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Environmental pressure of active fishing method: A study on carbon emission by trawlers from north-west Indian coast

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ABSTRACT

Carbon footprint of fishing activities is an utmost important study at present for mitigation of climate change. It is a simplified form of life cycle assessment (LCA) which measured total amount of carbon dioxide emissions. Assessment of emission and energy utilization in fishing were neglected earlier and very minimal information are available in Indian context. The present study analyzed the fuel consumption, energy utilized and carbon emission rate of trawlers from north-west coast of India. Efficiency of different categories of trawlers i.e., single-day (SD), multi-day small (MDS), multi-day medium (MDM) and multi-day large (MDL) trawlers was estimated. SD trawlers were found to be most efficient followed by MDM, MDL and MDS. Single-day fishing was significantly different from multi-day fishing in terms of fuel efficiency, energy intensity and carbon emission rate. A total of 1769 trawlers were operated from Versova (site I), SSD (Sassoon Dock) (site II) and NFW (New Ferry Wharf) (site III). Of these, more than 50% are MDL trawlers and 76% of the total fuel consumed by MDL trawlers. Trawlers of selected sites resulted into total diesel consumption of 119 million litres per year. The carbon emission due to combustion of diesel was 0.3 million tonnes which is 1/12th of total carbon emission by Indian fishing fleet. Considering the impacts of trawlers on environment, substantial phasing out of MDS trawlers and multi-day trawlers with high installed engine horsepower is necessary. The trawling operation in north-west coast of India needs a strict regulation in terms of number and engine horsepower.

1. Introduction

Carbon footprint has become a famous term and concept in the scientific research and public domain due to its importance and concern related to global climate change threat. The carbon footprint referred to the total amount of carbon dioxide emitted by an activity (includes both direct and indirect emissions) or the total emissions involved in the life stages of a product [55]. It is a simplified form of life cycle assessment (LCA) [25]. Its importance in public domain had increased over the last few years and thus it is widely discussed across the media, the government and in the business world. The conference of parties (COP21) held in Paris in 2015, of the United Nations Framework Convention on Climate Change highlighted the vital need to reverse the current trend of overexploitation and pollution to restore aquatic ecosystem services and the productive capacity of the oceans. The resultant Paris Agreement aims to keep the increase in global average temperature below 2 °C [21]. In the past, the emissions from agriculture and fisheries sector were not given importance as compared to major sectors for emissions in India. The study on impacts of Environmental issues and climate change on stocks and associated marine ecosystems were widely studied but few studies were done on emissions [49,53]. Later, its importance was highlighted in many reports, international convention and scientific publications [37,49,53]. Fishing is considered as the most energy-intensive food production method and is dependent on fossil fuels. Fishing from marine waters depends on the availability of fossil fuel for propulsion of fishing vessel engine which ultimately pose a threat to climate change and ocean acidification due to carbon emissions. The dependence on fossil fuel also pose a threat to economic

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viability of the fishing units.

India is one of the top 5 countries for GHG emissions in the world but emission rate in terms of emissions per Gross Domestic Product (GDP) is lesser than that of World's average [56]. The emission from fisheries sector is minimal in India but it has increased from 3.2 $MtCO_2e$ in 2005–5.1$MtCO_2e$ in 2014 [37]. The world's marine capture fish landing had been stagnant from 1990 to 2011 but the emissions from fishing fleet had increased by 28% [39]. In case of Indian marine fisheries, there was increase in diesel consumption and consequent rise in emissions, 0.30 million tonnes (mt) CO_2e in the year 1961–3.60 mt CO_2e in 2010 by fishing vessels [54]. India contributed 2.7% and 3.9% to the global marine fisheries CO_2 emission (134 mt) and fish production (90 mt) respectively [54]. Emissions can be estimated at 3 different phases of marine fisheries life cycle i.e., pre-harvest, harvest and post-harvest; and harvest phase contributed the highest emission [25]. Since, fishing vessels are the largest contributors to carbon footprint, replacing the fuel-intensive fishing method with alternate methods can reduce the emissions from fishery sector [25,44]. Carbon footprint reduction is feasible with profitable fishery [44]. Thrane et al. [47] had included 'carbon emissions from related activities' as one of the major issues facing commercial fisheries. The concern for inclusion of carbon footprint in the criteria for eco-labeling of seafood products had been raised by many researchers [36,47].

The resultant fossil-fuel consumption and CO_2 emission data can be interpreted to gain an insight into the increasing fishing cost and fish price, to evolve policies on regulating fishing effort and fuel subsidies, and to suggest climate change mitigation measures. The resultant forms and quantities of energy dissipated in fisheries, and in particular changes in energy-use over time, can also provide a powerful measure of the scarcity or abundance of fish population. Trawlers are fishing vessels which use trawls as fishing gear and are installed with sufficient powered engines to tow the net at desirable trawling speed [20]. Despite being an important gear, trawl nets are greatly known for its destructive nature. Juvenile fishing, bycatch, destruction of ocean floor and untargeted catch are some of the problems associated with trawl nets. Trawl nets are major gear in India in terms of the quantity of catch landed and Maharashtra is a state which contributes a large proportion to the total marine fish landing in India. In 2018, trawl nets contributed 54.7% of total landing in Maharashtra, India [13]. The carbon footprint in the present study was estimated only for harvest phase as contribution of this phase was the major component of carbon emissions in marine fisheries [25,29,31,33,44] and the environment impact could be maintained based on operation of fishing vessel [25]. Earlier studies of carbon footprint in India had focused exclusively on harvest phase [9,54], while Ghosh et al. [25] evaluated the carbon footprint at all stages of lifecycle of marine fisheries of Visakhapatnam. As there is no such report

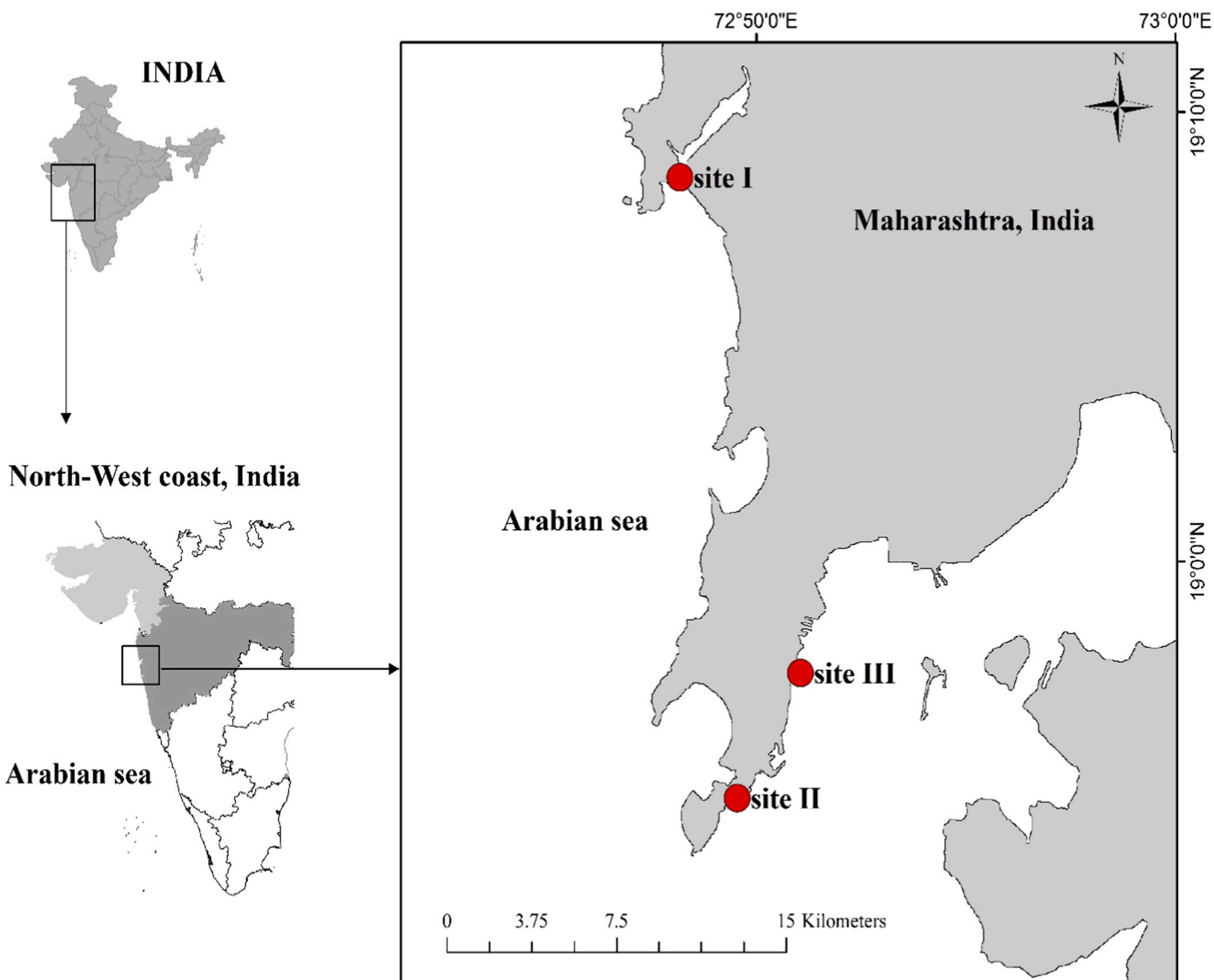

Fig. 1. Map showing the study locations of northwest coast of India (Site I- Versova, site II- Sassoon Dock and site III- New Ferry Wharf).

available in the published literatures, the present study served to be the first report estimating carbon footprint of trawlers operating from north-west coast. In this context, present study aimed to highlight the energy consumed and emissions from trawlers of north-west coast of India. Sites selected include major landing centers of north-west coast of India in terms of quantity landed and trawl nets are major gear operated. Thus, an insight into the fuel consumption and emission of trawlers of this region would provide an important information for formulation of climate change policy and implementation. With the rising concern and awareness of climate change and environmental impact of fishing, the information thus generated in the study would help in decision making of the fish harvesting. Thus, regional policy can be prepared to replace such intensive fishing practice with low impact fuel-efficient fishing.

2. Material and methods

2.1. Study area

Mumbai lies in the north-west coast of India, surrounded by Arabian Sea to the west. The sampling sites are given in Map (Fig. 1). Site I, site II and site III respectively indicated Versova, SSD (Sassoon Dock) and NFW (New Ferry Wharf) of Mumbai, Maharashtra, north-west coast of India are major landing centers which were selected as study areas, and trawl nets are the major gear operated. Trawlers of Gujarat, north-west coast, India also land their catch at NFW and thus the present study is a cumulative interpretation of the north-west coast of India.

2.2. Data analysis

The data on the amount of diesel consumption and fish landing was collected from 50 trawlers operated at north-west coast of India and classified according to size (Table 1). Duration of fishing was expressed in terms of number of fishing days in a year, number of trips in a year, number of days in a trip, and duration of fishing in a day (in hrs). Trawlers were selected based on the stratified random sampling techniques of Sukhatme and Sukhatme [43]. The data on diesel consumption was collected based on the pre-scheduled questionnaire for two years from Aug-2016 to May-2018 except during June and July (monsoon season). The questionnaire was administered to the skippers of the selected trawlers for keeping record of diesel consumption for each and every trip.

Fuel efficiency or fuel use intensity is the amount of fuel consumed to land unit weight of fish [48]. It is expressed in terms of litres of diesel per tonne of fish landed and kg of fuel per kg of fish landed. The amount of fuel in litre is converted to kilogram as 0.86 kg per litre of diesel following Schau et al. [41].

$$1\ litre\ diesel = 0.86\ kg\ diesel$$

$$Fuel\ used\ intensity = \frac{Fuel\ consumed\ (in\ tonnes)}{Catch\ landed\ (in\ tonnes)}$$

As per IPCC- Global Warming Potentials (GWPs) are a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas. It is defined as the cumulative radiative forcing – both direct and indirect effects – integrated over a period of time from the emission of a unit mass of gas relative to some reference gas. Carbon dioxide (CO_2) was chosen by the IPCC as this reference gas and its GWP is set equal to one (1). Thus, GWP values enabled us to compare different gases based on its impacts of emissions. CO_2 has a GWP of 1, methane has a GWP of approximately 25 (on a 100-year time horizon) [26]. In other words, for every 1 tonne of methane (CH_4) emitted, an equivalent of 25 tonnes of CO_2 would be emitted. Carbon dioxide is a major component of the Greenhouse gases warming our planet. Others include Methane, Nitrous oxide and Hydro-fluorocarbons. Compared to Carbon dioxide, each Greenhouse gas has a greater or lesser warming effect, but all are standardized into equivalent units of CO_2. Carbon footprints are therefore measured in terms of kilos or tonnes of Carbon dioxide (CO_2) [1]. Burning of fuel leads to emission of GHGs and diesel is the fuel used in trawlers in the present study. Here, the CO_2 emission was analyzed for only the diesel consumption from capture to landing of fish. This doesn't include the emissions arising from the complete life cycle of the product. Carbon emission intensity is estimated as the amount of carbon in kg per kg of fish landed. Carbon emission is estimated using the conversion factor, 2.7 kg of CO_2 is released per litre of diesel consumed [51].

$$1\ litre\ diesel = 2.7kg\ of\ CO_2$$

$$Carbon\ emission\ (in\ kg) = 2.7 \times\ Diesel\ consumed\ (in\ litres)$$

$$Carbon\ emission\ intensity = \frac{Total\ carbon\ emission\ (in\ kg)}{Catch\ landed\ (in\ kg)}$$

Energy utilization per litre of diesel is taken as 38.31 MJ (mega-joules) and 1000 MJ= 1 GJ (giga-joules) [50]. Energy intensity is the energy equivalent to quantity of fuel consumed in MJ to land a tonne of catch [11] or the energy required to land a unit weight of fish [48].

$$1000\ MJ = 1GJ\ (giga - joules)$$

$$1\ litre\ diesel = 38.31MJ\ (mega\ joules)$$

$$Energy\ intensity = \frac{Energy\ consumed\ (in\ giga - joules)}{Catch\ landed\ (in\ tonnes)}$$

The amount of annual fuel consumption, annual energy utilization and annual carbon emission of mechanized trawlers from Versova, SSD and NFW of Mumbai, north-west coast were derived from the average values obtained and number of trawlers in each category. Carbon emission and energy utilized is a linear function of the fuel used.

2.3. Statistical analysis

Microsoft excel 2010 was used for simple calculation like mean, error and to estimate the percentage of fuel consumption, energy utilized and carbon emission by the trawlers of different study locations. All other statistical analysis was performed in RStudio software [40]. SD, MDS, MDM and MDL trawlers were designated as 4 different treatments to compare the fuel efficiency, energy intensity and carbon emission efficiency. One-way ANOVA was conducted to compare means using package ggplot2 in RStudio software.

Table 1
Classification of trawlers based on size (length overall, L_{OA}).

L_{OA} (m)	Type of trawlers	Details of sampled trawlers	
		Length range (m)	Engine horsepower range (hp)
<12	Single-day (SD)	9.14–11.5	60 –106
<12	Multi-day small (MDS)	10.5–11.9	88–106
12 – <16	Multi-day medium (MDM)	12–15.9	88–400
16–24	Multi-day large (MDL)	17.8–20.1	99.27–411

3. Results and discussion

3.1. Operational details of mechanized trawlers along north-west coast

Trawlers of north-west coast varied in size according to its magnitude of operation, design and size of trawl nets used. Small trawlers conducted single-day fishing while large size trawlers and very few small trawlers conducted multi-day fishing. Operational details are given in Table 2. The average catch per hour was found to be highest for

Table 2
Details on trips and fuel consumption rate of mechanized trawlers along the north-west coast of India.

Type of trawlers	Average duration of fishing in a day (h)	Average number of days in a trip	Average number of trips in a year	Average number of fishing days in a year	Fuel consumption/hr (L)	Fuel consumption/ day (L)	Fuel consumption/ trip (L)	Average catch per trip (kg)
SD	7.00	1	207	207	9.52 ± 0.33^{a}	66.61 ± 2.32^{a}	66.61 ± 2.32^{a}	142.15 ± 481.14^{a}
MDS	9.00	4	51	217	18.97 ± 1.01^{bc}	170.71 ± 9.09^{b}	682.85 ± 36.35^{b}	867.70 ± 1853.91^{b}
MDM	11.30	10	22	223	22.52 ± 1.12^{cdb}	259.03 ± 12.90^{cd}	2590.33 ± 128.96^{c}	4011.43 ± 2837.06^{c}
MDL	12.00	12	21	252	25.02 ± 1.14^{dc}	300.22 ± 13.70^{dc}	3602.63 ± 64.40^{d}	5149.77 ± 3452.48^{d}

Note: Result is presented as the average values derived from the survey data collected during 2016–2018. Single-day (SD), Multi-day small (MDS), Multi-day medium (MDM), Multi-day large (MDL).

MDL (35.76 kg) followed by that of MDM (34.88 kg), MDS (24.1 kg) and SD (20.31 kg). The major species landed by the trawlers of Mumbai, north-west coast consisted of *Johnieops vogleri*, *Parapenaeopsis stylifera, Loligo duvauceli, Metapenaeus affinis, M. monoceros, Johnius macrorhynus, Otolithes cuvieri, Sepia aculeata, Priacanthus prolixus, Nemipterus randalli, Epinephalus diacanthus, Solenocera crassicornis, Acetes indicus, Trichiurus lepturus, Coilia dussumieri* and *Harpadon nehereus* [17].

Small trawlers of Mumbai coast which carried out single-day fishing are represented as SD. These trawlers targeted shrimps. Average number of fishing days varied from 180 days to 230 days during 2016–17 and 190–221 days during 2017–18 which is similar to that of single-day trawlers of Kerala [3]. Actual fishing hours expended by SD trawlers varied from 3:30–7:00 h in a trip. They conducted fishing for few hours in a day and hence the number of fishing days in a fishing season is equivalent to number of trips in that season. Dineshbabu [18] reported that average fishing hours for single-day trawlers operating along southwest coast of eastern Arabian sea was 3–5 h per day.

Some of the small trawlers operated in this area conducted multi-day fishing. These trawlers (MDS) targeted mainly shrimps and rarely fish. Average number of fishing days varied from 195 to 230 during 2016–17 and 195–239 during 2017–18. They spent 9 hrs a day and 4 days in a trip on an average. Medium size trawlers (MDM) conducted multi-day fishing. The average number of fishing days varied from 185 to 256 during 2016–17 and 134–261 during 2017–18. These types of boats spent on an average 11½ hrs. a day and 10 days in a trip. Large trawlers (MDL) conducted multi-day fishing. Average number of fishing days varied from 199 to 290 during 2016–17 and 199–296 during 2017–18. These trawlers spent 12 hrs a day and 12 days in a trip on an average.

The average duration of fishing trips are indicators of fuel consumption and also act as an important instrument for the survey [15]. Duration of single-day trawlers was 7 h while multi-day trawler spent 5 or more days at sea in Kerala, south-west coast, India [32]. Voyage duration of a trip for small mechanized (11–13 m), Sona (13–15 m), mini trawlers (16.5–20 m) and large trawlers (20–28 m) of Visakhapatnam district of Andhra Pradesh (south-east coast of India) were 1–5 days, 8–13 days, 20–25 days and 30–40 days respectively (Gopal, 2008). The study has reported fishing duration similar to that of Kerala but it is lower than that of large trawlers of Visakhapatnam district of Andhra Pradesh.

There was significant difference in duration among single-day and multi-day fishing. SD trawlers conducted highest number of fishing trips as single day of fishing was counted as a trip. On the contrary, multi-day trawlers conducted 21–51 trips in a year during 2016–18. However, the number of days spent at Sea ranged from 207 (SD) to 252 days (MDL).

3.2. Rate of fuel consumption by mechanized trawlers along north-west coast

Trawling is an active fishing method and diesel is the major fuel used by trawlers. There was abrupt rise in energy-intensive fishing vessel in India in 1980s and with the introduction of diesel-powered engines, larger vessels were fueled with diesel [37]. Rate of fuel consumption varied among different categories of trawlers. Fuel consumption varies according to the size of trawlers, engine horsepower and duration of fishing. Magnitude of operation in terms of number of fishing days in a trip varied among different size groups of trawlers and thus the fuel consumption per trip is not a desirable component to compare the rate of fuel consumption among categories of trawlers. Multi-day trawlers spend more than a day at sea for fishing without returning to shore till they complete a trip while single-day trawlers return to shore daily. Thus, the fuel consumption per hour and fuel consumption per day were used to compare the fuel consumption between SD, MDS, MDM and MDL. Rate of fuel consumption is given in Table 2.

Fuel consumption in litres per hour was highest for MDL (13.26–35.90) followed by MDM (11.13–34.02), MDS (14.61–30.42) and SD (7.57–12.84 l). The higher fuel consumption in large trawlers may be due to the fact that higher horsepower engines are installed in large trawlers [16]. Horse power of engines are one of the factors controlling fuel consumption and energy optimization in trawlers [5,30]. Fuel consumption of trawlers below and above 40 ft from Ratnagiri, Maharashtra were 12 litres/h and 16 litres/h respectively [4] which is similar to fuel consumed by the SD and MDS reported in the present study.

The present study showed that the average fuel consumption of SD trawlers ranged from 53 to 90 litres/day during 2016–17 and 54–79 litres/day during 2017–18. The average fuel consumption of MDS trawlers ranged from 526−1095 litres/day during 2016–17 and 607–1095 litres/day during 2017–18. The average fuel consumption of MDM trawlers ranged from 1570−3912 litres/day during 2016–17 and 1280–3830 litres/day during 2017–18. The average fuel consumption of MDL trawlers ranged from 1910 to 3975 litres/day during 2016–17 and 2190–5169 litres/day during 2017–18. The fuel consumption per day by SD was lower than that of MDS as single-day trawlers were out at Sea for about 7 h while MDS small trawlers spent 9 h a day. Also, single-day trawlers were fitted with lesser powered engines compared to MDS trawlers. Highest fuel consumption per day was recorded by MDL and lowest by SD. Diesel used per day by the single-day trawlers of Southwest coast of Eastern Arabian Sea was 205 litres [18]. Average per day fuel consumption in Andhra Pradesh was 117.83 litres for small mechanized, 202.44 litres for Sona, 502.54 litres for mini trawlers and 1173.26 litres for large trawlers [27]. Fuel consumption varied from 100−200 litres per day for MD medium and 250–300 litres of diesel per day for MD large trawlers of Kerala [3].

Fuel consumption per trip was highest for MDL followed by MDM, MDS and SD. Due to longer hours of fishing, a greater number of days in a trip, MDL trawlers consumed more fuel annually than other categories of trawlers. Fuel consumption varied from 500−1000 litres per trip for MD medium size trawlers and 1000−2000 litres for MD large trawlers [3]. Trawlers of Karwar, Karnataka with L_{OA} of 32–36 ft and engine capacity of 40–90 hp were found to consume 79 litres per trip of fuel [2]. Fuel consumption affects the economic efficiency of trawlers as fuel is the major contributor to variable cost [24,38]. The rising concern of increasing fuel cost and declining stock status threatens the economic efficiency of trawlers. Reduction in fuel consumption rate would help in economic efficiency. Gasoline consumption were proven to reduce in 2 stroke engines by the use of permanent magnets by a study conducted in

Iraq [22] while a study shows that there were no significant changes in fuel consumption in fishing with the use of magnets [23].

3.3. Fuel efficiency, energy intensity and carbon footprint of categories of trawlers along north-west coast

Fuel efficiency is an indicator for environmental effects of fishing and fuel used efficiency of a vessel according to European Commission [42]. It is estimated as fuel used in litres per tonne of fish landed and kg of fuel utilized per kg of fish landed in the present study. Fuel used in litres per tonne of fish landed ranged from 363.01 to 1057.65 for SD, 543.39–1428.57 for MDS, 303.39–1172.96 for MDM and 246.65–1185.07 for MDL trawlers. Fuel utilized in kg per kg of fish landed varied between 0.70 (MDS) and 0.42 (SD) (Fig. 3). Vivekanandan et al. [54] estimated that 393.3 litres of fuel were used to land one tonne of fish by fishing vessels of India. Boopendranath et al. [9] also reported that bottom trawling and midwater trawling utilized 1.34 and 0.33 kg of fuel to land 1 kg fish. On the south-east coast of India, MD trawlers of Chennai consumed 513 litres (or 2.0 kg) of fuel per tonne of fish landed [24]. Fuel used intensity of world's capture fisheries was 0.59 t per tonne of fish landed [28]. The studies over world for fuel used intensity of trawling in terms of kg of fuel per kg fish landed were reported mostly for species specific fishery i.e., 0.4 and 0.84 kg to land cod and flatfish respectively at Denmark [45,46], 0.52 kg fuel to land shrimps and prawn at Senegal [19], 0.3 kg fuel to land mackerel [34,46], 0.09–1.01 kg fuel [41]. In the present study, lowest value of fuel intensity was recorded for SD in terms of fuel utilized in litres per tonne of fish landed and fuel utilized in kg per kg of fish landed. This indicates that SD trawlers were more efficient in terms of fuel use intensity. Among the multi-day trawlers, MDM has the lowest value of fuel used in litres per tonne of fish landed (630.68) and fuel used in kg per kg of fish landed (0.56). MDM trawlers seem to be the most efficient in fuel use intensity among multi-day trawlers. Rise in fuel price and shortage of fossil fuel are the major concerns associated with such active fishing methods and thus the SD and MDM trawlers of Mumbai coast were more feasible as compared to MDS and MDL. MDS trawlers were less feasible compared to SD may be attributed to the more scouting time and location of fishing ground. The same reason applies to MDL trawlers but the difference is MDL trawlers landed higher economically valued fishes. The feasibility may alter in future majorly due to installation of overpowered engines disproportionately to the vessel size which is beyond recommendation. The results depicted that irrespective of size of trawlers; other factors play a major role in the fuel efficiency of trawlers operated at north-west coast of India. Time to time investigation of fuel use intensity and implementation of strict operation of appropriate vessel size with desired engine is utmost important.

Energy intensity is estimated as the energy required to produce a unit weight of fish. It is expressed as total joules of energy required to land a live weight of fish. SD trawlers were the most efficient in terms of energy intensity followed by MDM, MDL and MDS trawlers. The average energy intensity value in terms of GJ per tonne of fish landed was 17.78 for SD, 31.28 for MDS, 25.08 for MDM and 26.81 for MDL (Fig. 2). The average annual energy utilized in terms of GJ by individual trawler was 528.24 for SD, 1334.16 for MDS, 2183.19 for MDM and 2898.36 for MDL trawler (Table 3). The value of average annual energy utilization was highest for MDL trawlers as this group consumed more fuel. Boopendranath and Hameed [7] addressed the necessity for regulation of mini-trawl operations in coastal waters with respect to the high GER t fish^{-1} (20.2 GJ off Cochin, Kerala, India), predominant catch of juvenile and its negative impact on environment. Trawling is the most energy intensive fishing method as compared to other fishing methods like longlining, gillnetting and purse seining [5,30]. Energy efficiency in trawling may be improved by adopting energy audit system [10] or by using bond graph approach [35].

The carbon emission ranged from 0.98 kg to 2.86 kg for SD, 1.47–3.86 kg for MDS, 0.94–3.20 kg for MDM and 1.25–2.81 kg for MDL trawler (mean ± SE is given in Fig. 3). Average carbon emission by trawlers of north-west coast was estimated at 1.80 kg CO_2 per kg of fish landed. The present study has found that the emission rate is within the range as given by (1.02 kg for mini trawl, 0.99 kg for bottom trawl and 3.52 kg for large scale bottom trawl) Boopendranath, [8] but higher than the average value reported by Vivekanandan et al. [54]. Vivekanandan et al. [54] reported that there was increase in emission per tonne of fish caught by Indian capture fisheries from 0.50 t in 1961 and 1.02 t in 2010. It is lower than the average value of emission rate by world capture fisheries i.e., 1.7 kg CO_2 kg fish^{-1} [49], 2.2 kg CO_2 kg fish^{-1} [39]. Trawlers emission rate is higher than other fishing method [8,27,31,54]. The carbon emission of bottom trawling to catch horse mackerel was 2.3 tonnes per tonne of fish landed [52]. Carbon emission of European fishing was estimated to have an average value of 1.8 k/kg fish landed in 2008 [11]. Ziegler et al. [58] suggested that to reduce GHG emissions from production, it is more efficient to apply life-cycle based criteria to label products with an exact number of grams of GHG emissions emitted per package.

There was significant difference ($p < 0.05$) between single-day fishing and multi-day fishing in terms of the energy intensity (Gj/tonne), fuel efficiency (kg of fuel/kg of fish; Litres/tonne) and carbon emission rate (kg of carbon/kg of fish). Significant difference ($p < 0.05$) was observed between SD & MDL, MDS & MDM, SD & MDM and SD & MDS. There was no significant difference between MDM & MDL and MDS and MDL.

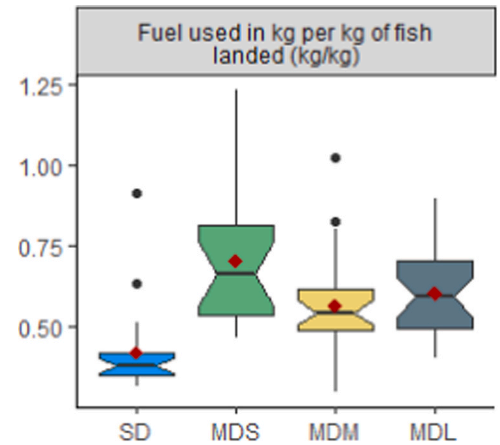

Fig. 2. Notched box plot representing fuel use intensity (in terms of kg of fuel utilized per kg of fish landed) of mechanized trawlers. Boxes represent 25th and 75th percentiles, the rhombus point represent the mean, central line represent median, whiskers show max and min values and point outside the boxes represent outliers. (SD = single-day, MDS = multi-day small, MDM = multi-day medium, MDL = multi-day large).

3.4. Actual and guesstimate of the emission on a regional and national level

Diesel used by motorized and mechanized boats in India increased by 6.65% annually and contributed 80–90% to the total emissions in marine fishing industry [37]. The annual total fuel consumption by trawlers of site I, site II and site III were estimated from the total number of active trawlers and the average annual fuel consumption by each trawler category (Table 3). Assuming that, 1769 trawlers were actively operated during 2016–18, the annual total fuel consumed by the trawlers of site I, site II and site III were estimated to be 119 million litres. About 59 nos. of SD trawlers contributed 1% while 68 nos. of MDS trawlers contributed 2% to the total annual fuel consumption (Fig. 4). Similarly, 445 nos. of MDM and 1197 nos. of MDL trawlers contributed 21% and 76% respectively to the total annual fuel consumption. Total annual fuel consumption was 1220 million litres by mechanized and motorized

Table 3
Estimated annual fuel consumption, annual energy utilization and annual carbon emission of mechanized trawlers from different study locations of north-west coast of India.

Type of trawler	Number of trawlers	Fuel consumption by one trawler in a year (L)	Total annual fuel consumption (L)	Total annual energy utilization (GJ)	Total carbon emission in a year
SD	59	13,788.5	8,13,520.3	31,166.0	2196,504.5
MDS	68	34,825.4	23,68,123.8	90,722.8	6393,931.2
MDM	445	56,987.3	2,53,59,361.9	971,517.2	68,470,370.0
MDL	1197	75,655.3	9,05,59,394.1	3469,330.4	244,510,364.1
Total	**1769**		**11,91,00,400.1**	**4562,736.3**	**321,571,169.8**

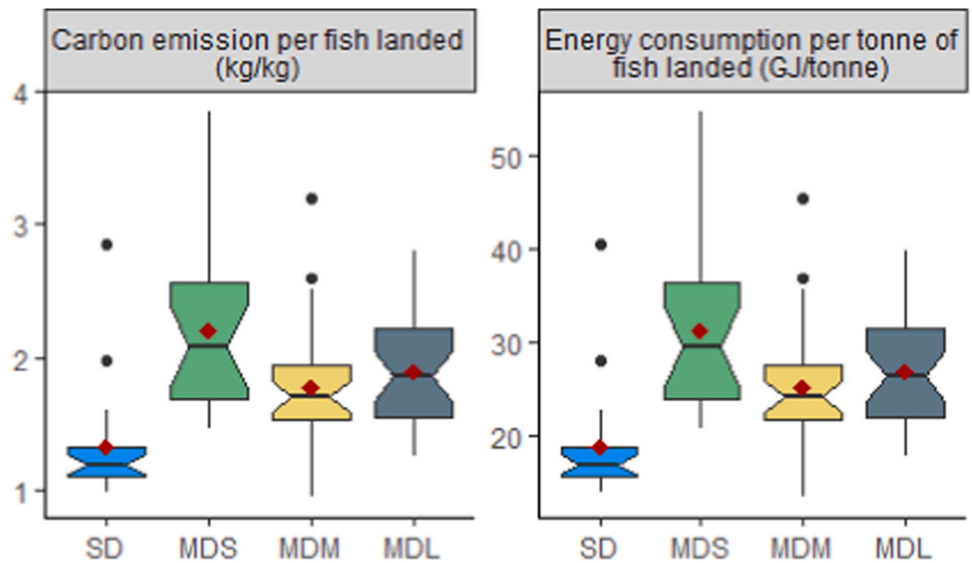

Fig. 3. Notched box plot representing efficiency of carbon emission (in terms of kg/kg) and energy consumption of mechanized trawlers. Boxes represent 25th and 75th percentiles, the rhombus point represent the mean, central line represent median, whiskers show max and min values and point outside the boxes represent outliers.

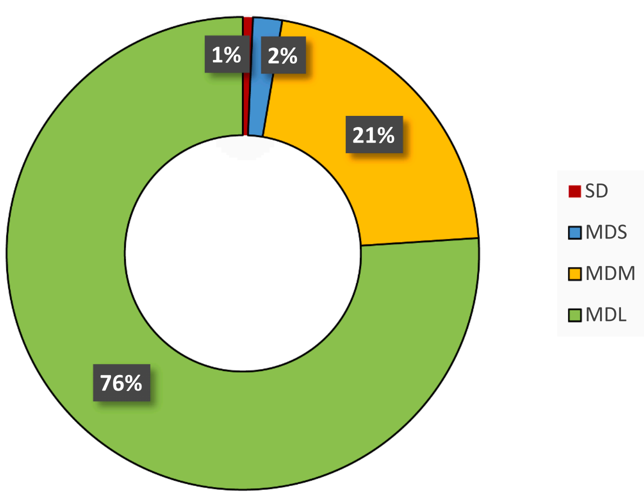

Fig. 4. Estimated share of different length-class of mechanized trawlers in the total fuel consumption, energy utilized and carbon emission by the trawlers of north-west coast of India.

fishing fleet of India annually [6]. 50 billion litres of fuel were consumed annually by world capture fishery [49]. 40 billion litres of fuel were utilized in 2011 by world fleet [39]. The average annual carbon emission by an individual trawler was 37,228.89 kg for SD, 94,028.4 kg for MDS, 153,866 kg for MDM and 204,269.31 kg for MDL trawlers. MDL trawlers altogether emitted highest amount of carbon contributing 76% to the carbon emission from site I, site II and site III (Fig. 4). Total carbon emission in a year by trawlers of site I, site II and site III are given in Table 3. The present study has estimated a total of 0.3 million tonnes of carbon emission by trawlers of site I, site II and site III which is 1/12th of that total emitted (3.60 million tonnes) [54] from Marine fishing vessel in India in 2010. Total emission from world fishing fleet in 2011 was estimated to 179 million tonnes of CO_2 eq. [39]. CO_2 emissions from world fleet was estimated to be 207 million tonnes in 2016 [28]. Total energy utilized by all the trawlers of Versova, SSD and NFW in a year are given in Table 3. The total energy utilized was highest for MDL (3469, 330.39 GJ) as the number of MDL trawlers was the highest compared to other category of trawlers. It contributed around 76% to the total energy utilized followed by MDM (21%), MDS (2%) and SD trawler (1%) (Fig. 4).

Trawl landings are the dominant contributor (>50%) to marine fish catch in India [18]. According to the total number i.e, 17,195 of trawlers operated along north-west coast (Maharashtra and Gujarat) recorded in Marine Fisheries Census-2010 [12] and the average value of Fuel consumption by one trawler in a year (45,314.125 L) obtained from Table 3, the diesel consumption by trawlers along NW coast, India is appraised to be 779.17 million litres. Similarly, for the trawlers in India [12], 1596.32 million litres of diesel was estimated to be consumed which is higher than the total emission from marine fishing fleet of India as reported by Boopendranath [6]. This may be attributed to the changes in fuel use intensity, target catch, fish abundance and location of fishing of the trawlers over a period of time. The corresponding CO_2 emission of trawlers from north west coast, and India as a whole estimated to be 2.1 million tonnes and 4.3 million tonnes respectively. The estimated value is higher than that of total CO_2 emission from marine fishing vessel of India in 2010 [54]. There was increased in CO_2 emission from marine fishing vessels of India during 1961–2010 which was due to increase in no. of fishing vessel, increase in efficiency of fishing boats and increase in scouting time. Total Energy utilized by trawlers of north west coast and India as a whole were 29,850,247.09 GJ and 61,155,248.89 GJ respectively.

Diesel is the main source of GHG emission [25,33,54,57] in marine capture fisheries and diesel engines are considered to be more efficient [5,14] but the present study showed that trawlers of site I, site II and site III has significant contribution to the total fuel consumption of Indian fishing fleet. Though the emission intensity in the present study is comparatively low but the overall total emissions are high due to large number of trawlers. This is a sign of overcapacity of trawlers along the north west coast. Strict regulation of trawl operation along north west coast is necessary in view of the high total energy utilized, number of trawlers, installed engine horsepower and negative implications to environment. Switching from energy intensive fishing methods to Low Impact Fuel Efficient (LIFE) fishing methods to be encouraged. Inclusion of emission in fish product ecolabeling would help awareness at consumer level. For this, a detailed LCA analysis of the product can be taken in further studies. Further, energy input and emissions to be considered for optimization of fleet size. Kyoto protocol aims at reduction of emissions of greenhouse gases to achieve sustainable management [10]. Also, conference of parties (COP21) of the United Nations Framework Convention on Climate Change aims at reduction of increase in global average temperature [21]. The result obtained in this study can be considered for climate change policies and implementation.

4. Conclusion

This study highlighted environmental impact of active fishing i.e., trawling off the north-west coast of India. This is an important finding with regard to concern for climate change and environmental impacts. Our findings show the necessity to reduce the operation of multi-day small trawlers and multi-day trawlers installed with inappropriate engine horsepower. The present study suggested the need for reduction in number of trawlers operated along north west coast to reduce emissions from fishing as a measure to support the climate change strategies. The west coast of India specifically north-west coast bound by Arabian Sea, contributed more in terms of landing than east coast with larger number of trawlers. Implementation of control measure in terms of maintaining numbers and installed engine horsepower in this area would help improve the fuel efficiency and carbon emission.

CRediT authorship contribution statement

Dr Manoharmayum Shaya Devi: Investigation, Formal analysis, Writing - original draft, Writing - review & editing. **Dr. K.A. Martin Xavier**: Conceptualization, Supervision, Validation, Visualization, Writing - review & editing. **Mr. Asem Sanjit Singh**: Data analysis, Writing paper & editing. **Dr. Leela Edwin**: Data curation, Editing the manuscript. **Dr. Veerendra Veer Singh**: Supervision, Methodology. **Dr. Latha Shenoy**: Conceptualization, Supervision, Methodology, Writing - review & editing.

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Conflict of interest

The authors declare no conflict of interest.

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