Carbon footprint of marine fisheries: life cycle analysis from Visakhapatnam

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The contribution of marine fisheries in Visakhapatnam at all stages of its life cycle to climate change during 2010–2012 was studied by determining its carbon footprint. Pre-harvest phase consisted of vessel construction and maintenance and provision of fishing gear; harvest phase included harvest from mechanized and motorized craft and post-harvest phase involved fish transportation and fish processing. The functional unit selected was 1 kg of marine fish to the consumer. Fuel and electricity consumption was 0.48 l/kg and 0.255 kWh/kg of fish. The C and CO_2 emitted were 0.382 kg C/kg and 1.404 kg CO_2/kg of fish. The highest consumption of energy and the highest emissions of CO_2 were observed from the harvest phase. The fuel and electricity consumption and C and CO_2 emissions were high for mechanized landings and low for motorized landings. Reduction in energy consumption and subsequent emissions is possible in mechanized craft by increasing the fuel efficiency of marine diesel engines, controlling craft speed, using large propeller with lower revolutions and reducing the craft drag.

Keywords: Carbon footprint, CO_2 emission, energy consumption, lifecycle analysis, marine fisheries.

As fishing relies entirely on the extraction of organisms from essentially wild ecosystems, most concerns regarding the environmental impacts of fishing have traditionally focused on its direct impacts on targeted stocks[1–3], by-catch and discards[4,5], destruction to benthic communities and substrates[6,7] and on the general alteration of ecosystem structure and function[8]. While this focus on biological concerns is understandable given the degraded state of many fish populations and aquatic ecosystems, it is also of paramount importance to study the diverse range of environmental impacts which flow from the interlinked series of industrial activities that characterize most modern fishing systems. These include the material and energy dissipated in the construction and maintenance of fishing vessels[9], provision of fishing gear[10], combustion of fuel while fishing[11–13] and transporting catch to markets or for further processing[14], and the discharge of waste and loss of fishing gear at sea[15]. The best way to evaluate the range of environmental impacts

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associated with the industrial aspects of fishing is through the use of life cycle assessment (LCA). LCA – also called ecobalance – is a method to assess the environmental impacts of a product/process. It is based on a perspective which includes the whole life cycle. Hence, the environmental impacts of a product/process are evaluated from cradle to grave, which means from the resource extraction up to the disposal of the product and also the production of waste. Estimation of 'carbon footprint' is similar to a simplified form of LCA. It provides a single numerical index of environmental performance which is easily understandable. Carbon footprint is a component of an ecological footprint defined as the total amount of carbon dioxide and other greenhouse gases emitted over the full life cycle of a product. The carbon footprint is usually measured in equivalent tonnes of CO_2. Fisheries, however, is a minor contributor to climate change. The average estimated ratio of CO_2 emissions for capture fisheries is around 3 teragrams (10^{12}) per million tonnes of fuel combustion.

Andhra Pradesh, with a coastline of about 974 km spread over nine coastal districts, ranks fifth in contribution to the marine fish landings of the country. The annual average catch has shown an increasing trend over the years. Visakhapatnam district, situated in the northern part of the state, contributes roughly a quarter to its total marine landings. The highest marine catch and the highest number of craft (mechanized and motorized) for Andhra Pradesh are recorded from Visakhapatnam district. In the district, bulk of the catch is landed in and around the city of Visakhapatnam. Marine fishing industry provides nutritional security, livelihood and income generation to a substantial part of the population in the city. The fishery at Visakhapatnam is contributed by mechanized, motorized and traditional sectors. However, the motorized and mechanized sectors are slowly and steadily replacing the traditional sectors thereby resulting in increased CO_2 emissions. The Visakhapatnam Fishing Harbour, which is the largest landing centre in the Visakhapatnam district, is home to all the mechanized craft operating from the district. Pedajalaripeta, Lawson's bay, Jodugullapalem, Mangamaripeta and Bheemilipatnam are the other landing centres in the city of Visakhapatnam harbouring motorized craft. The present study was undertaken as part of an effort to estimate the contribution of marine fisheries at Visakhapatnam to climate change during 2010–2012 by determining its carbon footprint. Additionally, fuel consumption and subsequent CO_2 emission data could be interpreted to gain insight into increasing fishing costs and fish prices, which in future would help in evolving policies on regulating fishing efforts and fuel subsidies and suggesting suitable climate change mitigation measures. In the present study the environmental performance of marine fisheries is evaluated at all stages of its life cycle. Earlier studies have focused only on the harvest phase, thereby ignoring the pre-harvest and post-harvest phases[16,17].

Carbon footprint is assessed via compiling relevant inputs and outputs of the marine fishing system and calculating the possible associated environmental impacts. The environmental impacts are calculated based on a functional unit which provides a reference to which the inputs and outputs are related. In our analysis, the functional unit selected was 1 kg of marine fish to the consumer, while its boundaries encompassed all major industrial activities required to catch, process and deliver marine fish to the consumer. The life cycle of the functional product in the present study was divided into three main phases – pre-harvest phase, harvest phase and transportation and post-harvest phase. Pre-harvest phase comprised of two activities, viz. vessel construction and maintenance, and provision of fishing gear. Harvest phase included harvest from mechanized and motorized craft. Post-harvest phase consisted of fish transportation and fish processing.

All the boat-building yards in the city of Visakhapatnam were surveyed extensively to gain insight into the materials used for construction and maintenance of mechanized and motorized craft. Data on fuel and electricity consumed at the boat-building yards were collected to estimate energy inputs and emissions for vessel construction and maintenance. The fuel involved in transportation of timber from timber depots was also taken into account. As prior analyses have found that the provision of fishing gear typically makes a smaller contribution to the overall material and energy profile of a fishery when compared with inputs to vessel construction[10,12,18,19], we have excluded it from this analysis. Solid waste and wastewater related to daily life on-board have not been taken into account in the present study, due to the insignificant importance shown in other studies[20] and to the fact that they are not directly connected to the production activity[10]. The average number of mechanized and motorized craft operating from Visakhapatnam during 2010–2012 was obtained from Marine Fisheries Census carried out by the Central Marine Fisheries Research Institute (CMFRI) and this was further corroborated in conversations with the fishermen. There are 615 mechanized craft operating from Visakhapatnam Fishing Harbour and 850 motorized craft operating from nearby centres, viz. Pedajalaripeta, Lawson's bay, Jodugullapalem, Mangamaripeta and Bheemilipatnam. A total of 124 mechanized craft and 166 motorized craft were thoroughly inspected to record their overall length, gross registered tonnage and propulsive engine power. The crew were interviewed for operational data which included the type, quality and amount of diesel fuel burned, number of voyages in a year, average duration of each voyage, ice carried in each voyage and crew size. Fishing effort data during 2010–2012 for all the above landing centres were obtained from Fishery Resource Assessment Division of CMFRI and were used to confirm the statements of the fishing crew. The fuel consumed during fishing coupled with electricity consumption for manufacture of ice carried in each fishing boat were energy input and emission associated with the harvest phase. The average marine landings at Visakhapatnam during 2010–2012 from the mechanized and the motorized craft was calculated following the procedure adopted by the Fishery Resource Assessment Division of CMFRI[21]. Traders buying marine fishes at the landing centre and sending them for sale into city markets, or drying and transporting these dried fishes to interior markets or storing them in ice and transporting them in thermocol boxes and insulated containers to distant places, or taking them to the processing plants were also extensively interviewed. The average quantum of landings from mechanized and motorized craft during 2010–2012 that were sold fresh, dried and transported, iced and transported and sent to processing plants was estimated from personal inspection and in consultation with the traders and processors. Eleven processing plants in and around Visakhapatnam were visited, and managers and technical staff were queried regarding production, electricity consumption and use of energy, refrigerants, packaging material, etc. The electricity consumption for manufacture of ice for storage and transportation and also for manufacture of thermocol boxes was obtained from ice factories located in proximity to Visakhapatnam Fishing Harbour. The fuel consumed for transporting fresh fish, dried fish, iced fish and processed fish to local and far-off markets was calculated in discussion with the traders, processors and transporters and by also keeping in view the shortest road distance between Visakhapatnam and the place to which the fish is transported and the mode of transport. The fuel consumed during transportation and electricity consumed in processing and ice manufacture were energy input and emission during the post-harvest phase.

All energy inputs and associated emissions in pre-harvest phase, harvest phase and transportation and post-harvest phase were converted into standardized indicators based on standardized characterization factors and were expressed in terms of C and CO_2 (ref. 22). The mechanized and motorized fishing vessels at Visakhapatnam use diesel for propulsion. Similarly, diesel was the fuel used in vehicles for transportation. For the estimation of C and CO_2 emission from fuel (diesel), the fuel (diesel) consumption was converted using the standard conversion factor that 1 l of fuel (diesel) produces 10.7 kWh of heat, and the C and CO_2 emitted from 1 kWh is 0.68 and 0.25 kg respectively[23]. The delivered grid electricity was used for the estimation of C and CO_2 and its consumption was noted from the electric meter. For the estimation of C and CO_2 emission from delivered grid electricity, the standard conversion factor that 1 kWh of delivered grid electricity produces 0.117 kg C and 0.43 kg CO_2 was used[23].

The materials required for construction of mechanized craft (overall length (OAL) 10–12 m) included wood (800–1000 cu ft), fibre (280–300 kg), resin (800 kg), gel (100 kg), iron fittings (200 kg), marine plywood sheets of 8 mm thickness (25 sheets) and paint (250–300 l). The materials required for fabricating a motorized craft (OAL 8–10 m) included wood (40–60 cu ft), fibre (70–80 kg), resin (200 kg), gel (10 kg), thermocol (20 kg) and marine plywood sheets of 8 mm thickness (8 sheets). There are 615 mechanized craft operating on an average from Visakhapatnam. With average lifespan of a mechanized craft being about 10 years, it was estimated that on an average 62 new mechanized craft are manufactured each year to replace the old damaged ones. There are 850 motorized craft operating from Pedajalaripeta, Lawson's bay, Jodugullapalem, Mangamaripeta and Bheemilipatnam. The average life of a motorized craft was found to be 4 years; hence every year 218 new motorized craft are manufactured to replace the old ones. Timber is transported from timber depots located 150–200 km away from the boat-building yard. The average fuel consumption involved in timber transportation for construction of one new mechanized craft amounted to 400 l. The average fuel consumption required for running a generator at the boat-building yard for constructing one mechanized craft and one motorized craft was 450 and 100 l respectively. The average electricity consumption at the boat-building yard for one mechanized and one motorized craft construction was 350 and 90 kWh respectively. The average annual fuel and electricity consumption for manufacture of 62 new mechanized craft and 218 new motorized craft was 52,700 l and 21,700 kWh, and 21,800 l and 19,350 kWh respectively. On detailed inspection and interviews at the boat-building yard and with the fishermen, it was decided that on an average the fuel and electricity consumed for maintenance of both old mechanized and motorized craft amounted to 10% of that required for construction of new ones. Thus, the average annual fuel and electricity consumption for maintenance of existing mechanized and motorized craft was 47,430 l and 19,530 kWh, and 6,540 l and 5,805 kWh respectively.

Out of 615 mechanized craft, 550 performed multi-day fishing voyages whereas 65 performed single-day voyages. The average number of voyages in a year performed by multi-day and single-day craft was 15 and 165 respectively. The average fuel consumption and the average ice carried in each voyage for multi-day and single-day craft were 3,000 l and 15 tonne, and 120 l and 0.45 tonne respectively. Average annual fuel consumption for 550 multi-day craft was 24,750,000 l and for 65 single-day craft it was 1,287,000 l. Average annual ice requirement for 550 multi-day craft was 123,750 tonne and for 65 single-day craft it was 4,826.3 tonne. The grid electricity consumed for manufacturing this annual ice requirement was 7,425,000 kWh for 550 multi-day craft and 289,575 kWh for 65 single-day craft. Among the 850 motorized craft, 750 performed single-day fishing operations with 160 fishing trips annually and carrying 18 l fuel on

Table 1. Energy consumed in mechanized, motorized and total catches at pre-harvest, harvest and post-harvest phases

	Mechanized catch		Motorized catch		Total catch	
	Fuel (l)/ kg of fish	Electricity (kWh)/ kg of fish	Fuel (l)/ kg of fish	Electricity (kWh)/ kg of fish	Fuel (l)/ kg of fish	Electricity (kWh)/ kg of fish
Pre-harvest	0.0022	0.0009	0.0015	0.0013	0.0020	0.0010
Harvest	0.5722	0.1696	0.1736	0.0377	0.4526	0.1300
Post-harvest						
Dried fish	0.0025		0.0017		0.0022	
Iced fish	0.0106	0.0083	0.0106	0.0083	0.0106	0.0083
Processed fish	0.0009	0.1065	0.0393	0.1195	0.0124	0.1104
Fresh fish	0.0045	0.0068	0.0020	0.0030	0.0038	0.0056
Total	0.5929	0.2920	0.2286	0.1697	0.4836	0.2553

an average for each fishing trip. The remaining 100 motorized craft performed multi-day fishing operations with 35 fishing trips annually and carrying 350 l fuel and 3.5 tonne of ice on an average for each fishing trip. Annual fuel consumption on an average for 750 single-day motorized craft and 100 multi-day motorized fishing craft was 2,160,000 and 1,225,000 l respectively. For manufacture of 12,250 tonne of ice required annually on an average by 100 multi-day motorized fishing craft, 735,000 kWh of grid electricity is consumed.

The annual average total landings from 615 mechanized craft and 850 motorized craft at Visakhapatnam was 45,500 and 19,500 tonne respectively. Out of 45,500 tonne landings from mechanized craft, 6,825 tonne was dried and transported to interior markets, 11,375 tonne was packed with ice in thermocol boxes and transported to distant places, 6,825 tonne was sent to processing units and 20,475 tonne was sold in local domestic markets. From the 19,500 tonne landings of motorized crafts, 1,950 tonne was dried and transported to interior markets, 10,875 tonne was packed with ice in thermocol boxes and insulated containers and transported to distant places, 2,775 tonne was sent to processing units and 3,900 tonne was sold in local domestic markets. The annual fuel consumed for transporting dry fish to interior markets in Madhya Pradesh and Chhattisgarh located approximately 750 km from Visakhapatnam was 113,739 l for mechanized landings and 32,497 l for motorized landings. Similarly, the fuel consumed annually for transporting iced fish in thermocol boxes and insulated containers to Chennai and Kolkata located approximately 1000 km from Visakhapatnam was 473,484 l for mechanized catches and 952,922 l for motorized catches. Additionally some fuel is consumed for distributing fish in local markets and for transporting fish to and fro from processing units and also for transporting thermocol boxes to the landing centre, which amounts to 254,231 l for mechanized catches and 59,306 l for motorized catches. In one thermocol box at the fishing harbour, 40 kg of fish is packed with 20 kg of ice whereas in insulated containers fish is packed with ice in 1 : 1 ratio. The annual requirement of thermocol boxes was 284,375 for the mechanized landings and 121,875 for the motorized landings. Since manufacture of one thermocol box consumed 0.12 kWh of grid electricity, the annual total electricity consumed for manufacture of thermocol boxes was 34,125 kWh for mechanized catches and 14,625 kWh for motorized catches. For the mechanized and the motorized landings, 5687.5 and 8,437.5 tonne of ice was required for packing fish in thermocol boxes and insulated containers, 6,825 and 2,775 tonne of ice was required for transporting fishes to processing plants and 5118.8 and 975 tonne of ice was required for domestic fish distribution respectively. The electricity consumed for mechanized and the motorized landings was 341,250 and 506,250 kWh for manufacture of ice for use in thermocol boxes and insulated containers, 409,500 and 166,500 kWh for manufacture of ice for transportation to processing plants and 307,125 and 58,500 kWh for manufacture of ice for domestic distribution respectively. The electricity consumed in 11 processing plants for processing 6825 tonne of mechanized landings and 2,775 tonne of motorized landings was 4,436,250 and 1,803,750 kWh respectively.

The fuel and electricity consumption was on an average 0.48 l/kg and 0.255 kWh/kg of marine fish at all life cycle phases at Visakhapatnam. The total fuel and electricity consumption in marine fisheries was 31,436,649 l and 16,593,835 kWh. Fuel and electricity consumption was low, 0.23 l/kg and 0.17 kWh/kg, for motorized landings, while it was high, 0.59 l/kg and 0.29 kWh/kg, for mechanized landings. The fuel and electricity consumed per kg of fish caught by the mechanized and motorized craft at pre-harvest, harvest and post-harvest phase is depicted in Table 1. Mechanized catches contributed 85.8% to the total fuel burnt and 80% to the total electricity consumed. The rest was contributed by the motorized landings. The harvest phase in mechanized (96.5%) and motorized (75.8%) catches burnt the most fuel. Electricity consumption in harvest phase and post-harvest phase was 58% and 41.6% for the mechanized landings, while it was 22.2% and 77% in harvest phase and post-harvest phase for the motorized landings.

Table 2. Emissions from mechanized, motorized and total catches at pre-harvest, harvest and post-harvest phases

	Mechanized catch		Motorized catch		Total catch	
	kg C emitted/ kg of fish	kg CO_2 emitted/ kg of fish	kg C emitted/ kg of fish	kg CO_2 emitted/ kg of fish	kg C emitted/ kg of fish	kg CO_2 emitted/ kg of fish
Pre-harvest	0.002	0.006	0.001	0.004	0.002	0.006
Harvest	0.436	1.604	0.131	0.481	0.345	1.267
Post-harvest						
Dried fish	0.002	0.007	0.001	0.004	0.002	0.006
Iced fish	0.009	0.032	0.009	0.032	0.009	0.032
Processed fish	0.013	0.048	0.043	0.157	0.022	0.081
Fresh fish	0.004	0.015	0.002	0.007	0.004	0.013
Total	0.466	1.712	0.186	0.685	0.382	1.404

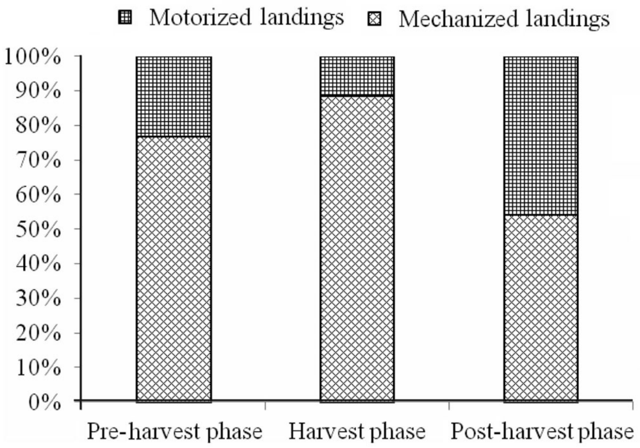

Figure 1. Contribution by mechanized and motorized landings to emissions at all life cycle stages.

Fisheries contribute to climate change by pumping out to the atmosphere 130 million tonnes of CO_2 every year or an average fuel consumption of 0.62 l/kg of landed fish[24]. Boopendranath[16] estimated the annual fuel consumption by the mechanized and motorized fishing fleet of India as 1,220 million litres forming 1% of the total fossil-fuel consumption in the country, which released 3.17 million tonnes of CO_2 into the atmosphere with an average of 1.13 tonnes of CO_2/tonne of landed marine fish. Vivekanandan *et al.*[17] reported energy intensity of the harvest phase as 393.3 l/tonne for marine fish caught in India. Energy intensity in North Atlantic fisheries ranged from 230 to 2,700 l/tonne with mean of 510 l/tonne (ref. 25). Tyedmers[12] reported that fuel use in fisheries ranges from 20 to 3,400 l/tonne of fish landed. Hospido and Tyedmers[20] reported an average fuel consumption of 0.44 l/kg for nine Spanish vessels targeting skipjack and yellowfin tuna. The resulting partial footprint was 1.15–5.27 kg CO_2/kg of landed tuna. The carbon footprint of tuna caught using long line gear, large pump boats and small pump boats was 6.64–8.86, 2.11–4.70 and 3.26–4.35 kg CO_2/kg landed tuna respectively. The carbon footprint during cold storage, canning and transportation ranged from 0.0025 to 0.12, 0.42 to 1.38 and 0.11 to 1.53 kgCO_2/kg landed tuna respectively. Carbon footprint was also calculated both for trawled and for long-lined cod, as 5.14 and 1.58 kg CO_2 equivalence respectively[26].

At Visakhapatnam, 0.382 kg C and 1.404 kg CO_2 was emitted per kilogram of marine fish over all its life cycle stages. The highest emission was in the harvest phase, wherein 0.345 kg C and 1.267 kg CO_2 was emitted per kilogram of marine fish landed. Harvest phase contributed 90.2% to the total emissions. The emissions at the pre-harvest and post-harvest phases were trivial, to the tune of 0.002 kg C and 0.006 kg CO_2 and 0.036 kg C and 0.131 kg CO_2 respectively. During post-harvest phase, icing and processing contributed more in the range of 0.009 kg C and 0.032 kg CO_2 and 0.022 kg C and 0.081 kg CO_2 respectively. The total kg C and CO_2 emitted per kilogram of fish caught by the mechanized and motorized craft at pre-harvest, harvest and post-harvest phase is summarized in Table 2. The harvest phase contributed the most 93.7% for the mechanized craft and 70% for the motorized craft, to the emission of C and CO_2. Post-harvest phase in motorized landings contributed 29.3% to the emissions. Mechanized landings contributed 77%, 89% and 54% to the emissions during pre-harvest, harvest and post-harvest phases, whereas motorized catches contributed 23%, 11% and 46% (Figure 1).

According to Vivekanandan *et al.*[17], for every tonne of fish caught, CO_2 emission increased from 0.5 to 1.02 tonne during 1961–2000. However, they considered only the harvest phase and the pre-harvest and post-harvest phases were ignored. They reported that mechanized craft emitted 1.18 tonne CO_2/tonne of fish caught and the motorized boats emitted 0.59 tonne CO_2/tonne of fish caught. Emission intensity at Visakhapatnam (1.404 kg CO_2/kg of fish landed) is low by about 17.5% per tonne of live weight landed compared to the global estimate of 1.7 tonne CO_2/tonne of live weight landed[24]. Internationally, most of the large commercial fishing vessels with OAL > 100 ft and engine capacity > 400 hp undertake industrial fishing in distant, deep and oceanic fishing grounds with on-board processing facilities. On the contrary, at Visakhapatnam the fishing craft rarely exceed 53 ft in OAL and they operate mostly in near-shore waters. Fishing in India is still labour-intensive rather than the energy-intensive industrial fishing practised in other nations. It has been observed that direct fuel energy inputs to fishing typically account for a major share of 90% of total energy inputs. The higher efficiency of mechanized craft has contributed to its increase in diesel consumption. Similar results were obtained earlier, where an 18 ft boat with 7 hp OBM (out-board motor) consumed 0.52 l diesel/nautical mile (nm), whereas a 22 ft boat with 7 hp OBM consumed 0.70 l diesel/nm at a speed of 6 knots[27]. Moreover, the scouting time for fish has substantially increased over the years. Increasing fuel consumption directly increases the fishing cost and price of fish. Fuel cost accounts for 50–54% of the operating cost of mechanized boats and 36–44% of the operating cost of motorized boats[17].

A significant reduction in CO_2 emissions could be achieved by switching over from fuel-intensive fishing techniques to alternate ones that use less fuel. From the results obtained in the present study, it is obvious that the main area for improving the environmental impact of fishing lies in the harvest phase and in particular in the operation of the fishing vessels. The variation in CO_2 emission between craft types observed in the present study is due to the mode of operation. Mechanized craft consumed more fuel than motorized craft. Mechanized craft use fuel for propulsion as well as for actual fishing operation. Motorized craft, on the other hand, used fuel only for propulsion and fishing operation is performed manually. A combination of improvement in fish-finding technologies and increase in fuel efficiency of marine diesel engines is the solution for the mechanized sector. The choice of operating speed of mechanized craft is the most important measure for saving fuel. With reduction in speed to the tune of 10–20%, particularly while cruising to the fishing ground and back, fuel saving is possible to the extent of 35% to 61% (ref. 27). Considerable fuel saving in mechanized craft is also possible by usage of large propeller with lower RPM (larger gear reduction ration) matched to absorb the engine power. The drag of mechanized craft, which contributes significantly to high fuel consumption, varies depending on the design, and rigging and operating conditions. Using knotless netting, thinner twine and large mesh netting are viable options for reducing drag in mechanized craft[28].

Mechanized craft at Visakhapatnam catch almost all demersal, crustacean and cephalopod resources and few pelagic resources, whereas motorized craft land mostly pelagic resources. Therefore, it can be concluded that demersal, crustacean and cephalopod fisheries are much more energy-intensive than pelagic fisheries. Thrane[13] compared the fuel efficiency of various craft and recommended focusing on cleaner fishing techniques and passive and semi-active fishing methods. He opined that sustainable management of fish stocks could reduce the amount of energy used per kilogram of landed fish as low catch rates are linked to high fuel consumption.

The use of large amounts of fossil fuel (diesel) in fisheries has resulted in considerable emissions of greenhouse gases as evident in the present study. Increasing levels of greenhouse gases are leading to global climate change with catastrophic long-term implications for the marine environment. Climate change would lead to shifts in abundance and distribution of fish populations. Acidification caused due to release of greenhouse gases would lead to the death or migration of fish stocks. Climate change also disrupts marine food webs, which would have serious consequences for the survival and productivity of fish species. These climate change-related impacts would pressurize the fish stocks that are heavily stressed because of overfishing. It has been observed that the most fuel-intensive fishing practices not only contributed the most to climate change, but are also often the most damaging to seabed habitats and reef formations. The fishing industry at Visakhapatnam, and in general, could lower its fuel costs, reduce its greenhouse gas emissions and decrease the damage it inflicts on marine ecosystems by shifting to less fuel-intensive and low-impact fishing methods and gears than simply using more energy-efficient engines. From management perspective, subsidies to fuel-efficient fishing methods, fuel taxes, or banning of certain fishing methods could be introduced as measures to promote sustainable fisheries. Another possibility would be the inclusion of eco-labelling of fish products.

1. Pauly, D. *et al.*, Towards sustainability in world fisheries. *Nature*, 2002, **418**, 689–695.
2. Christensen, V., Guenette, S., Heymans, J. J., Walters, C. J., Watson, R., Zeller, D. and Pauly, D., Hundred-year decline of North Atlantic predatory fishes. *Fish Fish*., 2003, **4**(1), 1–24.
3. Myers, R. A. and Worm, B., Rapid worldwide depletion of predatory fish communities. *Nature*, 2003, **423**, 280–283.
4. Alverson, D. L., Freeberg, M. H., Murawski, S. A. and Pope, J. G., A global assessment of fisheries by catch and discards. FAO FISH, Technical Paper No. 339. FAO, Rome, 1994.
5. Glass, C. W., Conservation of fish stocks through bycatch reduction: a review. *Northeast Nat*., 2000, **7**(4), 395–410.
6. Johnson, K. A., Review of national and international literature on the effects of fishing on benthic habitats. NOAA Technical Memorandum NMFSF/SPO No. 57, Maryland, USA, 2002.
7. Chuenpagdee, R., Morgan, L. E., Maxwell, S. M., Norse, E. A. and Pauly, D., Shifting gears: assessing collateral impacts of fishing methods in US waters. *Front. Ecol. Environ*., 2003, **1**(10), 517–524.
8. Jackson, J. B. C. *et al.*, Historical overfishing and the recent collapse of coastal ecosystems. *Science*, 2001, **293**, 629–638.
9. Watanabe, H. and Okubo, M., Energy input in marine fisheries of Japan. *Bull. Jpn. Soc. Sci. Fish*., 1989, **53**, 1525–1531.
10. Ziegler, F., Nilsson, P., Mattsson, B. and Walther, Y., Life cycle assessment of frozen cod fillets including fishery-specific environmental impacts. *Int. J. Life Cycle Assess*., 2003, **8**(1), 39–47.
11. Ziegler, F. and Hansson, P. A., Emissions from fuel combustion in Swedish cod fishery. *J. Clean. Prod*., 2003, **11**, 303–314.

12. Tyedmers, P. H., Fishing and energy use. In *Encyclopedia of Energy* (ed. Cleveleand, C.), Elsevier, Amsterdam, 2004, vol. 2, pp. 683–693.
13. Thrane, M., Environmental impacts from Danish fish product – hot spots and environmental policies. Ph D thesis, Alborg University, Denmark, 2004.
14. Andersen, O., Transport of fish from Norway: energy analysis using industrial ecology as the framework. *J. Clean. Prod.*, 2002, **10**, 581–588.
15. Derraik, J. G. B., The pollution of the marine environment by plastic debris: a review. *Mar. Pollut. Bull.*, 2002, **44**(9), 842–852.
16. Boopendranath, M. R., Responsible fishing operations. In *Handbook of Fishing Technology* (eds Meenakumari, B. *et al.*), Central Institute of Fisheries Technology, Cochin, 2009, pp. 259–295.
17. Vivekanandan, E., Singh, V. V. and Kizhakudan, J. K., Carbon footprint by marine fishing boats of India. *Curr. Sci.*, 2013, **105**(3), 361–366.
18. Rawitscher, M. A. and Mayer, J., Nutritional outputs and energy inputs in sea foods. *Science*, 1977, **198**, 261–264.
19. Tyedmers, P., Salmon and sustainability: the biophysical cost of producing salmon through the commercial salmon fishery and the intensive salmon culture industry. Ph D thesis, University of British Columbia, Vancouver, Canada, 2000.
20. Hospido, A. and Tyedmers, P., Life cycle environmental impacts of Spanish tuna fisheries. *Fish. Res.*, 2005, **76**, 174–186.
21. Srinath, M., Kuriakose, S. and Mini, K. G., *Methodology for Estimation Fish Landings in India*, CMFRI Special Publication, 2005, 86, p. 57.
22. FAO, *The State of World Fisheries and Aquaculture 2012*, Food and Agriculture Organization, Rome, 2012, p. 230.
23. Energy and carbon conversions. Carbon Trust, United Kingdom, p. 4; www.thecarbontrust.co.uk/energy
24. Tyedmers, P. H., Watson, R. and Pauly, D., Fueling global fishing fleets. *Ambio*, 2005, **34**, 635–638.
25. Eyjolfsdottir, H. R., Yngvadottir, E., Mattsson, B. and Ziegler, F., Report on Second workshop on Life Cycle Assessment of Seafood, Reykjavik, Iceland, 21–22 March 2002, p. 27.
26. Guttormsdottir, A. B., Life cycle assessment on icelandic cod product based on two different fishing methods: environmental impacts from fisheries. Master's thesis, University of Iceland, Reykjavik, Iceland, 2009, p. 105.
27. Gulbrandsen, O., Reducing the fuel costs of small fishing boats. Bay of Bengal Programme, Chennai, Working Paper 27, 1986, p. 29.
28. Wileman, D. A., Project oil fish: investigation of the resistance of trawl. The Danish Institute of Fisheries Technology, 1984, p. 123.

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