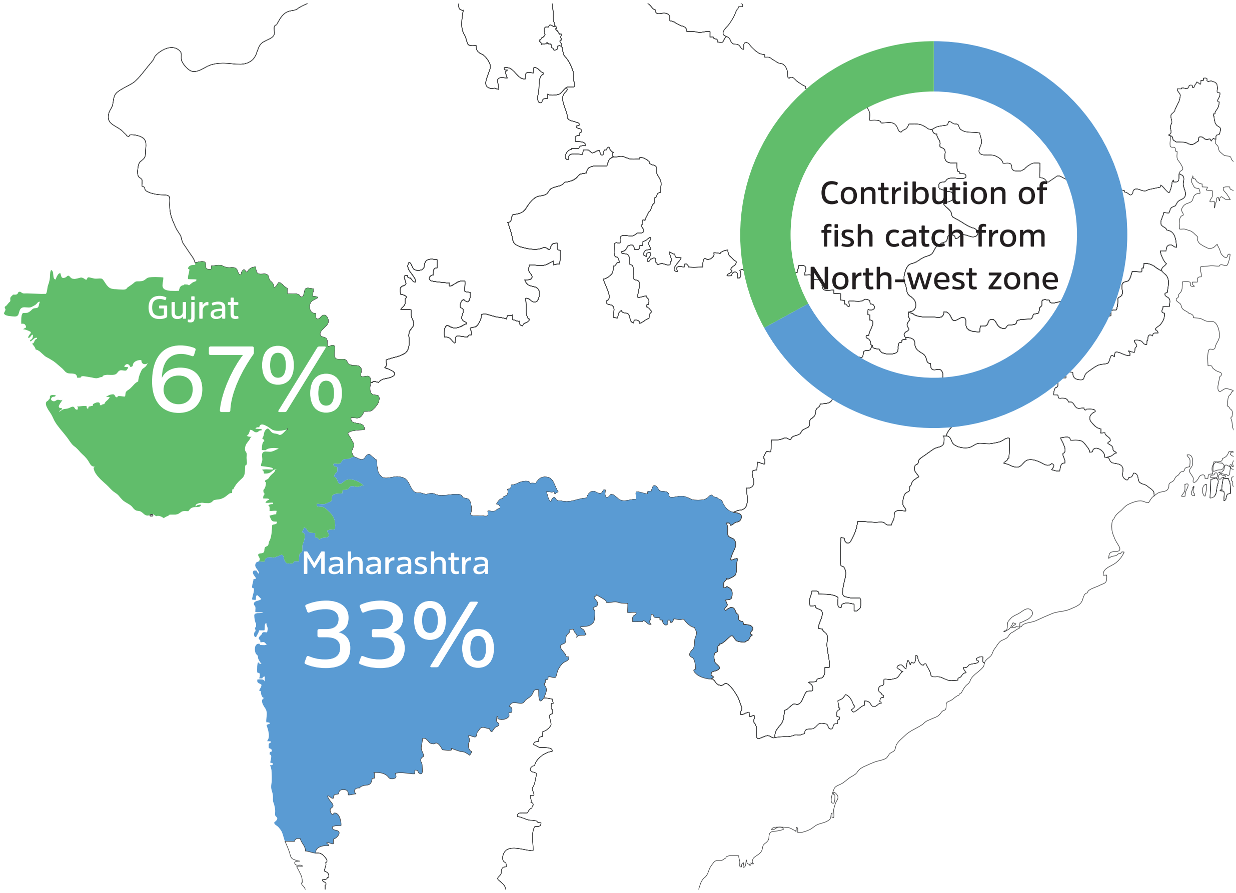
Table 6. Performance of the marine fisheries sector from the South-west coast of India, in terms of carbon dioxide equivalent gas emission

	Kerala		Karnataka		Goa		South-west coast of India	
Sector	Mechanized sector	Total marine fishery sector	Mechanized sector	Total marine fishery sector	Mechanized sector	Total marine fishery sector	Mechanized sector	Total marine fishery sector
Fishing units	3800	21684	3810	11884	606	1730	8216	35298
Total catch (t)	428000	584683	507684	547784	87863	100175	1023547	1232642
Pre-harvest CO_2 (t)	8001	10257	3138	3922	1385	1731	12524	15910
Harvest CO_2(t)	698152	913063	660090	746054	47871	67197	1406113	1726314
Post-harvest CO_2 (t)	125806	161289	53933	61592	12463	13848	192202	236729
Total CO_2(t)	831958	1084609	717160	811569	61719	81830	1610839	1978953
CO_2e emission per kg of fish caught	1.94	1.86	1.41	1.48	0.70	0.82	1.57	1.61

North-west Zone

North-west zone has one of the most productive waters along Indian coast with a variety of fishery resources, craft-gear combinations and fishing operations. Among the mechanized fishing sector, trawl fishery was the dominant contributor. Gujarat contributes two thirds of the fishery production from this zone.

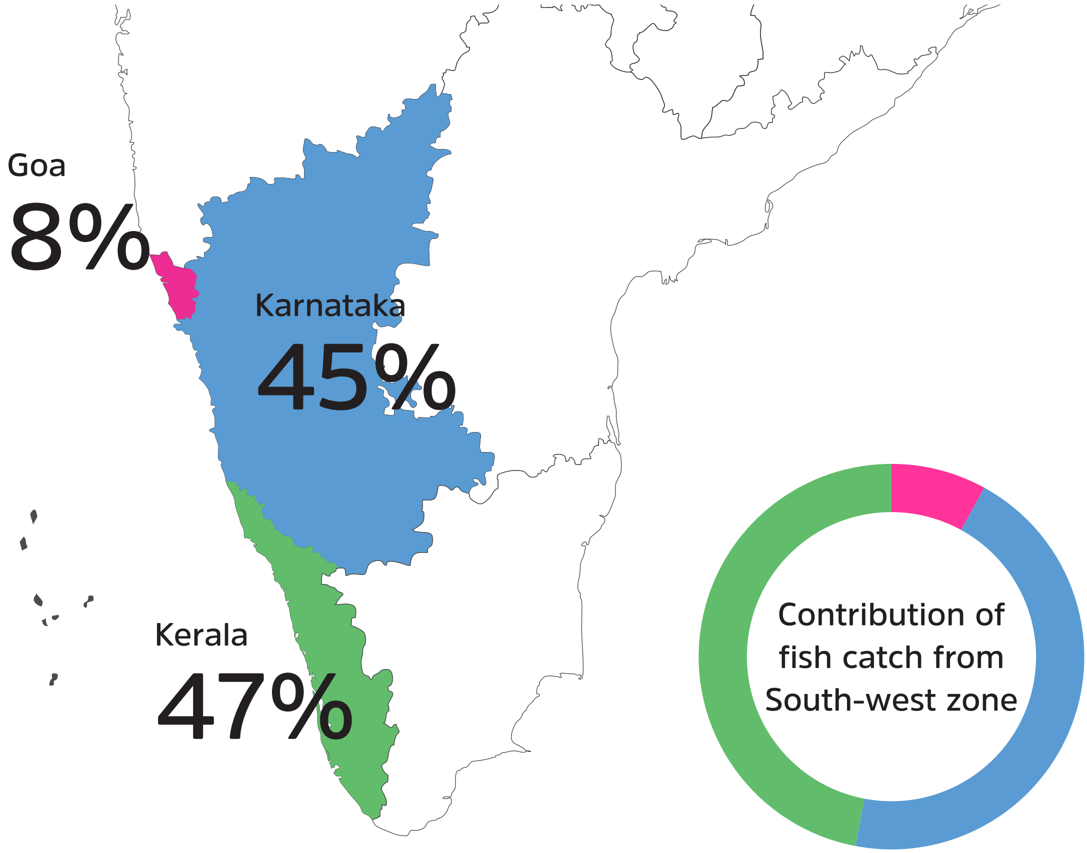
As there are no restrictions in landing of low-value bycatch, huge landings of non-penaeid shrimps were landed in Gujarat. In Maharashtra, in most of the landing centres, landing of low-value bycatch was restricted. Unlike other zones, dolnet fishery contribute substantially in this zone. The emission of CO_2e from marine fisheries of Gujarat and Maharashtra were 1.32 and 1.38 kg respectively with an average emission of 1.34 kg CO_2e per kg of fish from the fishing related operations from NW coast.



South-west Zone

South-west zone contributed 33% to the marine fish production in India. Among the mechanized fishing sector, trawl fishery was the dominant contributor in Kerala and Karnataka. Kerala has huge contribution of pelagic fishes from ring seines and in Karnataka mechanized purse seines contribute substantially. The contribution of the fishery from Kerala and Karnataka was almost equal, 47% and 45% respectively.

When compared to Kerala, there was a higher landing of low-value bycatch in Karnataka in trawl fishery, which was the major reason for lower emission per kg from Karnataka. In Goa, the contribution of the catch was mainly by the pelagic species caught in good quantities lowering the rate of emission per kg of fish. The emission of CO_2e from marine fisheries of Kerala, Karnataka and Goa were 1.86, 1.48, and 0.82 kg respectively with an average emission of 1.61 kg CO_2e per kg of fish.

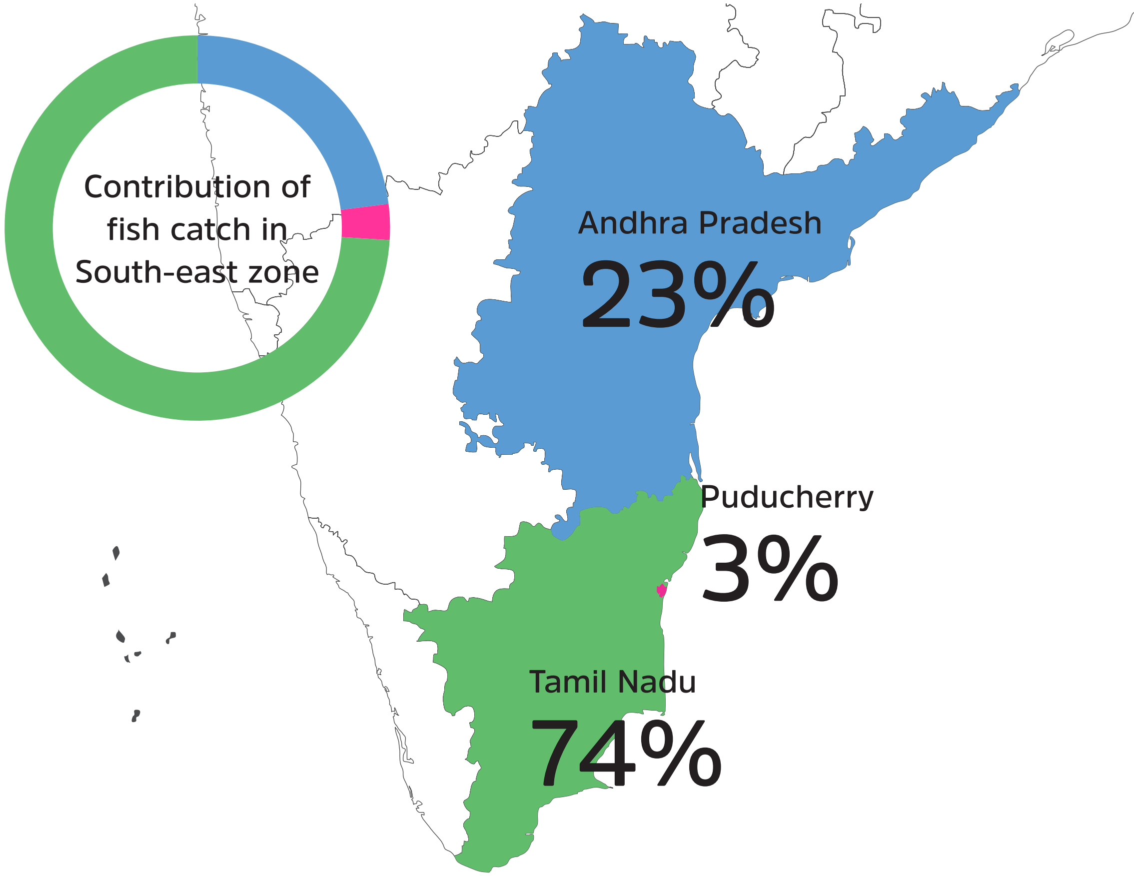


South-east Zone

The South-east zone contributed 23% to the marine fish production in India. Tamil Nadu was the major contributor to the fishery of the South-east zone (74%). The emission of CO_2e from marine fisheries of Tamil Nadu, Andhra Pradesh, and Puducherry were 1.46, 1.69, and 1.89 kg respectively, with an average emission of 1.51 kg CO_2e per kg of fish.

Table 7. Performance of the marine fisheries sector from the South-east coast of India, in terms of carbon dioxide equivalent gas emission

	Tamil Nadu		Andhra Pradesh		Puducherry		South-east coast of India	
Sector	Mechanized sector	Total marine fishery sector	Mechanized sector	Total marine fishery sector	Mechanized sector	Total marine fishery sector	Mechanized sector	Total marine fishery sector
Fishing units	5961	43255	1176	20219	301	2319	7438	65793
Total catch (t)	490841	646286	92654	199658	23030	27010	606525	872954
Pre-harvest CO_2 (t)	7353	24512	2564	5129	32020	42350	41937	71991
Harvest CO_2(t)	703884	746866	146710	278581	7333	8148	857927	1033595
Post-harvest CO_2 (t)	51848	172826	23736	47472	39926	51134	115510	271432
Total CO_2(t)	763086	944204	173010	331182	32020	42350	968116	1317736
CO_2e emission per kg of fish caught	1.55	1.46	1.87	1.69	1.73	1.89	1.6	1.51



North-east Zone

In the North-east zone, almost 75% of the landings was contributed by West Bengal. Similar to the NW coast, this zone, has fishing operations with mechanized bagnets, which land a considerable quantity of fishes. The emission of CO_2e from marine fisheries of Odisha and West Bengal were 1.73 and 1.78 kg respectively with an average emission of 1.764 kg CO_2e per kg of fish from the NE coast.

Table 8. Performance of the marine fisheries sector from the North-east coast of India, in terms of carbon dioxide equivalent gas emission.

	Odisha		West Bengal		North-east coast of India	
Sector	Mechanized sector	Total marine fishery sector	Mechanized sector	Total marine fishery sector	Mechanized sector	Total marine fishery sector
Fishing units	1748	8682	4014	11054	5762	19736
Total catch (t)	88333	126958	329708	360873	418041	487831
Pre-harvest CO_2 (t)	822	1371	9650	13786	10473	15157
Harvest CO_2(t)	155500	203893	531254	595575	686754	799468
Post-harvest CO_2(t)	8741	9712	29715	33016	38456	42729
Total CO_2(t)	165064	21497	570619	642377	735682	857354
CO_2e emission per kg of fish caught	1.87	1.69	1.73	1.78	1.76	1.76

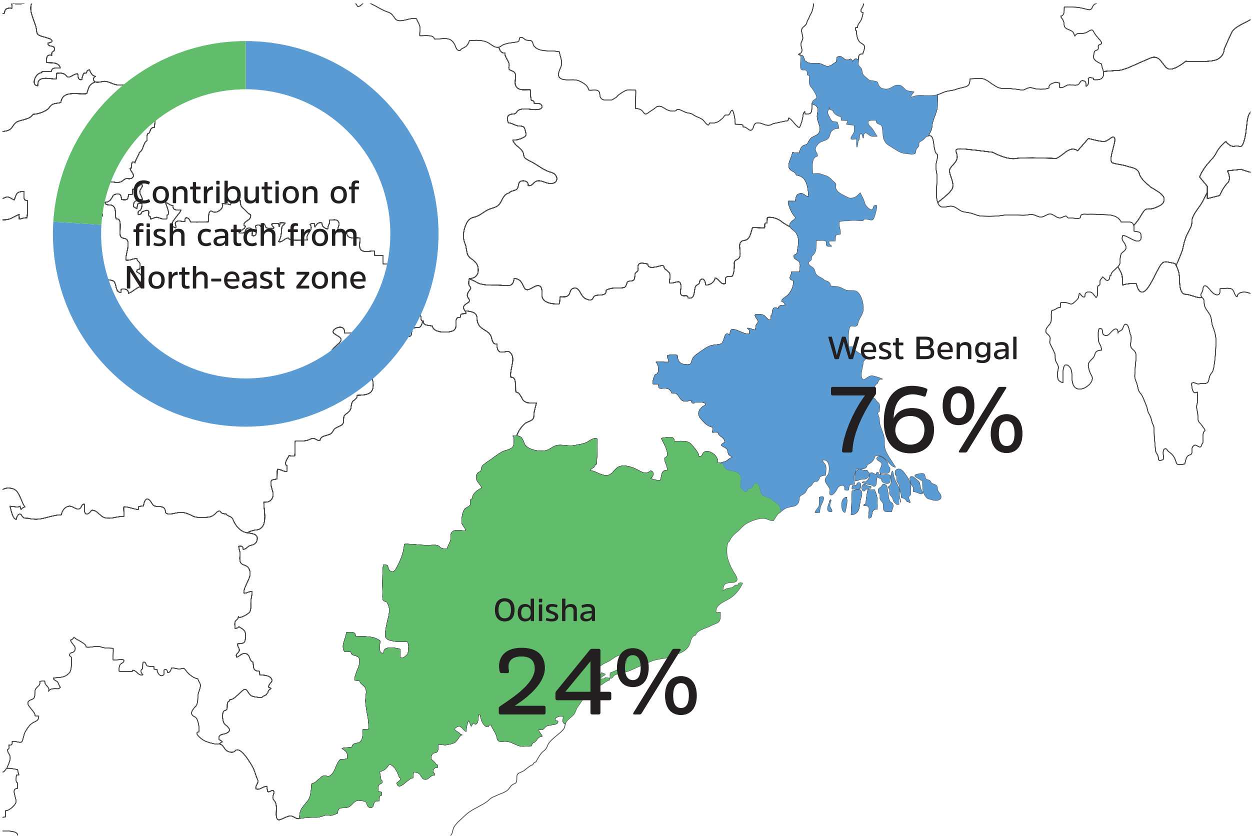


Table 9. Performance of the marine fisheries sector along the Indian coast, in terms of carbon dioxide equivalent gas emission

Zones	NW	SW	SE	NE	All India
Total catch (t)	1169921	1232642	872954	487831	3763348
Pre-harvest CO_2 (t)	47840	15910	71991	15157	150898
Harvest CO_2(t)	1500676	1726314	1033595	799468	5060053
Post-harvest CO_2(t)	19437	236729	271432	42729	570327
Total CO_2(t)	1567953	1978953	1317736	857354	5721996
CO_2e emission per kg of fish caught	1.34	1.61	1.51	1.76	1.52

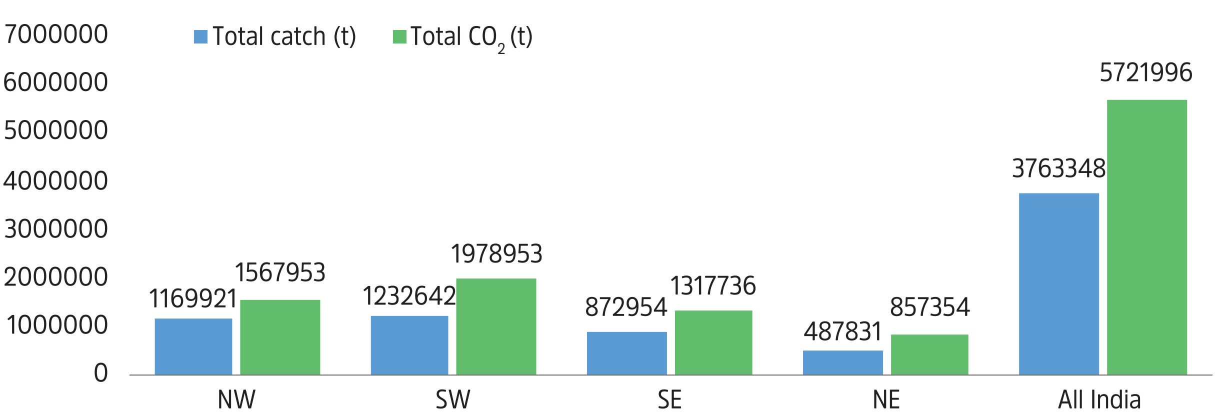


Fig.6. Catch (t) and CO_2e (t) status in four agro-climatic zones of India

Table 10. Performance of the mechanized fishery sector In India, in terms of carbon dioxide equivalent gas emission

Zones	NW	SW	SE	NE	All India
Total catch(t)	1117745	1023547	606525	418041	3165858
Pre-harvest CO_2(t)	24267	12524	41937	10473	89201
Harvest CO_2(t)	1314592	1406113	857927	686754	4265386
Post-harvest CO_2(t)	7521	192202	115510	38456	353689
Total CO_2(t)	1346381	1610839	968116	735682	4661018
CO_2e emission (kg) per kg of fish caught	1.2	1.57	1.6	1.76	1.47

Discussion

Marine fisheries is an important industry in India that supports the livelihood of nearly 38 lakh people. India has around 3,477 marine fishing villages spread along its coastline, where active fishermen are based (CMFRI, 2020). ICAR-Central Marine Fisheries Research Institute has been collecting information on various aspects of fishing, such as the amount of fish caught, types of fishing boats and equipment used, and the social and economic status of the people involved in fishing. Of late, there is a growing concern about the environmental impact of fishing, particularly in terms of greenhouse gas (GHG) emissions. Efforts are being made to reduce the amount of GHGs emitted per kilogram of fish caught.

Almost 91.6% of the families involved in fishing are traditional fisher families. There are large number of fishing units in operation, totalling 1,66,333. Among these units, only 29% are mechanized, while the rest are either motorized or non-motorized. The mechanized sector in India cannot be compared with that of other industrialized fishing nations, since all the fishing boats which are in regular operation in India are comparatively small, with OAL < 25 meters, and engine capacity <500 hp. Unlike other fishing industries, human energy plays a major role in the Indian marine fishing sector. For example, more than 10 crew members work on trawlers, and up to 50 fishermen are involved in activities like shooting nets, hauling the catch, and separating the fish onboard. Landing of fish catch at landing centres is also done manually. Many other related activities, such as boat building, ice factories, freezing plants, curing yards, peeling sheds, and net mending centres also rely on human labour and physical activity. The

findings of the study highlight the significant use of human power in fish production in India. Unlike an industrial activity, Indian marine fisheries should be seen as a means of livelihood for millions of fisher families and the various secondary and tertiary stakeholders in the marine fishing sector.

Over time, marine fisheries operations in India have expanded beyond the territorial waters of the state they originate from. For this study, data was collected from different maritime states and Union territories (UT). The fishing areas were divided into four zones – North-west (NW), South-west (SW), South-east (SE) and North-east (NE).

The NW is highly productive, with Gujarat and Maharashtra states and the UT of Daman and Diu contributing to 31% of India's marine fish landings. Trawlnet and Dolnet are the main fishing gears used in this zone. The amount of GHG emissions (CO_2e) from marine fisheries in this zone was 1.34 kg CO_2e per kg of fish. High catch rate of trawlers and the fuel-efficient fishing method used by dolnetters have resulted in low average emission from this zone.

The SW zone, including the states of Goa, Karnataka and Kerala, contributed to 33% of India's marine fisheries production. Trawlers dominate the mechanized fishing sector in this zone. Apart from trawlers, Kerala relies on ring seines to catch pelagic fish, while mechanized purse seines play a significant role in Karnataka. The average GHG emissions from the SW zone was 1.61 kg CO_2e per kg of fish.

The SE zone contributed to 23% of India's marine fisheries production and has an average emission of 1.51 kg CO_2e per kg of fish. The NE zone's average emission is 1.764 kg CO_2e per kg of fish. Gillnetters that target high-value fishes in low quantities were operated comparatively in high proportion in the SE zone, leading to higher emissions per catch in weight projection. However, these emissions were lower than the global standards.

A recent study on GHG emissions and fuel use in the fishing industry (Parker et al., 2018) found that to catch one kg of marine fish, approximately 2.2 kg of CO_2e were released. The study showed variations in emission rates depending on the type of fish being targeted. For instance, catching pelagic shoaling fish required less fuel, resulting in an average of 1.9 kg CO_2e kg^{-1} of fish. On the other hand, targeting crustaceans and demersal species required more effort and fuel, leading to an average of 7.9 kg CO_2e kg^{-1} of fish (Dallaghan et al., 2023).

In India's mechanized fishery sector, which includes various fishing craft and gear like trawlers, gillnetters, dolnetters, longliners, purse seiners, and ring seiners, the average emissions were estimated to be 1.47 kg CO_2e kg^{-1} of fish. Trawlers used to catch non-shoaling species had the highest emissions at 1.81 kg CO_2e kg^{-1} of fish nationwide. Certain gears targeting shoaling fish, such as mechanized ring seines in Kerala and purse seines in Karnataka were more environment-friendly, emitting 0.93 kg and 0.68 kg CO_2e kg^{-1} of fish, respectively. Dolnetters in Gujarat and Maharashtra were found to be the most eco-friendly, emitting only 0.34 and 0.39 kg CO_2e kg^{-1} of fish landed, as they used relatively less fuel during fishing operations.

In Irish fisheries, the average emissions per tonne of fish landed was calculated to be 1.57 t CO_2e t^{-1} of fish, ranging from 1.13 t CO_2e t^{-1} to 2.10 t CO_2e t^{-1}. This is higher than the emissions recorded from seine fishery along the SW coast of India. In India, seine fishery employs large crew; skilled and unskilled labourers are used instead of machines that

consume fuel. This resulted in lower GHG emissions from Indian pelagic fishery scenario. On the other hand, gillnets, which are less fuel-intensive compared to trawlers, show higher emissions per kg of fish due to their selective catches of high-value fish, as observed in the Irish fishery (Dallaghan et al., 2023).

Overall, Indian fishing units performed better than global fleets as they have lower emission profiles. The study showed that the harvest part (active fishing) used more than 90% of the fuel used in the fisheries sector in all the zones. Monitoring fuel use in this phase is necessary to recommend measures for reduction in emission. In the present study, non-mechanized sector, which does not use fuel for harvesting, was not considered for calculating the Indian emission status. If the non-mechanized sector is also considered, the emission of CO_2 for one tonne of fish produced from Indian marine fisheries will be <1.52 t. By global standards, emissions from Indian fishing units are thus significantly low. However, considerable and persistent efforts are needed to reduce CO_2e emissions from mechanized and motorized fishing operations to ensure that marine fisheries in India becomes greener.

The emission intensity per kg fish production in trawl fisheries was 1.81 kg CO_2e. Given that 75% of India's export commodities from capture fisheries originate from trawl fisheries, the lower carbon footprint positions Indian trawl fisheries to demand premium prices in the export market and qualify for carbon trading credentials.

References

Abdou, K., Aubin, J., Romdhane, M.S., Le Loc'h, F., Lasram, F.B.R. 2017. Environmental assessment of seabass (*Dicentrarchus labrax*) and seabream (*Sparus aurata*) farming from a life cycle perspective: A case study of a Tunisian aquaculture farm. Aquaculture, 471, 204–212.

Aubin, J., Papatryphon, E., van der Werf, H.M.G., Chatzifotis, S. 2009. Assessment of the environmental impact of carnivorous finfish production systems using life cycle assessment. Journal of Cleaner Production 17, 354–361.

Aubin, J., Papatryphon, E., Van der Werf, H.M.G., Petit, J., Morvan, Y.M. 2006. Characterisation of the environmental impact of a turbot (*Scophthalmus maximus*) re-circulating production system using life cycle assessment. Aquaculture 261 (4), 1259–1268.

Avadía Angel, Fréon Pierre 2013. Life cycle assessment of fisheries: A review for fisheries scientists and managers. Fisheries Research 143 21–38.

Ayer, N. W., Tyedmers, P. H., Pelletier, N. L., Sonesson, U., Scholz, A. 2006. Co-product allocation in life cycle assessments of seafood production systems: Review of problems and strategies. The International Journal of Life Cycle Assessment, 12(7), 480–487.

Ayer, N.W., Tyedmers, P.H. 2009. Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture in Canada. Journal of Cleaner Production 17, 362–373.

Birgir Örn Smárason, Ólafur Ögmundarson, Jón Árnason, Rannveig Björnsdóttir, Brynhildur Davíðsdóttir 2017. Life Cycle Assessment of Icelandic Arctic Char Fed Three Different Feed Types. Turkish Journal of Fisheries and Aquatic Sciences 17: 79-90.

Bohnes, F. A., Hauschild, M. Z., Schlundt, J., Laurent, A. 2018. Life cycle assessments of aquaculture systems: a critical review of reported findings with recommendations for policy and system development. Reviews in Aquaculture. doi:10.1111/raq.12280.

BSI 2008. Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services. British Standards Institute, London.

Buchspies, B., Tölle, S.J., Jungbluth, N. 2011. Life Cycle Assessment of High-Sea Fish and Salmon Aquaculture; ESU-Services Ltd. Schaffhausen, Switzerland, .

Claussen E., Cochran V. A., Davis D. P. 2001. Climate Change: Science, Strategies, & Solutions, University of Michigan, 373p..

CMFRI-FSI-DoF 2020. Marine Fisheries Census 2016–India. Central Marine Fisheries Research Institute, Indian Council of Agricultural Research, Ministry of Agriculture and Farmers Welfare; Fishery Survey of India and Department of Fisheries, Ministry of Fisheries, Animal Husbandry and Dairying, Government of India. 116p.

Dallaghan, B., Jackson, E., Cooney, R., Rihan, D., McHugh, M., Barrett, C., Cosgrove, R., Chopin, N. and Watson, L. 2023. Carbom Footprint Report of the Irish Seafood Sector. Bord Iascaigh Mhara. 52p.

d'Orbcastel Emmanuelle Roque, Blancheton Jean-Paul, Aubin Joel 2009. Towards environmentally sustainable aquaculture: Comparison between two trout farming systems using Life Cycle Assessment. Aquacultural Engineering 40, 113–119

Defra, D. 2011. Guidelines to Defra/DECC's GHG Conversion Factors for Company Reporting," AEA for the Department of Energy and Climate Change (DECC).

Dineshbabu, A. P., Thomas, Sujitha and Shailaja, S. 2017. Efficacy of spatial study on catch and effort from fishing vessels for strengthening fisheries management. Journal of the

Marine Biological Association of India, 59 (1). pp. 31-35.

Ellingsen, H., Aanondsen, S.A. 2006. Environmental impacts of wild caught cod and farmed salmon – a comparison with chicken. International Journal of Life Cycle Assessment 11, 60–65.

Ellingsen, H., Olaussen, J.O., Utne, I.B. 2009. Environmental analysis of the Norwegian fishery and aquaculture industry – a preliminary study focusing on farmed salmon. Marine Policy 33, 479–488.

FAO (Food and Agriculture Organization of the United Nations). 2017. *Workshop on Improving Our Knowledge on Small-Scale Fisheries: Data Needs and Methodologies* (Rome, Italy: FAO Fisheries and Aquaculture Proceedings No. 55).

FAO (Food and Agriculture Organization of the United Nations) 2018. The State of the World Fisheries and Aquaculture (SOFIA) 2018. Eds. Alder J., Barg U., Funge-Smith S., Mannini P., Taconet M., Plummer J., Barange M. (Rome, Italy: FAO Secretariat). Available at: http://www.fao.org/publications/sofia/en/.

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Suh, S. 2009. Recent developments in Life Cycle Assessment. Journal of Environmental Management, 91(1), 1–21.

Gaspard Philis, Friederike Ziegler, Lars Christian Gansel, Mona Dverdal Jansen, Erik Olav Gracey and Anne Stene 2019. Comparing Life Cycle Assessment (LCA) of Salmonid Aquaculture Production Systems: Status and Perspectives. Sustainability, 11, 2517; doi:10.3390/su11092517.

Ghamkhar, R., Boxman, S. E., Main, K. L., Zhang, Q., Trotz, M. A., & Hicks, A. 2020. Life Cycle Assessment of Aquaculture Systems: Does Burden Shifting Occur with an Increase in Production Intensity? Aquacultural Engineering, 102130. doi:10.1016/j.aquaeng.2020.10213.

Ghosh, S., Rao, M.V.H., Kumar, M.S., Mahesh, V.U., Muktha, M., Zacharia, P.U. 2014. Carbon footprint of marine fisheries: Life cycle analysis from Visakhapatnam. Current Science, 107, 515–521.

Goedkoop, M., Oele, M. 2003. Database Manual—Methods Library. PRe Consultants, Amersfoort, The Netherlands.

Greer, K., Zeller, D., Woroniak, J., Coulter, A., Winchester, M., Palomares, M.L.D. and Pauly, D. 2019. Global trends in carbon dioxide (CO_2) emissions from fuel combustion in marine fisheries from 1950 to 2016. Marine Policy, 107: 103382.

Gronroos, J., Seppala, J., Silvenius, F., Makinen, T. 2006. Life cycle assessment of Finnish cultivated rainbow trout. Boreal Environment Research 11, 401–414.

Guinée, J.B., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., van Oers, L., Wegener, A., Suh, S., Udo de Haes, H.A. 2001. Life cycle assessment—an operational guide to the ISO standards. Centre of Environmental Science, Leiden, The Netherlands.

Hospido, A,, Tyedmers, P. 2005. Life cycle environmental impacts of Spanish tuna fisheries. Fisheries Research, 76, 174–186.

ICAEW 2021. Definitions: can you tell your LCA from your carbon footprint? ICAEW insights. https://www.icaew.com/insights/viewpoints-on-the-news/2021/jun-2021/netzero-can-you-tell-your-lca-from-your-carbon-footprint#Life%20Cycle%20Assessment%20(LCA)%20vs%20Carbon%20Footprint

Iribarren, D., Vázquez-Rowe, I., Hospido, A., Moreira, M.T., Feijoo, G. 2010. Estimation of the carbon footprint of the Galician fishing activity (NW Spain). Science of the Total Environment 408, 5284–5294.

Jerbi, M. A., Aubin, J., Garnaoui, K., Achour, L., Kacem, A. 2012. Life cycle assessment (LCA) of two rearing techniques of sea bass (*Dicentrarchus labrax*). Aquacultural Engineering, 46, 1–9.

Kallitsis, E., Korre, A., Mousamas, D., Avramidis, P. 2020. Environmental Life Cycle Assessment of Mediterranean Sea Bass and Sea Bream. Sustainability, 12(22), 9617.

Li Zhi, Zhang Liuyue, Wang Wenju and Ma Wenwu 2022. Assessment of

Carbon Emission and Carbon Sink Capacity of China's Marine Fishery under Carbon Neutrality Target. Journal of Marine Science and Engineering, 10, 1179.

Kristofersson, D., Gunnlaugsson, S., Valtysson, H. 2021. Factors affecting greenhouse gas emissions in fisheries: Evidence from Iceland's demersal fisheries. ICES Journal of Marine Science, 78: 2385–2394.

Li, Z., Zhang, Li., Wang, W. and Ma, W. 2022. Assessment of Carbon Emission and Carbon Sink Capacity of China's Marine Fishery under Carbon Neutrality Target. Journal of Marine Science and Engineering, 10, 1179. https://doi.org/10.3390/jmse10091179

Mohamed, K. S. and Sathianandan, T. V. and Padua, Shelton 2018. Integrated spatial management of marine fisheries of India for more robust stock assessments and moving towards a quota system. Marine Fisheries Information Service; Technical and Extension Series (236). pp. 7-15.

Nijdam Durk, Rood Trudy, Westhoek Henk 2012. The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy 37, 760–770.

Papatryphon, E., Petit, J., Kaushik, S.J., Van Der Werf, H.M.G. 2004. Environmental impact assessment of salmonid feeds using life cycle assessment (LCA). Ambio 33 (6), 316–323.

Parker Robert Wayne Ray, Julia Blanchard, Caleb Gardner, Bridget S. Green, Klaas Hartmann, Peter Tyedmers, Reg Watson 2018. Fuel use and greenhouse gas emissions of world fisheries, Nature Climate Change 8(4):333-337. DOI:10.1038/s41558-018-0117-x

Patrik J.G. Henriksson, Jeroen B.Guinée, René Kleijn Geert R. deSnoo 2012. Life cycle assessment of aquaculture systems—a review of methodologies. The International Journal of Life Cycle Assessment 17:304–313.

Pelletier, N.L., Tyedmers, P.H. 2010. A life cycle assessment of frozen Indonesian tilapia fillets from lake and pond-based production systems. Journal of Industrial Ecology 14:467–481.

Pelletier, N.L., Tyedmers, P.H. 2007. Feeding farmed salmon: is organic better? Aquaculture 272:399–416.

Pelletier, N.L., Tyedmers, P.H., Sonesson, U., Scholz, A., Zeigler, F., Flysjo, A., Kruse, S.A., Cancino, B., Silverman, H.. 2009. Not all salmon are created equal: life cycle assessment (LCA) of global salmon farming systems. Environmental Science & Technology 43:8730–8736.

Pelletier, N. L., Ayer, N. W., Tyedmers, P. H., Kruse, S. A., Flysjo, A., Robillard, G., Sonesson, U. 2006. Impact categories for life cycle assessment research of seafood production systems: Review and prospectus. The International Journal of Life Cycle Assessment, 12(6), 414–421.

Phong, L.T., de Boer, I.J.M., Udo, H.M.J. 2011. Life cycle assessment of food production in integrated agriculture–aquaculture systems of the Mekong Delta. Livestock Science 139:80–90.

Ramos S, Cebrián M, Zufia J 2010. Simplified life cycle assessment of cod fishing by Basque fleet. VII International conference on life cycle assessment in the agri-food sector. Bari, Italy, September 2010.

Ramos, S., Vázquez-Rowe, I., Artetxe, I., Moreira, M. T., Feijoo, G., & Zufía, J. 2011. Environmental assessment of the Atlantic mackerel (*Scomber scombrus*) season in the Basque Country. Increasing the timeline delimitation in fishery LCA studies. The International Journal of Life Cycle Assessment, 16(7), 599–610.

Renju Ravi, P.H. Dhiju Das, Leela Edwin 2020. Life Cycle Assessment based identification of Environmental Hotspots in Commercial Trawl Fisheries of Kerala and Mitigation Strategies. Fishery Technology 57: 234 – 242.

Samuel-Fitwi, B., Nagel, F., Meyer, S., Schroeder, J. P., Schulz, C. 2013. Comparative life cycle assessment (LCA) of raising rainbow trout (*Oncorhynchus mykiss*) in different production systems. Aquacultural Engineering, 54, 85–92. https://doi.org/10.1016/j.aquaeng.2012.12.002.

Sayana, K.A., Remesan, M.P. 2020. Assessment of Fuel Consumption Rate of Mechanized Trawlers in Kerala, South India. Agro Economist–An International Journal, 7(1): 51-56.

Sherry, J., Koester, J. 2020. Life Cycle Assessment of Aquaculture Stewardship Council Certified Atlantic Salmon (*Salmo salar*). Sustainability, 12(15), 6079. doi:10.3390/su1215607

Svanes, E., Vold, M., Hanssen, O.J., 2011. Environmental assessment of cod (*Gadus morhua*) from autoline fisheries. International Journal of Life Cycle Assessment 16, 611–624.

Thrane, M. 2006. LCA of Danish fish products: New methods and insights. International Journal of Life Cycle Assessment 11 (1) 66–75.

Tyedmers, P.H., Watson, R., Pauly, D. 2005. Fueling global fishing fleets. Ambio, 34(8): 635-638.

Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. 2010. Life cycle assessment of horse mackerel fisheries in Galicia (NW Spain). Comparative analysis of two major fishing methods. Fisheries Research, 106:517–527.

Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. 2011. Life cycle assessment of fresh hake fillets captured by the Galician fleet in the Northern Stock. Fisheries Research 110:128–135.

Vázquez-Rowe, I., Moreira, M.T., Feijoo, G. 2012. Environmental assessment of frozen common octopus (*Octopus vulgaris*) captured by Spanish fishing vessels in the Mauritanian EEZ. Marine Policy 36, 180–188.

Vivekanandan, E. 2011. Marine Fisheries Policy Brief-3; Climate change and Indian Marine Fisheries. CMFRI Special Publication, 105. pp. 1-97.

Watanabe, H. Okubo, M. 1989. Energy input in marine fisheries of Japan. Bulletin of the Japanese Society for the Science of Fish, 53: 1525–1531.

Wilson, J.D.K. 1999. Fuel and Financial Savings for Operators of Small Fishing Vessels. FAO Fisheries Technical Paper 383, FAO, Rome.

Yue, D.D., Wang, L.M., Wang, Q.; Zhou, Y.S. 2013. GHG emissions estimation and efficiency analysis of marine fisheries. Journal of Shanxi Agricultural Sciences, 1: 873–876.

Ziegler, F., Eichelsheim, J.L., Emanuelsson, A., Flysjö, A., Ndiaye, V., Thrane, M. 2009.. Life cycle assessment of southern pink shrimp products from Senegal. An environmental comparison between artisanal fisheries in the Casamance region and a trawl fishery based in Dakar. FAO Fisheries and Aquaculture Circular No. 1044.

Ziegler, F., Nilsson, P., Mattsson, B., Walther, Y. 2003. Life Cycle Assessment of frozen cod fillets including fishery-specific environmental impacts. International Journal of Life Cycle Assessment 8 (1) 39–47.

Ziegler Friederike, Hilborn Ray 2023. Fished or farmed: Life cycle impacts of salmon consumer decisions and opportunities for reducing impacts. Science of the Total Environment 854 158591.

Ziegler, F., Emanuelsson, A., Eichelsheim, J.L., Flysjö, A., Ndiaye, V., Thrane, M. 2011. Extended life cycle assessment of southern pink shrimp products originating in Senegalese artisanal and industrial fisheries for export to Europe. Journal of Industrial Ecology 15, 527–538.

Ziegler, F., Valentinsson, D. 2008. Environmental life cycle assessment of Norway lobster (*Nephrops norvegicus*) caught along the Swedish west coast by creels and conventional trawls – LCA methodology with case study. The International Journal of Life Cycle Assessment 13(6):487-497.

Notes

Notes

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