Carbon footprint by marine fishing boats of India

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In Indian marine fisheries, the enhanced fishing effort and efficiency in the last five decades has resulted in substantial increase in diesel consumption, equivalent to CO_2 emission of 0.30 million tonnes (mt) in the year 1961 to 3.60 mt in 2010. For every tonne of fish caught, the CO_2 emission has increased from 0.50 to 1.02 t during the period. Large differences in CO_2 emission between craft types were observed. In 2010, the larger mechanized boats (with inboard engine) emitted 1.18 t CO_2/t of fish caught, and the smaller motorized boats (with outboard motor) 0.59 t CO_2/t of fish caught. Among the mechanized craft, 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). There is scope to reduce CO_2 by setting emission norms and improving fuel efficiency of marine fishing boats.

Keywords: CO_2 emission, climate change, craft type, diesel consumption, fish catch.

MARINE fisheries contribute to nutritional security, livelihood and income generation to a large population in India. The sector currently faces several sustainability issues such as overexploitation, pollution and habitat degradation. In recent years, concerns have been extended to environmental issues, and climate change in particular, has been recognized as one of the critical issues in fisheries[1]. One of the characteristics of fishing is its dependence on fossil fuels and the resultant emission of greenhouse gases (GHGs). Fishing is considered as the most energy-intensive food production method in the world[2]. However, the energy cost of fishing has remained less obvious, and consequently receives much less attention than the direct impact that fishing has on stocks and associated marine ecosystems[3]. With regard to GHG emissions, insufficient attention has been paid to the fisheries sector as a whole and to fishing operations in particular. While the use of fossil fuels has increased the availability of fish to fisheries, the dependence of the fishing sector on fossil fuels raises concerns related to climate change, ocean acidification and economic vulnerability. When partial pressure of CO_2 increases in the atmosphere, miscibility in sea water increases, and the water absorbs more CO_2 (ref. 4). In an energy-sensitive, carbon-constrained world,

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Table 1. Increase in number and length of boats during 1961–2010 (refs 7 and 8)

Year	Mechanized boat < 30′	Mechanized boat 30–40′	Mechanized boat > 40′	Mechanized boat Total	Motorized boat	Total	Nonmotorized boat
1961	3,877	2,448	383	6,708	0	6,708	93,099
1973	4,088	3,315	683	8,086	0	8,086	106,480
1980	9,086	7,800	2,324	19,210	0	19,210	142,669
1998	20,019	16,200	12,851	49,070	50,922	99,992	76,596
2005	23,034	18,321	17,556	58,911	75,591	134,502	74,270
2010	25,468	22,566	24,525	72,559	71,313	143,872	50,618

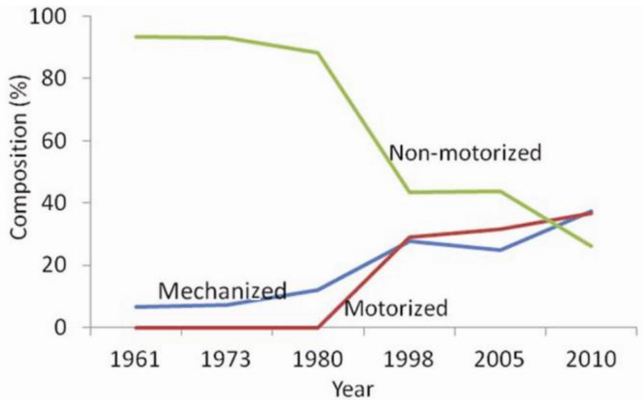

Figure 1. Change in composition of fishing boats (% of total number of boats) in India.

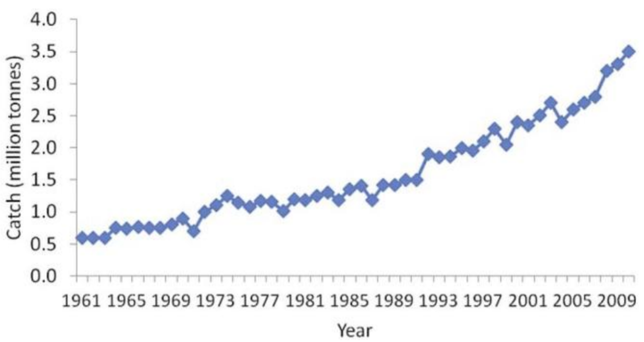

Figure 2. Estimated marine fish catch along the Indian coast during 1961–2010.

CO_2 by considering the standard conversion factor that 1 litre of diesel produces 2.63 kg CO_2 (www.eia.doe/gov). Other conversion factors used were: 1 litre of diesel weighs 0.83 kg and 1 t of diesel emits 3.16 t CO_2 (www.simetric.co.uk).

Mechanized fishing boats were introduced in India in the late 1950s, which became popular from the early 1960s. Consequently, the number of mechanized boats increased from 6708 in 1961 to 72,559 in 2010 (Table 1).

Parallel to the number of boats, the efficiency of the boats also increased. In 1961, only 5.7% of the boats were of large category (OAL > 40′), whereas in 2010 about 30% of the boats were of large category. The estimated mean engine horsepower of mechanized boats increased from about 55 hp in 1961 to 122 hp in 2010, an increase in fishing efficiency by 2.2 times over the 50-year period.

In the mid-1980s, outboard motor was introduced, which became immensely popular among small-scale fishing boats. Until then, the small-scale subsector, which was using boats < 10 m OAL, was dependent on wind, sail and oar for propulsion. Outboard motor with engine horsepower ranging from 10 to 30 hp was fitted to these smaller craft, and by 2010, as many as 71,313 boats were motorized (Table 1). It is estimated that the overall horsepower of marine fishing fleet in India (mechanized + motorized craft) increased approximately from 0.37 to 10.13 million in 50 years. In short, the fishing power of the entire fishing fleet increased by about 27 times.

Another important feature is the continued presence of the traditional sub-sector, viz. the non-motorized craft, which use wind, sail and oar for propulsion. However, their number has reduced over the last five decades (Table 1). Nevertheless, the overall composition of fishing fleet has changed (Figure 1) and fishing has gradually moved from an energy-free operation of the 1950s to energy-intensive activity in the last 60 years.

Consequent upon (i) increase in the number and efficiency of fishing boats, (ii) increased endurance at sea, and (iii) extension of fishing to offshore grounds, fish landings consistently increased from 0.6 million tonnes (mt) in 1961 to 3.53 mt in 2010 (Figure 2). This is different from the global trend, which showed stagnation of landings at around 90 mt since the year 1995 (ref. 10). However, the increase in landings in India did not commensurate with increase in fishing efficiency. Whereas the fishing efficiency increased by 27 times, the catch increased by only six times in the 50-year period.

Change in fleet composition was reflected in the contribution of the three sub-sectors to the overall landings. Contribution of the mechanized craft increased from 15.3% to the overall landings in 1961 to 76.2% in 2010, and that of the non-motorized craft reduced from 84.7% to a mere 3.7% (Figure 3).

All the mechanized and motorized fishing vessels in India use diesel for propulsion. We have estimated that diesel burning by the sector increased by 12 times, from 114.9 million litres (ml) in 1961 to 1378.8 ml in 2010 (Figure 4). The energy intensity for catching 1 t of fish increased from 191.5 l in 1961 to 393.3 l in 2010. It was also found that of the total quantity of diesel burned in all the six years that have been selected for analysis here, 84% was in the later three years, i.e. 1998, 2005 and 2010.

Burning fuel in the engine plays a large part in GHG emission. The CO_2 emission equivalents of burning diesel increased from 0.3 mt in 1961 to 3.6 mt in 2010 (Figure 5). However, as the fish catches did not proportionately

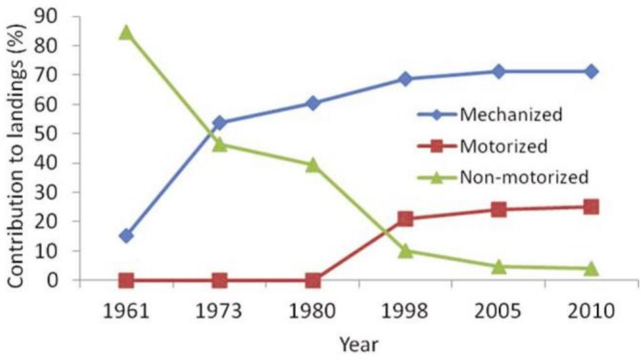

Figure 3. Contribution of three sub-sectors to fishing landings in India.

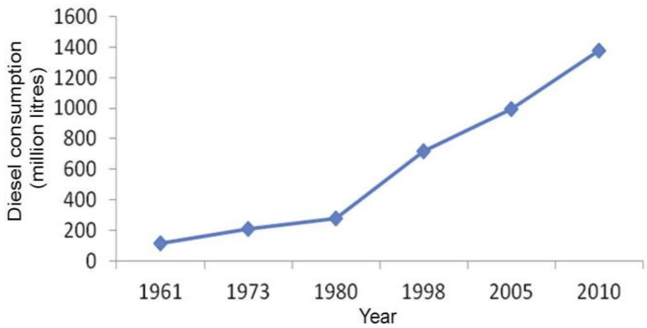

Figure 4. Estimated diesel consumption by marine fishing boats in India.

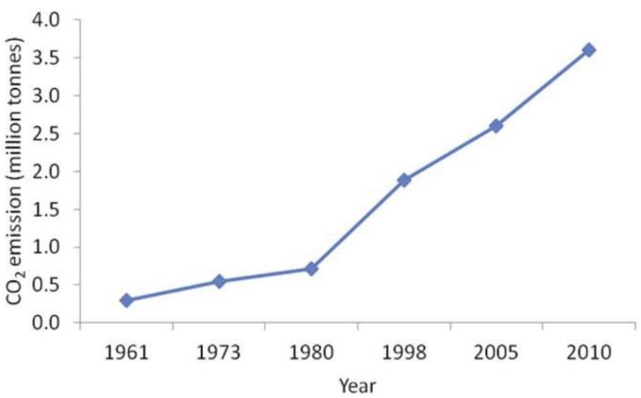

Figure 5. Estimated CO_2 emission by marine fishing boats in India.

increase, the CO_2 emission per tonne of fish caught increased from 0.50 t in 1961 to 1.02 t in 2010. In other words, the CO_2 emission doubled for every tonne of fish caught in 2010 with reference to the year 1961 (Figure 6). There are two major reasons for the substantial increase in absolute CO_2 emission as well as the intensity of emission.

(1) The increase in the number and efficiency of fishing boats contributed to the absolute increase in diesel consumption. For instance, Gulbrandsen[11] estimated that an 18′ boat fitted with outboard motor of 7 hp consumes 0.52 l diesel/nautical mile (nm), whereas a 22′ boat with 12 hp consumes 0.70 l diesel/nm at a speed of six knots along the southeast coast of India.

(2) The scouting time for fish has substantially increased over the years. Available information shows that the mechanized boats were involved in single-day fishing until the late 1980s, each trip lasting for not more than 24 h with actual fishing effort of 10–12 h per trip[12]. In later years, the larger boats, on an average, ventured for 5–7 days into the sea, with actual fishing effort of 45–50 h per trip, expending more time for fish scouting. These two factors are responsible not only for releasing more CO_2 into the atmosphere, but also for increase in the cost of fishing.

A large number of craft and gear combinations operate along the Indian coasts to exploit different fish stocks. In the mechanized sub-sector, the major craft types are trawler, gillnetter, bagnetter, dolnetter (a specialized bagnetter to catch bombayduck), liner, seiner and a few other miscellaneous types (Table 2). In the motorized sub-sector, the classification is based on boat design, construction material and gear used. The major types in this sub-sector are dugout canoes, catamaran, ringseiners (specialized miniature purseseiner to catch small pelagics), and plank-built, fiberglass, ferrocement and plywood boats.

In 2010, trawlers expended 35.58 million fishing hours, with catch rate of 44.4 kg/h (Table 3). Trawlers contributed 58.7% to the landings, and 71.1% to the CO_2 emission by the mechanized sub-sector. CO_2 emission rate by

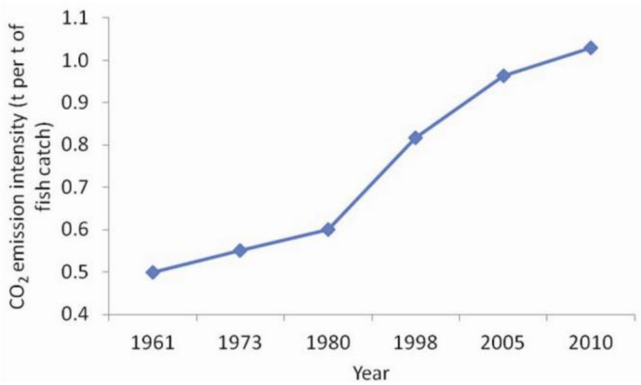

Figure 6. CO_2 emission in relation to fish catch.

Table 2. Number of boats in each type[7,8]

Craft type	2005	2010
Mechanized		
Trawler	29,241	35,228
Gillnetter	14,183	20,257
Dolnetter	8,862	11,794
Liner	1,190	1,158
Seiner	1,983	2,200
Others	3,452	1,922
Total	58,911	72,559
Motorized		
Dugout canoe	1,725	2,632
Catamaran	14,765	6,353
Plank-built	16,772	7,314
Ringseine	3,071	3,299
Fibreglass	36,545	39,693
Ferrocement	118	270
Plywood	0	8,909
Others	2,594	2,843
Total	75,591	71,313

trawlers was 63.5 t per fishing hour. In the mechanized sub-sector, the CO_2 emission intensity was highest for trawlers (1.43 t CO_2/t of fish caught) and considerably low for other craft types (0.56–1.07 t CO_2/t of fish caught). The average CO_2 emission by the mechanized sub-sector was 1.18 t CO_2/t of fish caught in 2010.

The motorized sub-sector expended 26.12 million fishing hours, with a catch rate of 27.2 kg/h (Table 3), and contributed 20.1% to the overall landings. CO_2 emission rate by the motorized sub-sector was 16.1 t per fishing hour; the sub-sector emitted 0.59 t CO_2/t of fish caught 2010.

Consistent increase in marine fish catches in the last 50 years masks several important issues confronting the sector. Expansion of fleet and new fishing grounds have helped increase the catches, but overexploitation of few stocks[13] and fishing down marine food web[14] have been reported. The catch (3.53 mt in 2010) is approaching the estimated potential yield (4.4 mt)[15]. In this communication, we have flagged another issue, the increasing fossil-fuel burning and thereby increase in the carbon footprint by the sector in its endeavour to take more fish. In that context, we have documented the extent to which Indian fisheries are dependent upon large inputs of non-renewable fossil fuels. On one hand, it indicates that the carbon footprint is highly sensitive to depletion of stocks, and that the average footprint may increase as fisheries consume more energy to maintain catch levels[16]. On the other hand, it indicates considerable potential for reduction of carbon footprint.

In addition to releasing more quantities of CO_2 into the atmosphere, the increasing fuel consumption over time indicates the following issues facing fisheries: (1) Increasing fuel consumption directly increases fishing cost and price of fish. Fuel cost accounts for 50–54% of operating cost of mechanized boats, and 36–44% of operating cost of motorized boats[17]. Majority of fish types, which form staple diet, is becoming unaffordable to common people due to increasing fishing cost. (2) Use of more energy by contemporary fisheries shows increasing scouting time as a result of resource scarcity. Availability of abundant fossil energy (even though it is becoming costly) would enable contemporary fisheries to continue until fish stocks collapse. (3) To sustain marine fisheries, India is implementing Marine Fishing Regulation Act. One of the prominent instruments of the act is closure of mechanized fishing for 45 days every year, which is being followed for the last 12–25 years in different regions along the coast. Analysing the performance of fisheries before and after implementation of seasonal ban, Vivekanandan *et al.*[18] concluded that the ban has helped stabilizing the annual fishing hours and has provided short-term benefits to increase the catches, but has not helped improving the stock biomass. Increasing fuel consumption, as observed in the present analysis, shows that stabilization of fishing effort is offset by increasing fishing efficiency.

Wide difference in CO_2 emission between craft types is due to the mode of operation. Active, towed gears consume more fuel than passive gears. For instance, operation of active gear, namely the trawl emits about 50% more gas than operation of passive gear like the gillnet. Trawlers use fuel for propulsion as well as for actual fishing operation, namely net release and haul. All the other craft use fuel only for propulsion and fishing operation is performed manually. Since all the trawlers employ bottom trawlnets, it may be assumed that demersal fisheries, which are predominantly trawl-dependent, are more energy-intensive compared to pelagic fisheries targeting small and large pelagic resources. Encircling gear types that are dragged for a limited distance at slow speed such as seines also consume high fuel[19]. However, as the seines can catch several tonnes of fish in one haul, fuel consumption/CO_2 emission is generally low in relation to quantity of catch[19].

It has been estimated that fossil-fuel burning by global fisheries is 42.4 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/t of live weight landed product[3,20]. Our estimate on emission by marine fishing boats in India (3.6 mt of CO_2) and fish production from marine capture fisheries (3.53 mt) shows that India contributes 2.7% and 3.9% to the global marine fisheries CO_2 emission (134 mt) and fish production (90 mt) respectively. Considering global estimate of 1.7 t CO_2/t of live weight landed, India's emission intensity (1.02 t CO_2/t of fish landed) is low by about 40% per tonne of live weight landed. In spite of substantial increase in the fishing power of Indian boats following introduction of larger vessels in recent years, these

Table 3. CO_2 emission by craft types in 2010

Craft	Fishing hours (million)	Catch (mt)	Catch rate (kg/h)	CO_2 emission (mt)	Emission rate (kg/h)	Emission intensity (t CO_2/t catch)
Mechanized craft						
Trawler	35.58	1.58	44.4	2.260	63.5	1.43
Gillnetter	13.60	0.21	15.4	0.190	14.0	0.90
Bagnetter	0.96	0.05	52.1	0.047	49.0	0.94
Dolnetter	7.52	0.35	46.5	0.376	50.0	1.07
Liner	0.29	0.01	34.5	0.007	24.1	0.70
Seiner	3.95	0.40	101.3	0.250	63.3	0.63
Others	0.80	0.09	112.5	0.050	62.5	0.56
Sub-total	62.70	2.69	42.9	3.180	50.7	1.18
Motorized craft						
All gear	26.12	0.71	27.2	0.420	16.1	0.59
Non-motorized craft						
All gear	12.11	0.13	0.01	Nil	Nil	Nil
Grand total	100.93	3.53	35.2	3.600	35.7	1.02

vessels cannot be compared with the industrial-type of vessels operated by several other countries. Most of the large commercial fishing vessels in several fishing nations exceed OAL 100′ with > 400 hp engine and undertake industrial fishing in distant, deep and oceanic fishing grounds with on-board processing facilities. On the contrary, the fishing vessels in India rarely exceed OAL 60′ and operate mostly within the continental shelf. According to FAO classification, as all the vessels in India are below OAL 24 m (= OAL 80′), they can be grouped as small-scale fisheries. Moreover, traditional, low-energy input, non-motorized craft, which depend on wind and animate energy to propel and haul nets, still persist in India. Thus, compared to industrial fishing practised elsewhere, fishing in India still remains labour-intensive rather than energy-intensive.

For this analysis, we have considered fuel consumption and CO_2 emission by fishing activity alone. Other fisheries-related activities which demand energy input, such as boat construction, net fabrication, post-harvest processing, transportation, etc. have not been considered here. It has been estimated that direct fuel energy inputs to fishing typically account for a major share of 75–90% of total energy inputs of the sector[21]. Life cycle assessment considering all these activities will provide a holistic estimation of carbon footprint by the marine fisheries sector[22]. Energy return on investment ratio, which is calculated from the energy input to edible food energy output will also be useful to calculate the energy efficiency of fisheries[6].

Considering the scales at which fuel is consumed, it is essential that it should be addressed explicitly in future fisheries planning[23], both with regard to subsidies from which fishing fleet benefit and the climate change impact of fossil fuels burned by fisheries[3]. Overfished stocks at lower densities and smaller individual body sizes require vessels to exert more effort, catch greater numbers of individual fish, travel to more distant or deeper grounds or fish over a wider area, all of which would increase fuel use per tonne of landings[24]. By implementing fuel efficiency norms for fishing vessels, there is scope for reducing CO_2 emission in India. Fuel efficiency is defined primarily by motor, propulsion and gear characteristics, but is substantially affected by fisheries management and practice. A significant reduction in CO_2 emissions can be achieved by switching from fuel-intensive fishing techniques. A shift from fuel-intensive active fishing methods such as trawling to passive methods such as seining, lining and gillnetting may provide a sustainable long-term solution. It is well demonstrated that, through technological improvements, gear modifications and behavioural change, the fishing sector can substantially decrease the damage to aquatic ecosystems, reduce GHG emissions (which is a legal obligation for governments under existing international conventions) and lower operational costs for fuel without excessive negative impacts[9].

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Baseline sensitivity of brinjal shoot and fruit borer, *Leucinodes orbonalis* (Guenée) in South India to Cry1Ac insecticidal protein of *Bacillus thuringiensis*

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Studies were carried out to determine the baseline sensitivity of the brinjal shoot and fruit borer, *Leucinodes orbonalis* (Guenée) to Cry1Ac insecticidal protein of *Bacillus thuringiensis* (*Bt*) by a diet incorporation method for the populations collected from different locations in South India. A total of 14 districts from five South Indian states (Karnataka, Maharashtra, Andhra Pradesh, Tamil Nadu and Goa) were sampled during 2009 and 2010 cropping seasons to understand the spatial baseline sensitivity. Median lethal concentrations (LC_{50}) ranged between 0.020 and 0.042 ppm and moult inhibitory concentration (MIC_{50}) values for *L. orbonalis* ranged from 0.003 to 0.014 ppm for 14 populations across two seasons. The overall variability in the sensitivity was 1–4-fold between the study locations. These benchmark values will be referenced while monitoring resistance to Cry1Ac provided *Bt* brinjal hybrids expressing Cry1Ac are approved for commercial cultivation in India.

Keywords: *Bacillus thuringiensis*, baseline sensitivity, brinjal, Cry1Ac endotoxin, *Leucinodes orbonalis*.

BRINJAL, *Solanum melongena* (family Solanaceae), is a widely cultivated common man's vegetable in India. Indian people annually consume between 8 and 9 million metric tonnes of brinjal which is grown on > 500,000 ha. In spite of its popularity among small and resource-poor farmers, brinjal cultivation is often input-intensive, especially for insecticide applications. Like any other solanaceous vegetables, brinjal has a diverse pest complex, but the most serious is the shoot and fruit borer (SFB), *Leucinodes orbonalis* (Guenée) (family: Pyralidae). The pest poses a serious problem because of its high reproductive potential, rapid turnover of generations and intensive cultivation of brinjal both in wet and dry seasons of the year. The larva confines its feeding activities on the shoot in the early stages of crop causing wilting and dieback of the branch terminals, which reduces the fruit-bearing capacity of the plant, and later, on the fruits which become unfit for human consumption[1]. Fruit feeding is the major cause of damage. It feeds on brinjal shoots and

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