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Carbon Footprint and Associated Environmental Impacts in Construction of Fishing Vessels: A Preliminary Study

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Abstract

The pre-harvest, harvest and post-harvest sectors of fishery require intensive energy input which primarily depend on fossil fuels. Pre-harvest phase involves the dissipation of energy and other input to accomplish construction of fishing vessel and other fishing accessories. Analyses of energy in terms of fishing vessel construction, and changes in energy use over time can provide a powerful tool to know the environmental impact specially global warming potential (GWP) and carbon footprint associated with it. In the present study a comparative account of carbon footprint and global warming potential due to construction of mechanized gillnetter-cum-longliner made of two different materials (steel and wood) was made. Six numbers of vessels of both categories with size range of 65 feet were selected for comparison. Since goal of the study was to compare GWP and carbon footprint due to construction process only, a cradle to gate approach has been adopted. SimaPro® software package was used for analysis. Results showed that during construction of wooden vessel, CO_2 equivalent was primarily contributed by FRP sheath (41.3%) followed by bronze (23.7%) and copper nail (19.6%), whereas for steel vessel construction, CO_2 equivalent was contributed maximum by steel plates (65.8%) followed by bronze (24.1%) and welding arc (4.6%). During the study it was found that the wooden fishing vessel leaves 0.211 kg CO_2 eq kg^{-1} of functional unit, compared to 0.709 kg CO_2 eq kg^{-1} of functional unit for steel vessel. Outcome of the study shown that construction of steel fishing vessel (gillnetter-cum-longliner) of 65 ft L_{OA}, create three times more GWP and carbon footprint than wooden fishing vessel of similar type and size.

Keywords: Carbon footprint, Global Warming Potential, mechanised fishing vessel, gillnetter-cum-longliner, south west coast of India

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Introduction

Fishing is considered as one of the most energy-intensive food production system in the world which utilizes mainly fossil fuels resulting in emission of greenhouse gases (Wilson, 1999). Carbon footprint and global warming potential (GWP), a sub-set of Life Cycle Assessment is deeply connected to fisheries sector, because of the strong impact on global warming due to emission from vessel construction and fuel combustion. CO_2 equivalent is a metric measure to compare the emissions from various greenhouse gases on the basis of their global warming potential by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential. Global warming potential is relative potency of a greenhouse gas, taking account of how long it remains active in the atmosphere. Life Cycle Assessment (LCA) is an important multipurpose impact assessment tool across the globe. It has emerged as a commonly used and suggested framework to workout environmental impacts due to process or product which leads to new insights to environmental impact of processes or products (Ziegler et al., 2019). Life Cycle Assessment (LCA) takes into account all related activities to provide estimates of CO_2 emission due to construction (Thrane, 2006). It is a progressive four step process *viz.,* goal and scope, definition, inventory analysis, impact assessment and interpretation of results. LCA was introduced in fisheries and aquaculture during 2000s and is now popular worldwide. Many authors reported effect of marine capture fisheries on environment using life cycle assessment method, *viz.,* Tyedmers, 2001; Ziegler & Hansson, 2003; Thrane, 2006; Ellingsen & Aanondsen, 2006; Ziegler & Valentinsson, 2008; Vázquez-Rowe et al., 2010a & 2010b; Ramos et al., 2011 and Svanes et al., 2011. Broadly a marine capture fishery (harvest) has two processes; the first involving construction of fishing vessel, gear and other accessories and the second involves actual fishing process (Jha & Edwin, 2019). The environmental cost of fishing is less understood and receives less attention than the direct impact on fishery stock and marine ecosystem (Edwin & Jha, 2020). Limited studies in India have been reported in energy use in fisheries that too mainly confined with harvest phase and not pre harvest phase (Edwin & Hridayanathan, 1997; Boopendranath, 2000; Boopendranath & Hameed, 2009; 2010; Vivekanandan, 2011; Vivekanandan et al., 2013; Ghosh et al., 2014; Ravi, 2015; Das & Edwin, 2016 and Ravi et al., 2020). The pre-harvest phase mainly constitutes the construction process of fishing vessel, gear and other accessories. Since there is lack of LCA studies on pre-harvest phase of Indian fisheries along the coast, an attempt has been made to evaluate carbon footprint and GWP of fishing vessel construction. Several materials are used to construct different types of fishing vessel *viz.,* wood, steel, Fiber Reinforced Plastic (FRP) etc. Out of different types of mechanized fishing vessel, gillnetter-cum-longliners were selected for the study, because of its popularity among deep sea venturing fishermen along the south-west coast of India. Annual fuel consumption by Indian fishing fleet was estimated at 1220 million litres (1% of the total fossil fuel consumption during 2000) which emitted about 3.17 million tonnes of CO_2 to the atmosphere. This corresponds to 1.13 tonnes of CO_2 per tonne of marine fish landed (Boopendranath, 2009). The present study concentrates on comparative analysis of carbon footprint/GWP caused due to construction of mechanized gillnetters-cum-longliner, made of two different materials (*viz.* steel and wood).

Materials and Methods

Mechanized gillnetter-cum-longliner made of steel and wood at Munambam, Ernakulam, Kerala, were selected for study. Six numbers of vessels (three each for steel and wooden) in the size range of 65 feet were selected for comparison (Fig. 1 & 2; Edwin et al., 2014).

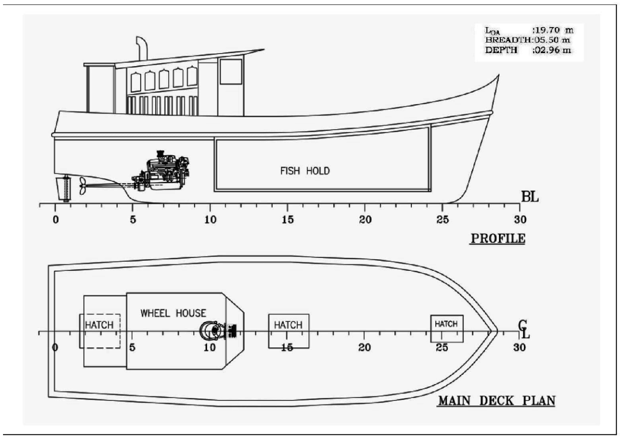

Fig. 1. Profile and deck layout of wooden gillnetter-cum-longliner (Taken from CIFT Fishing systems catalogue 1; mechanized marine fishing systems: Kerala)

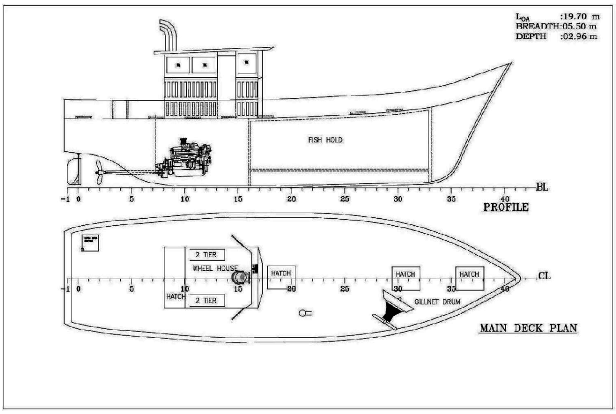

Fig. 2. Profile and deck layout of steel gillnetter-cum-longliner (Taken from CIFT Fishing systems catalogue 1; mechanized marine fishing systems: Kerala)

Personal interview method was adopted for data collection, with the help of pre-tested structured questionnaire. To understand the processes of input and output, system boundary was drawn (Fig. 3). The inventories of fishing vessels made of two different materials are shown in Table 1. Functional unit is the functional quantifiable definition of the particular system which is to be studied and one fishing vessel is taken as the functional unit in this study. The data sources (including owner, fishermen and boat building yard staff) provided information on quantity of different input (inventory) used for entire construction process of fishing vessels, out of which the average value was considered for analysis of several factors contributing to carbon emission and global warming potential during the whole process of fishing vessel construction made of steel and wood.

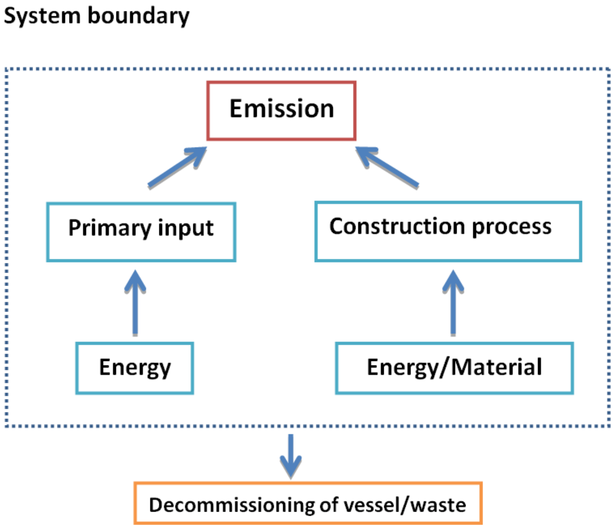

Fig. 3. System boundary for fishing vessel construction process

Table 1. Showing average quantity of inventories for steel and wooden fishing vessel

Input	Steel	Wood
Bronze (kg)	150	150
Steel (kg)	26325	175
Wood (kg)	12000	47500
Acrylic varnish (kg)	120	120
Calcium carbonate (kg)	150	150
Glass wool mat (kg)	350	325
FRP (kg)	1100	1250
Welding rod (kg)	1350	50
Electricity (kWh)	2000	500
Copper (kg)	-	500
Cotton fibre (kg)	-	310

SimaPro® software package (ISO-14040) was used for analysing foreground and background systems inventories along with midpoint impacts of the different materials by means of ReCiPe 2016 (Goedkoop et al., 2009). Sufficient published LCA studies on mechanised vessel construction and other similar domain are few in Asian/Indian context and selected impact categories were taken for comparison with the available published studies. For background process ecoinvent 3.2 data were used (Moreno, 2015). In the present study residence time of atmospheric gases is assumed to be 100 year. Carbon Dioxide Equivalents (CO_2-Eq) was taken as a standard for calculation of Global Warming Potential (GWP). Characterization and normalization of the resource inputs of environmental impacts and emissions were taken under CML-IA methodology, which is defined for the midpoint approach. Amount of wood required for the vessel was recorded in kilograms instead of m^3, which was later converted to volume (due to input intake format for software). For density conversion, a factor of 825 kg m^{-3} was used (Althaus et al., 2007) and marine engine component were selected as per Jiang et al., (2014). Most of the background processes were adjusted to account for Indian scenario, while some background data is based on Rest of the World (RoW) averages. Mass allocation method was used to allocate the inventory to both types of selected fishing vessel. CO_2 equivalent and Global warming potential are important indicators in the extent of damage due to environmental degradation by emitting CO_2 in atmosphere. In the present study to quantify the environmental impacts associated with the construction of fishing vessel with both materials *viz.*, wood and steel; twenty-two impact categories were selected which have effect on environment, human health and resource (Table 2). Since study deals with the CO_2 equivalent of emission due to construction process only so that other fisheries-related activities which demand energy input, such as net fabrication, fishing gear operation, post-harvest processing, transportation etc. have not been considered here. Cradle to gate approach has been adopted, since the process is not cyclic but starts with a step and ends at next step. The operational life of fishing vessel assumed was ten and fifteen years for wooden and steel vessel respectively, though the life span of the vessel was not considered for calculation. The present study also does not include the scope on decommissioning of vessel and emission related to it. It is also assumed while transportation of inputs from production site to workshop it is unlikely carrier will only carry input for single fishing vessel, and thus transportation of above was excluded from the study, however it is important while calculating the carbon emission on an activity.

Results and Discussion

Fishing vessel is made up with different components and its construction is a complex process.

Certain quantities of greenhouse gases are produced in the process of construction of fishing vessels, which can be converted in terms of equivalent CO_2. The findings of the present study showed that for steel vessel construction, CO_2 equivalent was contributed maximum by steel plates (65.8%) followed by bronze (24.1%) and welding arc (4.65%) (Fig. 4). Steel has relatively high strength with elasticity and durability. The criteria like reasonable cost, welding compatible with simple equipment, suitable for flame cutting, good ductility and homogeneity etc. for construction of large mechanized fishing vessel, steel is more ideal than any other boat building material. One of the major concerns regarding popularity of steel vessel is low maintenance cost than wooden vessel. There is increased fishermen's preference towards steel than any other boat building material. Normally for mechanized fishing vessel construction; mild steel with carbon content of 0.15 to 0.30% is ideal (Santhakumaran & Jain, 1986). In the case of wooden vessel, CO_2 equivalent was primarily contributed by FRP sheath (41.3%) followed by bronze (23.7%) and copper nail (19.6%). FRP sheath, an outer protective layer on wooden vessel to increase service life, was a major contributor for CO_2 equivalent in the case of wooden vessels (Fig. 4).

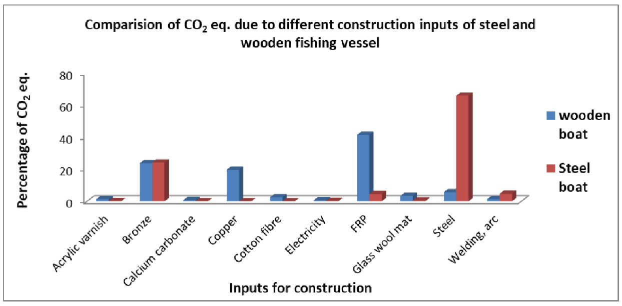

Fig. 4. CO_2 eq. due to different components of steel and wooden fishing vessel

During earlier time copper and aluminium sheating were used as a sheathing material for wooden boats, presently which is phased out and now it is completely replaced by FRP sheathing, due to its technical superiority for the purpose. Wood as a major input material for wooden vessel, have negative/lowest GWP due to the biogenic carbon sink, so values are not mentioned in results. The extent of lower value of GWP/eq. CO_2 for wood will depend on the process how the timber was grown and handled, again it is main product or co-product, and the most important it depends on the system boundary of the study. In the study it was found that the wooden fishing vessel leaves 0.211 kg CO_2 eq kg^{-1} of functional unit, compared to 0.709 kg CO_2 eq kg^{-1} of functional unit for steel vessel whichis 29.7% less carbon footprint than steel fishing vessel (Fig. 5).

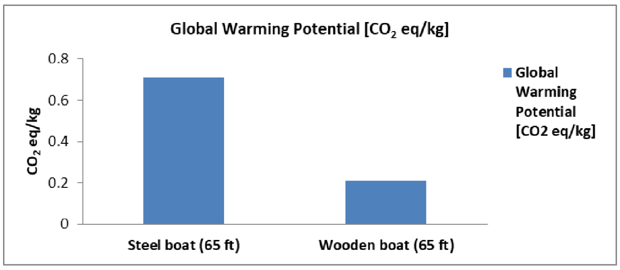

Fig. 5. GWP (CO_2 eq kg^{-1}) due to construction of steel and wooden fishing vessel

In present study, there are three major reasons behind higher carbon footprint for steel vessel than wooden vessel; first is the quantity of steel used, which is about 26,325 kg for steel vessel compared to only 175 kg of steel for wooden vessel. The second is the quantity of welding rod which is used in the joining of steel plates for vessel construction, welding is comparatively less in wooden vessel construction. Welding rods emit harmful gases during welding process of steel plate which adversely affects environment (mainly to ozone layer) and have higher CO_2 eq. value. For 65 ft steel vessel construction the quantity of welding rod required was about 1350 kg. The third major contributor is electricity used for welding and other processes. About 2000 kwh electricity was consumed, whereas for wooden vessel construction electricity used was only 500 kwh. Quantity of these three inventories used for construction of steel vessel are higher compared to construction of wooden vessel, which play a pivotal role in emitting higher CO_2 eq. value for construction of steel vessel than wooden vessel (Table 1). In India about 60 different types of timbers are used for construction of fishing vessel. In wooden vessel most used timbers are aini (*Artocarpus hirsuta*), chaplash (*A. chaplasha*), sal (*Shorea robusta*), shisham (*Dalbergia sissoo*) mastwood (*Calophyllum inophyllum*) and walnut (*Albizzia lebbek*). Selected wood should have some of the criteria *viz.,* Good strength, moderately heavy (480-624 kg m^{-3} @12% moisture content), elastic, good shape retention, low water absorption and durable against biological agents especially marine borers, are required for boat building. In due course of time wooden vessels may be phased off and gradually replaced by steel and FRP vessel. The present study only deals with pre-harvest phase and not harvest phase (actual fishing process) or post-harvest phase. In addition to the pre harvest phase i.e. construction of fishing vessels, the active fishing is one of the major causes of huge emission by fisheries sector. However, the contribution of fisheries sector is negligible which roughly <1% to global GHG emission (Tyedmers, 2004). During last 3-4 decades several factors in the sector which increased amount of emission viz. increment of fleet size and number (overcapacity), which resulted higher catch (Srinath et al., 2004). The other associated important environmental parameters by which health of environment, human and resource can be evaluated after any construction process are; terrestrial acidification, formation of fine particulate matters, Water consumption, Ionizing radiation, ozone formation, human carcinogenic toxicity, fossil resource scarcity, mineral resource scarcity environment deterioration, human health, resource depletion and stratospheric ozone depletion etc. (Table 2). Results of different impact categories found in the present study shown similar trend as reported by Ravi (2015) by using LCA software GaBi. In addition, carbon footprint details could be one of the important inputs for traceability and eco-labelling (Thrane et al., 2009; Madin & Macreadie, 2015).

Different types of vessel and gear combinations are used in Indian marine capture fisheries to exploit various fish stocks. Under mechanized categories, the important vessel types are trawler, gillnetter-cum-longliner, bagnetter, dolnetter, longliner, purse seiner etc. One major reason for the substantial

Table 2: Total impacts based on ecoinvent 3.2 at midpoint level for selected impact categories for fishing vessel construction by wood and steel (FU: per boat constructed)

Impact category	Mechanized Steel boat (65 ft)	Mechanized wooden boat (65 ft)
Global warming, Human health [CO_2 eq kg^{-1}]	0.14438	0.692686
Global warming, Terrestrial ecosystems [CO_2 eq kg^{-1}]	0.00028	0.001385
Global warming, Freshwater ecosystems [CO_2 eq kg^{-1}]	7.88E-08	3.78E-08
Stratospheric ozone depletion [CFC-11 eq kg^{-1}]	6.89E-05	6.57E-05
Ionizing radiation [CFC-11 eq kg^{-1}]	2.32E-05	6.21E-05
Ozone formation, Human health [CFC-11 eq kg^{-1}]	5.65E-05	0.000147
Fine particulate matter formation [PM 2.5 eq g^{-1}]	0.071811	0.093964
Ozone formation, Terrestrial ecosystems [CFC-11 eq kg^{-1}]	8.46E-06	2.20E-05
Terrestrial acidification [SO_2 eq kg^{-1}]	6.78E-05	5.21E-05
Freshwater eutrophication [P eq kg^{-1}]	5.93E-05	3.98E-05
Marine eutrophication [P eq kg^{-1}]	5.08E-09	4.29E-09
Terrestrial ecotoxicity [1,4-DCB eq kg^{-1}]	3.62E-05	8.52E-06
Freshwater ecotoxicity [1,4-DCB eq kg^{-1}]	1.09E-05	6.14E-06
Marine ecotoxicity [1,4-DCB eq kg^{-1}]	0.021292	0.010625
Human carcinogenic toxicity [1,4-DCB eq kg^{-1}]	1.023359	9.062817
Human non-carcinogenic toxicity [1,4-DCB eq kg^{-1}]	39.01556	18.93794
Land use [m^2/yr]	2.94E-05	1.33E-05
Mineral resource scarcity [Fe eq kg^{-1}]	262.8971	626.836
Fossil resource scarcity [Oil eq kg^{-1}]	1139.547	3169.21
Water consumption, Human health [m^3]	0.001166	0.00090
Water consumption, Terrestrial ecosystem [m^3]	8.05E-06	5.55E-06
Water consumption, Aquatic ecosystems [m^3]	6.78E-10	0.69268

increase in carbon footprint by construction process is the increase in number and efficiency of fishing vessels along the Indian coast otherwise called overcapacity, which need more inputs and equipment, results in more eq. CO_2 emission. By selecting two different materials for construction of mechanized wooden and steel fishing vessels, study was focused on carbon footprint and global warming potential during the construction stage along with other associated impacts on environment, human health and natural resource. Study shows that construction of steel fishing vessel (gillnetter-cum-longliner) of 65 ft L_{OA}, create three times more GWP and carbon footprint than wooden fishing vessel of similar type and size (Fig. 5). It was found that the wooden fishing vessel emits 0.211 kg CO_2 eq kg^{-1} of functional unit, compared to 0.709 kg CO_2 eq/kg of functional unit for steel vessel. At the point of construction wooden fishing vessel emits one third less CO_2 eq. than steel fishing vessel. Since life span of wooden and steel fishing vessels were assumed as ten and fifteen years respectively. The total life span of vessels the computed carbon footprint values for steel fishing vessel, would be slightly less if life span is considered. Both types of vessels are common in India and sub continental waters and the study is first of its kind in the said area, thus the output could be used for other Asian countries, particularly Southeast Asian countries. Pre-harvest phase of Indian marine capture fisheries and standardization about LCA/carbon footprint in such studies with their findings can be useful in formulating constructional/operational recommendations to improve environmental performance of fisheries, under the context of ecosystem approach to fisheries along with future certification and different eco-labelling of fisheries. Studies related to pre-harvest, harvest and post-harvest fisheries, LCA/carbon footprint analysis would be more appreciated by policy makers for regulation of fishing boat yards and other related fishing ventures. Findings of this study would help in create GHG emissions models along with policies for fishing.

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