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Carbon footprint in life cycle of marine fisheries at major fishing harbours of Andhra Pradesh, India

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ABSTRACT

Contribution of marine fisheries at all stages of its life cycle, to climate change during 2012-2013 was studied by determining their carbon footprint at four major fishing harbours/fish landing centres in Andhra Pradesh *viz*., Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam . Functional unit was 1 kg of marine fish to the consumer. Fuel and electricity consumption per kg of marine fish was on an average 0.43 l and 0.24 kWh at Visakhapatnam, 0.41 l and 0.15 kWh at Kakinada, 0.52 l and 0.26 kWh at Nizamapatnam and 0.48 l and 0.21 kWh at Machilipatnam. Mechanised catches contributed 80-85% of the total fuel burnt and 79-90% of the total electricity consumed. The harvest phase (88-93%) burnt the most fuel, while the post-harvest phase (51-62%) contributed the most to the electricity consumption. Emission intensity per kg of marine fish was 0.34 kg C and 1.26 kg CO_2 in Visakhapatnam, 0.31 kg C and 1.16 kg CO_2 in Kakinada, 0.41 kg C and 1.50 kg CO_2 at Nizamapatnam and 0.37 kg C and 1.37 kg CO_2 at Machilipatnam. Fuel and electricity consumption and emission intensity was high for mechanised landings and low for motorised landings. The highest emissions were recorded in the harvest phase at all the places. Energy consumption and subsequent emissions can be reduced by making suitable modifications to the diesel engines, speed of operation and to the craft and propeller designs.

Keywords: CO_2 emission, Fuel and electricity consumption, Kakinada, Machilipatnam, Marine fisheries, Mechanised crafts, Motorised crafts, Nizamapatnam, Visakhapatnam

Introduction

The state of Andhra Pradesh with 974 km length of coastline spread over nine coastal districts ranks among the top states in the marine fish landings of the country. The districts of Visakhapatnam and East Godavari situated in the northern part of the state contribute nearly half of the total marine landings of the state. These two districts are also home to the highest marine landings of the state as well as the highest number of fishing crafts (mechanised and motorised). The Visakhapatnam Fishing Harbour dominated by mechanised trawlers is the largest landing centre in the district of Visakhapatnam. Pedajalaripeta, Lawson's Bay, Jodugullapalem, Mangamaripeta and Bheemilipatnam are the other landing centres wherein motorised crafts are landed (Ghosh *et al*., 2014). Kakinada Fishing Harbour, Bhairavapalem and Dummulapeta are the three major landing centres in the district of East Godavari harbouring both mechanised and motorised crafts. Off late, Nizamapatnam situated in Guntur District and Machilipatnam situated in Krishna District have emerged alongside the traditionally major fishing harbours of Visakhapatnam and Kakinada, as major fishing harbours of the state. Fishery at Nizamapatnam and Machilipatnam is contributed by both the mechanised and motorised sectors.

The annual landings of Andhra Pradesh which was 0.5 lakh t in 1951 has increased by six folds to more than 3 lakh t in 2012 (Maheswarudu *et al*., 2013). During 1950s and early 1960s, only indigenous country crafts were involved in the fishing operations in nearshore waters. Small mechanised boats engaged in single day fishing started in 1964 and by 1980s large mechanised trawlers (*sona* boats) with voyage fishing spanning for 8 -15 days came into vogue, revolutionising the marine fishing industry of the state. Subsequently, mechanised vessels operating gillnets and indigenous crafts using outboard engines started from the late 1990s (Rajkumar *et al*., 2004). There has been a radical shift in the marine fishing fleet of the state with fishing gradually moving from an energy free operation of the 1950s to energy-intensive activity over the last decade. Similar scenarios were observed nationally, where the fishing power of the marine fishing fleet has increased by 27 times, from 0.37 million HP in 1960 to 10.13 million HP in 2010 (Vivekanandan *et al*., 2013).

The uncontrolled expansion in the fishing fleet of the state has led to the fishing sector facing several sustainability issues such as overexploitation, pollution and habitat degradation. Additionally, the environmental impacts of fishing *viz*., energy dissipated in the construction and maintenance of fishing vessels (Watanabe and Okubo, 1989), provision of fishing gear (Zeigler *et al*., 2003), combustion of fuel and consumption of energy during fishing (Zeigler and Hansson, 2003; Thrane, 2004; Tyedmers, 2004) and transporting catch to markets or for further processing (Anderson, 2002) and the discharge of wastes and loss of fishing gear at sea (Derraik, 2002) also assumes paramount importance in context of this ever increasing consumption of power in the fishing sector. The best way to evaluate the environmental impacts associated with fishing is through the use of life cycle assessment (LCA), also called as ecobalance. LCA is a method to assess the environmental impacts of a product/process during the entire life cycle. 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 wastes (Ghosh *et al*., 2014). "Carbon footprint" is a simplified form of LCA which provides a single numerical index of environmental performance which is easily understandable (Ghosh *et al*., 2014). Carbon footprint is a component of an ecological footprint defined as the total amount of carbon-di-oxide and other green house gases emitted over the full life cycle of a product (Ghosh *et al*., 2014). The Carbon footprint is typically measured in equivalent tonnes of CO_2. The present study was carried out to estimate the contribution of marine fisheries of Andhra Pradesh to climate change during 2012 - 2013 by determining their carbon footprints at major fishing harbours and major fish landing centres of the state *viz*., Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam. The present findings are part of a study, in which the environmental performance of marine fisheries is evaluated at all stages of its life cycle (Ghosh *et al*., 2014).

Materials and methods

Environmental impacts of the marine fishing system are evaluated based on a functional unit. In the present study, the functional unit selected was 1 kg of marine fish to the consumer. The life cycle of the functional product was divided into three main phases *viz*., pre-harvest phase, harvest phase and post-harvest phase (Ghosh *et al*., 2014). As the name suggests, the pre-harvest phase consisted of activities before actual fishing, namely, vessel construction and maintenance as well as provision of fishing gear; the harvest phase included the actual fishing operations by mechanised and motorised crafts and the post-harvest phase comprised of the activities after fishing, namely the transportation of fish and its processing (Ghosh *et al*., 2014). The data collection methodology followed Ghosh *et al*. (2014). Boat building yards at Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam were surveyed for information on craft construction including the materials used and the energy used for the construction process. Survey of fishing gear manufacturing was excluded as per Ghosh *et al*. (2014). Information on the average number of mechanised and motorised crafts operating from Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam during 2012 and 2013 was collected from fishermen and also from the 2010 marine fisheries census data (CMFRI, 2010). There are currently, 620, 490, 180 and 105 mechanised crafts operating from Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam, while the numbers of motorised crafts are 860, 260, 120 and 54, respectively. The overall length, gross tonnage and propulsive engine power of 126 mechanised crafts and 169 motorised crafts at Visakhapatnam, 88 mechanised crafts and 52 motorised crafts at Kakinada, 28 mechanised crafts and 22 motorised crafts at Nizamapatnam and 18 mechanised crafts and 15 motorised crafts at Machilipatnam were recorded. The information on type, quality and amount of diesel fuel burned; annual number of voyages; average duration of each voyage and ice carried in each voyage were obtained by interviewing the crew of these crafts (Ghosh *et al*., 2014). This was supplemented with fishing effort data for 2012 and 2013 for Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam obtained from Fishery Resource Assessment Division of ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI). The fuel consumed during fishing coupled with electricity consumption for manufacture of ice carried in each fishing boat was energy inputs and emissions associated with the harvest phase (Ghosh *et al*., 2014). The marine landings from the mechanised and the motorised crafts at Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam in 2012 and 2013 were calculated following the stratified multistage random sampling design of the Fishery Resources Assessment Division of ICAR-CMFRI (Srinath *et al*., 2005). A survey was also conducted in the domestic fish marketing network and fish processing industry to obtain data for the post-harvest phase. Information was collected on quantities of fresh, iced and dried fish sold locally as well as transported to distant markets. Information was also collected on ice manufacture, packaging materials and mode of transportation. Processing units in the vicinity of all the four major fish landing centres were visited and information was gathered on production, electricity consumption and the use of energy, refrigerants and packaging material. The energy inputs and emissions during the post-harvest phase was taken as the fuel consumed during transportation and the electricity consumed in processing and ice manufacture (Ghosh *et al*., 2014).

Energy inputs and associated emissions in pre-harvest, harvest and post-harvest phases were expressed in terms of C and CO_2 (FAO, 2012). All mechanised and motorised fishing vessels at Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam use diesel for propulsion. Similarly, diesel was the fuel used in vehicles at all the four places for transportation. The diesel consumption was converted for estimating C and CO_2 emission using the standard conversion factor *i.e*., 1 l of diesel produces 10.7 kWh of heat and C and CO_2 emitted from 1 kWh is 0.68 and 0.25 kg respectively (www.thecarbontrust.co.uk/energy). The electricity consumption was noted from the electric meter, while the C and CO_2 emission from delivered grid electricity was calculated based on the standard conversion factor *i.e.,* 1 kWh of delivered grid electricity produces 0.117 kg C and 0.43 kg CO_2 (www.thecarbontrust.co.uk/energy).

Results

There were 620, 490, 180 and 105 mechanised crafts and 860, 260, 120 and 54 motorised crafts operating at Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam during 2012-2013. Most of the mechanised crafts at Visakhapatnam and Kakinada perform multiday fishing voyages and few perform single day voyages. The number of mechanised crafts performing multiday fishing voyages was 555 at Visakhapatnam and 385 at Kakinada, whereas the number of mechanised crafts performing single day fishing voyages was 65 and 105. At Nizamapatnam and Machilipatnam, all mechanised crafts performed multiday fishing voyages. Among the 860 and 260 motorised crafts operating at Visakhapatnam and Kakinada, 755 and 90 perform single day fishing operations and 105 and 170 perform multiday fishing operations. All the motorised crafts at Nizamapatnam and Machilipatnam perform multiday fishing operations. The fishing details of mechanised and motorised crafts at the four major harbours are summarised in Table 1. The average life span of a mechanised craft and motorised craft was 10 years and 4 years respectively (Ghosh *et al*., 2014) and this did not vary between the fishing harbours. Therefore at all the fishing harbours, one tenth of the total mechanised crafts and one fourth of the total motorised crafts are manufactured each year to replace the old damaged and dented ones. The fuel and electricity consumed for maintenance of old mechanised and motorised crafts amounted to 10% of that required for construction of new ones (Ghosh *et al*., 2014). The annual fuel and electricity consumption for manufacture of new crafts and for maintenance of existing mechanised as well as motorised crafts are presented in Tables 2 and 3. Details of annual fuel consumption for all crafts along with grid electricity consumed for manufacture of ice carried onboard during harvest are also given in Tables 2 and 3.

Annual average total landings from mechanised and motorised crafts were 51465 and 22400 t at Visakhapatnam, 54800 and 11380 t at Kakinada, 18750 and 4800 t at Nizamapatnam and 11250 and 3200 t at Machilipatnam. The various post-harvest operations are shown in Table 4. Dried fish is transported by trucks to

Table 1. Fishing details of mechanised and motorised crafts at Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam

Details of fishing	Visakhapatnam	Kakinada	Nizamapatnam	Machilipatnam
Mechanised craft				
No. of annual voyages	15 for multiday and 165 for single day	40 for multiday and 165 for single day	40 for multiday	40 for multiday
Average fuel consumption/voyage	3000 l for multiday and 120 l for single day	1200 l for multiday and 120 l for single day	1300 l for multiday	1200 l for multiday
Average ice carried/voyage	15 t for multiday and 0.45 t for single day	3 t for multiday and 0.45 t for single day	4 t for multiday	3 t for multiday
Motorised craft				
No. of annual voyages	35 for multiday and for single day	45 for multiday and 160 for single day	40 for multiday	40 for multiday 160
Average fuel consumption/voyage	350 l for multiday and 18 l for single day	375 l for multiday and 18 l for single day	400 l for multiday	400 l for multiday
Average ice carried/voyage	3.5 t for multiday	1 t for multiday	3 t for multiday	3 t for multiday

Table 2. Fuel and electricity consumed in mechanised landings at pre-harvest, harvest and post-harvest phases at Visakhapatnam, Kakinada, Machilipatnam and Nizamapatnam

	Visakhapatnam		Kakinada		Machilipatnam		Nizamapatnam		Total	
	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)
Pre-harvest										
New craft	52700	21700	41650	17150	8925	3675	15300	3675	118575	46200
Existing craft	47430	19530	37485	15435	8033	3308	13770	3308	106718	41580
Harvest	26262000	7782075	20559000	3291750	5460000	1008000	9360000	1728000	61641000	13809825
Post-harvest										
Dried fish	116905		108323		53496		77328		356051	
Iced fish	519352	410850	1536319	1250850	83370	64000	157969	120000	2297010	1845700
Processed fish	43500	5147500	36300	4295500	12000	1420000	27000	3195000	118800	14058000
Fresh fish	247500	371250	77000	115500	32600		45000		402100	486750
Total	27289387	13752905	22396077	8986185	5658424	2498983	9696367	5049983	65040254	30288055

Table 3. Fuel and electricity consumed in motorised catches at pre-harvest, harvest and post-harvest phases at Visakhapatnam, Kakinada, Machilipatnam and Nizamapatnam

	Visakhapatnam		Kakinada		Machilipatnam		Nizamapatnam		Total	
	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)
Pre-harvest										
New craft	21500	19350	6500	5850	1350	1215	3000	1215	32350	27630
Existing craft	6450	5805	1950	1755	405	365	900	365	9705	8289
Harvest	3460650	771750	3127950	459000	864000	388800	1920000	864000	9372600	2483550
Post-harvest										
Dried fish	34163		14832						48995	
Iced fish	277405	219450	1153073	556260	400000	192000	600000	288000	2430477	1255710
Processed fish	769200	2632000	120	14200					769320	2646200
Fresh fish	45000	67500	11000	16500					56000	84000
Total	4614368	3715855	4315424	1053565	1265755	582380	2523900	1153580	12719447	6505379

Table 4. Post-harvest phase of the marine landings at Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam

Fishing harbour	Dried fish (t)		Iced fish (t)		Processed fish (t)		Fresh fish (t)	
	Mechanised	Motorised	Mechanised	Motorised	Mechanised	Motorised	Mechanised	Motorised
Visakhapatnam	7015	2050	12450	12650	7250	3200	24750	4500
Kakinada	6500	890	34550	9370	6050	20	7700	1100
Nizamapatnam	6000		3750	4800	4500		4500	
Machilipatnam	4000		2000	3200	2000		3250	

interior markets in Madhya Pradesh and Chhattisgarh (Ghosh *et al*., 2014). Iced fish is packed in thermocol boxes and insulated containers and sent to either Kolkata or Chennai. At the fishing harbours, fish is packed in thermocol boxes with ice in 2:1 ratio whereas in insulated containers fish is packed with ice in 1:1 ratio. Processed fish from processing units are either air lifted or sent by ships to various locations or are sent by rail. Fresh fish is distributed in domestic markets located in the vicinity of the landing centres. The annual fuel consumed for fish transportation and total grid electricity consumed for ice manufacture and in fish processing units are given in Tables 2 and 3.

Fuel and electricity consumption per kg of marine fish at all life cycle phases was on an average 0.43 l and 0.24 kWh at Visakhapatnam, 0.41 l and 0.15 kWh at Kakinada, 0.52 l and 0.26 kWh at Nizamapatnam and 0.48 l and 0.21 kWh at Machilipatnam. In all the four fishing harbours, fuel and electricity consumption was high for mechanised landings and low for motorised landings.

Fuel and electricity consumption per kg of fish caught by the mechanised crafts were 0.53 l and 0.27 kWh at Visakhapatnam, 0.41 l and 0.16 kWh at Kakinada, 0.52 l and 0.27 kWh at Nizamapatnam and 0.50 l and 0.22 kWh at Machilipatnam. For each kg of fish caught by the motorised craft, fuel and electricity consumption was 0.21 l and 0.17 kWh at Visakhapatnam, 0.38 l and 0.09 kWh at Kakinada, 0.53 l and 0.24 kWh at Nizamapatnam and 0.40 l and 0.18 kWh at Machilipatnam. Fuel and electricity consumed per kg of marine fish by the mechanised and motorised crafts at pre-harvest, harvest and post-harvest phases are depicted in Tables 5 and 6. In Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam; mechanised catches contributed 85.5, 84, 79.3 and 81.7% to the total fuel burned and 78.7, 89.5, 81.4 and 81.1% to the total electricity consumed. The rest was contributed by motorised landings. Most fuel was burned by the harvest phase; 93.2% in Visakhapatnam, 87.8% in Kakinada, 92.3% in Nizamapatnam and 91.3% in Machilipatnam. Electricity consumption was mostly contributed by post-harvest phase; 50.7% at Visakhapatnam, 62.2% at Kakinada, 58.1% at Nizamapatnam and 54.4% at Machilipatnam.

Emission intensity per kg of marine fish over all its life cycle stages was 0.34 kg C and 1.26 kg CO_2 in Visakhapatnam, 0.31 kg C and 1.16 kg CO_2 in Kakinada, 0.41 kg C and 1.50 kg CO_2 at Nizamapatnam and 0.37 kg C and 1.37 kg CO_2 at Machilipatnam. The emissions were higher for mechanised crafts (0.42 kg C and 1.53 kg CO_2 in Visakhapatnam, 0.32 kg C and 1.16 kg CO_2 in Kakinada, 0.41 kg C and 1.50 kg CO_2 in Nizamapatnam and 0.39 kg C and 1.44 kg CO_2 in Machilipatnam) and lower for motorised crafts

Table 5. Energy consumed per kg of fish in mechanised catches at pre-harvest, harvest and post-harvest phases at Visakhapatnam, Kakinada, Machilipatnam and Nizamapatnam

	Visakhapatnam		Kakinada		Machilipatnam		Nizamapatnam		Total	
	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)
Pre-harvest										
New craft	0.0010	0.0004	0.0008	0.0003	0.0008	0.0003	0.0008	0.0002	0.0009	0.0003
Existing craft	0.0009	0.0004	0.0007	0.0003	0.0007	0.0003	0.0007	0.0002	0.0008	0.0003
Harvest	0.5103	0.1512	0.3752	0.0601	0.4853	0.0896	0.4992	0.0922	0.4524	0.1013
Post-harvest										
Dried fish	0.0023		0.0020		0.0048		0.0041		0.0026	
Iced fish	0.0101	0.0080	0.0280	0.0228	0.0074	0.0057	0.0084	0.0064	0.0169	0.0135
Processed fish	0.0008	0.1000	0.0007	0.0784	0.0011	0.1262	0.0014	0.1704	0.0009	0.1032
Fresh fish	0.0048	0.0072	0.0014	0.0021	0.0029	0.0000	0.0024	0.0000	0.0030	0.0036
Total	0.5303	0.2672	0.4087	0.1640	0.5030	0.2221	0.5171	0.2693	0.4773	0.2223

Table 6. Energy consumed per kg of fish in motorised catches at pre-harvest, harvest and post-harvest phases at Visakhapatnam, Kakinada, Machilipatnam and Nizamapatnam

	Visakhapatnam		Kakinada		Machilipatnam		Nizamapatnam		Total	
	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)	Fuel (l)	Electricity (kWh)
Pre-harvest										
New craft	0.0010	0.0009	0.0006	0.0005	0.0004	0.0004	0.0006	0.0003	0.0008	0.0007
Existing craft	0.0003	0.0003	0.0002	0.0002	0.0001	0.0001	0.0002	0.0001	0.0002	0.0002
Harvest	0.1545	0.0345	0.2749	0.0403	0.2700	0.1215	0.4000	0.1800	0.2243	0.0594
Post-harvest										
Dried fish	0.0015		0.0013						0.0012	0.0000
Iced fish	0.0124	0.0098	0.1013	0.0489	0.1250	0.0600	0.1250	0.0600	0.0582	0.0301
Processed fish	0.0343	0.1175		0.0012					0.0184	0.0633
Fresh fish	0.0020	0.0030	0.0010	0.0014					0.0013	0.0020
Total	0.2060	0.1659	0.3792	0.0926	0.3955	0.1820	0.5258	0.2403	0.3044	0.1557

(0.17 kg C and 0.62 kg CO_2 in Visakhapatnam, 0.29 kg C and 1.05 kg CO_2 in Kakinada, 0.41 kg C and 1.51 kg CO_2 in Nizamapatnam and 0.31 kg C and 1.14 kg CO_2 in Machilipatnam) (Fig. 1). The highest emissions for mechanised and motorised crafts were recorded in the harvest phase at all the places (Fig. 2). The total emissions by the mechanised and motorised crafts at pre-harvest, harvest and post-harvest phases at Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam are summarised in Tables 7 and 8.

Discussion

The global estimate of emission intensity and fuel consumption is 1.7 kg CO_2 and 0.62 l per kg of landed fish respectively (Tyedmers *et al*., 2005). At Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam; the fuel consumption and the emission intensity was less by 25.9, 31.8, 11.8 and 19.4%, respectively from the global estimates. Boopendranath (2009) estimated the annual fuel consumption by mechanised and motorised fishing fleets of India as 1220 million l releasing 3.17 million t of CO_2 with an average of 1.13 t of CO_2 per tonne of landed marine fish. Vivekanandan *et al*. (2013) reported energy intensity of the harvest phase as 393.3 l t^{-1} for marine fish caught in India. They stated that mechanised crafts emitted 1.18 t CO_2 t^{-1} of fish caught and the motorised boats emitted 0.59 t CO_2 t^{-1} of fish caught. According to them, for every tonne of fish caught, CO_2 emission increased from 0.5 to 1.02 t during 1961-2000 in the harvest phase alone. Much higher fuel usage and energy intensities have been reported by various authors from across the globe, ranging from 20-3400 l t^{-1} with

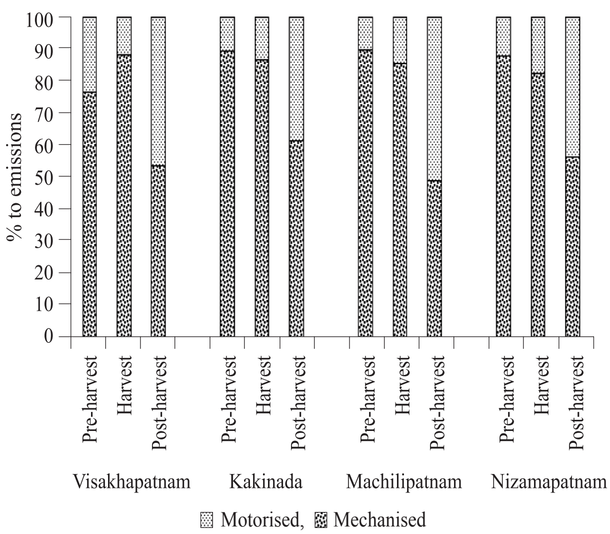

Fig. 1. Contribution by mechanised and motorised landings to emissions at all life cycle stages at Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam

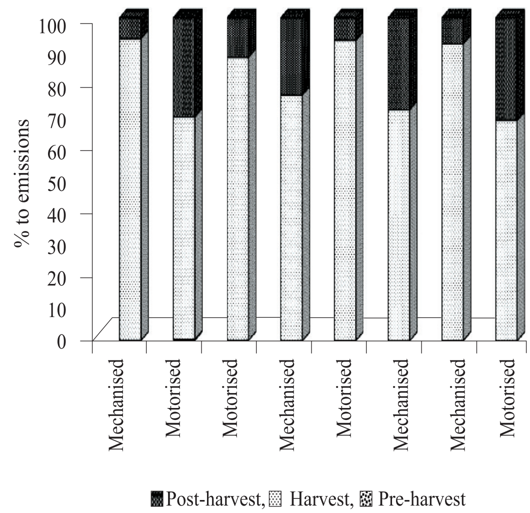

Fig. 2. Contribution by pre-harvest, harvest and post-harvest phases to emissions in mechanised and motorised landings at Visakhapatnam, Kakinada, Nizamapatnam and Machilipatnam

Table 7. Emissions per kg of fish in mechanised catches at pre-harvest, harvest and post-harvest phases at Visakhapatnam, Kakinada, Machilipatnam and Nizamapatnam

	Visakhapatnam		Kakinada		Machilipatnam		Nizamapatnam		Total	
	kg C	kg CO_2	kg C	kg CO_2	kg C	kg CO_2	kg C	kg CO_2	kg C	kg CO_2
Pre-harvest										
New craft	0.0008	0.0029	0.0006	0.0022	0.0006	0.0023	0.0006	0.0023	0.0007	0.0025
Existing craft	0.0007	0.0026	0.0005	0.0020	0.0006	0.0020	0.0006	0.0020	0.0006	0.0022
Harvest	0.3890	1.4300	0.2800	1.0294	0.3636	1.3368	0.3740	1.3750	0.3410	1.2536
Post-harvest										
Dried fish	0.0017	0.0061	0.0014	0.0053	0.0035	0.0127	0.0030	0.0110	0.0019	0.0070
Iced fish	0.0083	0.0304	0.0231	0.0848	0.0061	0.0223	0.0069	0.0253	0.0153	0.0561
Processed fish	0.0123	0.0453	0.0097	0.0355	0.0155	0.0571	0.0210	0.0771	0.0095	0.0349
Fresh fish	0.0043	0.0160	0.0013	0.0047	0.0021	0.0078	0.0017	0.0064	0.0026	0.0094
Total	0.4171	1.5333	0.3165	1.1638	0.3920	1.4410	0.4078	1.4992	0.3715	1.3658

Table 8. Emissions per kg of fish in motorised catches at pre-harvest, harvest and post-harvest phases at Visakhapatnam, Kakinada, Machilipatnam and Nizamapatnam

	Visakhapatnam		Kakinada		Machilipatnam		Nizamapatnam		Total	
	kg C	kg CO_2	kg C	kg CO_2	kg C	kg CO_2	kg C	kg CO_2	kg C	kg CO_2
Pre-harvest										
New craft	0.0008	0.0029	0.0006	0.0017	0.0004	0.0013	0.0005	0.0018	0.0006	0.0024
Existing craft	0.0002	0.0009	0.0005	0.0005	0.0001	0.0004	0.0002	0.0007	0.0002	0.0007
Harvest	0.1164	0.4281	0.3614	0.7526	0.2107	0.7745	0.3121	1.1474	0.1702	0.6256
Post-harvest										
Dried fish	0.0011	0.0041	0.0024	0.0035					0.0009	0.0031
Iced fish	0.0102	0.0373	0.0794	0.2921	0.0980	0.3602	0.0980	0.3602	0.0458	0.1685
Processed fish	0.0387	0.1424	0.0002	0.0006					0.0240	0.0881
Fresh fish	0.0018	0.0067	0.0014	0.0032					0.0012	0.0044
Total	0.1693	0.6224	0.2867	1.0542	0.3091	1.1363	0.4107	1.5100	0.2429	0.8930

means of 510 l t^{-1} in North Atlantic fisheries (Eyjolfsdottir *et al*., 2002) and 440 l t^{-1} for Spanish vessels targeting skipjack and yellowfin tuna (Hospido and Tyedmers, 2005). Carbon footprints varied from 1.15 to 5.27 kg CO_2 kg^{-1} of tuna landed (Hospido and Tyedmers, 2005) and 1.58 to 5.14 kg CO_2 kg^{-1} of cod landed (Guttormsdottir *et al*., 2009). In developed nations, fishing is highly energy intensive with large commercial fishing vessels with OAL >100 ft and engine capacity >400 hp undertaking industrial fishing in distant fishing grounds, with onboard processing facilities. Unlike these nations, fishing in India is still labour intensive with fishing crafts rarely exceeding 53 ft OAL. As a result, emissions from marine fisheries in India are much lower than the global and international figures.

Marine fishing in India can be made further ecofriendly by using alternate fishing techniques which use less fuel to reduce CO_2 emissions. Ninety per cent of the total energy inputs in fishing are contributed by fuel (Ghosh *et al*., 2014). Fuel cost accounts for 50-54% of the operating cost of mechanised boats and 36-44% of operating cost of motorised boats (Vivekanandan *et al*., 2013). Mechanised crafts use fuel for reaching the fishing ground as well as for operation of fishing gear. Motorised crafts on the other hand use fuel only for reaching the fishing grounds. Hence the fuel usage is much higher in mechanised crafts and is also the source of high CO_2 emissions. The reduction in the operating speed of crafts by 10-20% during cruising to the fishing ground and back helps to save fuel by 35 to 61% (Gulbrandsen, 1986). Similarly the proper use of potential fishing zone (PFZ) advisories can help in reducing time spent in scouting for fish, further leading to reduction of CO_2 emissions. An improvement in fish finding techniques and fuel efficiency of marine diesel engines will also help reduce CO_2 emissions (Ghosh *et al*., 2014). The usage of large propeller with lower revolutions per minute matched to absorb the engine power helps in considerable fuel savings (Ghosh *et al*., 2014). Drag, which contributes significantly to high fuel consumption is reduced by use of knotless netting, thinner twine and large mesh netting (Wileman, 1984). Proper designing of fish holds is another option which leads to economy in use of ice, ultimately leading to low electricity consumption. Cleaner fishing techniques and passive and semi-active fishing methods coupled with sustainable management of fish stocks could reduce the amount of energy used per kg of landed fish (Thrane, 2004).

From the present study, it is evident that the usage of large amounts of fuel (diesel) and electricity in marine fisheries has resulted in considerable emissions of greenhouse gases. CO_2 emissions from India's marine fleets are relatively low, and they present the country with both challenge as well as an opportunity. Increasing levels of greenhouse gases in the atmosphere causes global warming with potential catastrophic long-term implications for the marine environment. Increased climate variability affects the spatial and temporal distribution, patterns of migration, diversity and abundance, reproduction and recruitment of economically important species (Murawski, 1993; Jacobson and Maccall, 1995; Finney *et al*., 2000). Climate variability induced impacts would be disastrous, especially for overfished highly stressed fish stocks. However the situation also provides opportunities for research on alternate, less fuel-intensive fishing methods and development of low impact fishing gears which could lower fuel usage and costs and reduce greenhouse gas emissions.

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