Life Cycle Assessment (LCA): A technique for energy optimisation in fisheries

Paras Nath Jha

Fishing Technology Division, ICAR- CIFT, Cochin

Introduction

Fisheries can be considered as a primary industry which starts at a point of supply chains of local, regional and global significance. It plays a key role in food security due to high protein content of fish and fishery products. Fisheries also act as promising way for employment generator and nutritional security (FAO, 2012). Worldwide about 58.3 million people are directly or indirectly involved in fisheries and aquaculture. Out of which about 37% people are directly dependent on fishing and rest are in other allied activities like processing and marketing. Global human consumption of fish and fishery product rose from 20 million tonnes in 1950 to more than 156 million tonnes in 2012, with total production of about 179 million tonnes (FAO, 2020). All over the world diverse range of fish catching methods with different fishing gears are used by artisanal to mechanised systems.

Fuel use and GHG emission

Fishing operation is an external energy-intensive operation which produces emissions mainly due to burning of fossil fuels (Parker et al., 2018). Other related activities which demand energy input, such as net fabrication, fishing gear operation, post-harvest activities etc. Fossil fuel is a dominant energy sources in different fishing methods such as long-lining, gillnetting, trawling, ring seining and purse seining. Mechanized and motorized fishing operations are dependent on fossil fuels which are non-renewable and releases high levels of carbon dioxide to the atmosphere contributing to greenhouse (H) (Driscoll & Tyedmers, 2010). 40 2011 179 O_2 q (O_2 q) H (P , 2018) In 2016, a total CO_2 emission of the industrial fishing sector was 159 million tonnes compared to 39 million tonnes in 1950 (Gray & Vancouver, 2019). Due to , , emission of GHGs also increased which finally led to (Muir, 2015). The energy and material used in the fishing vessels can create negative environmental impacts, mainly due to the consumption of fuel, gear usage and loss, anti-fouling

agents, paint and ice consumption (Rowe et al, 2010). The use of energy is now increasingly important in comparative resource-use analysis, potential trade trends, and in carbon and related greenhouse gas (GHG) impacts in climate change mitigation (Poseidon, 2011; FAO, 2012). The active cost of fishing is less understood and consequently receives less attention than the direct impact on fishery stock and marine ecosystem (Jha & Edwin, 2019). During the last decade, the price of fuel and other energy sources was on a rising trend. In 2001, fuel was estimated to account for 21% of revenue from landed catch, whereas in 2008 this increased to about 50%. Fuel use varies usually with type of fishing and level of effort, but as one of the key cost components over which the fisheries sector has no direct control. Profitability and livelihoods are potentially highly sensitive to energy costs (FAO, 2015; Muir, 2015). The emissions from fisheries were not given importance as compared to other sectors, however, the contribution of fisheries sector is negligible which roughly may be <1% to global GHG emission (Tyedmers, 2004). Later many studies, research publications and report highlighted its importance (Tyedmers, 2001; Vivekanandan, 2011). During last 3-4 decades several factors played a pivotal role in increased emission viz. increment of fleet size and number (overcapacity), which resulted higher catch (Srinath et al., 2004). The major direct and indirect energy inputs can be systematically analysed using process analysis and input-output techniques. Mostly direct fuel inputs are used primarily for vessel propulsion. On an average direct fuel energy inputs account for between 75 and 90% of the total energy inputs, irrespective of the fishing gear used or the species targeted. Remaining 10 to 25% is generally dependents on vessel construction and maintenance, and the provision of labour, fishing gear, bait, and ice if used which depending on the character of the fishery and the scope of the analysis conducted. The secondary energy-consuming activities, which include on-board processing and storage is negligible compared to primary energy consumption in terms of fuel burned. Here squid jigging is an example in which relatively large proportion of fuel inputs are used for activities other than vessel propulsion. These include mainly batteries of high intensity lamps, automated jigging machines, and on-board storage facility etc. The energy requirement is met by diesel-fuelled generators to attract, hook, and preserve the catch while fishing. On an average the non-propulsion energy demands account for 40% of the total fuel burned. Out of total indirect energy inputs, largest fraction account for building and maintaining the fishing vessels.
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fabricated basically from energy-intensive materials such as aluminium and steel as compared to wood or fiberglass.

Energy requirement in different fishing operations

Based on behaviour and habitat, there are different methods of fish harvest and on the basis of their operation the quantum of fuel and energy requirement also varies. According to the study of Thomson (1980) globally large-scale industrial fishing sector consumed about 14-19 million t and small-scale fishing sector consumed about 1-2.5 million t of fuel oil. The production of fish per tonne of fuel was 2-5 t in the industrial sector and 10-20 t in the small-scale sector. In energy context some of the important fishing methods are listed below:

Trawling: Trawling is one of the most energy intensive fishing methods. It consumed nearly 5 times more fuel compared to longlining and gillnetting (passive fishing methods) and over 11 times to purse seining for every kilogram of fish produced. For large trawlers, 90% fuel consumption accounts during active trawling operation. Percentage of fuel cost in the operational expenditure of trawlers may vary between 45% and 75%, depending on engine power and duration of voyage.

Gillnetting/longlining: Gillnetting and longlining are the passive type of fishing where the gross energy requirement is comparatively lower than trawling. These passive gears are either fixed or drifting in water column which do not require energy for operation process except hauling where it is done by mechanical means.

Purse seining: Purse seining is one of the most aggressive and efficient commercial fishing methods for capture of shoaling pelagic species (Ben-Yami, 1989; Ben-Yami and Anderson, 1985). It is a fishing technique which targets pelagic shoaling fishes. Before actual operation the shoal detection needs more fuel for fish scout, once shoal gets detected the encircling, capture and hauling process is follow-up. Purse seine operations are relatively energy efficient and greenhouse gas (GHG) emissions for small scale mechanised purse seine operations is low compared to trawling, gillnetting and lining operations.

Traps and pots: Traps or pots are gears in which fish are retained or enter voluntarily and will be hampered from escaping. They are designed in such a way that the entrance itself became a non-return device, allowing the fish to enter the trap but making it impossible to leave the catching chamber. It can be baited or non-baited. Generally passive fishing gears like gillnets and trammel nets, tangle nets, longlines, trap nets and pots, and other lift nets consuming very little power in fishing and in some cases no mechanical energy. Although travelling, setting and retrieval of gear may use some energy, target stocks are attracted by bait or are carried to the gear or encounter it by chance and are trapped. Tyedmers (2001) reviewed over an approximately 20-year period (early 1980s to late 1990s) and found about 330 L of fuel used to catch per t of catch in a crab trap.

Other types of fishing: There are several fish harvest practices which require more energy; light fishing is one of them. Fishing using lights has been practiced from historic times, a classic example is 200-year old Chinese dipnet, which use lights (earlier hurricane lamp and now CFL lamps) to attract fish to the net. Chinese dipnets are mostly animate energy based sustainable fishing operation. More than half of the purse-seine vessels, stick-held dipnet and squid jigging boats use artificial light. Report of the ICES-FAO Working Group on Fishing Technology and Fish Behaviour (WGFTFB), 2012, suggests that roughly global marine catches using lights is 1.09 million tonnes (1.6% of global catches) in 2010. Roughly 16% of the light fishing catches comprise of squids, and the remaining >80% are fish species (Mohamed, 2016).

Measures for energy optimisation

Energy security and conservation have great significance on account of responsible fishing and also to meet the demand-supply gap of fossil fuel. During the tow, resistance of the vessel is insignificant compared to the resistance of the gear. The gear resistance therefore has a large effect up on overall fuel economy. Fuel cost can be over 50 percent of the total expenses on a fishing trip. Generally fuel consumption due to floats, sweeps, warp, otter boards, foot rope and webbing are nearly 3%, 4%, 5%, 20%, 10% and 58% respectively. Some of the preventive measures can save fuel in trawling operation are use of knotless netting, thinner twine, large meshes, cambered otter boards, optimal angle of attack of otter boards, slotted otter boards, multi-rig trawling, pair trawling etc. The fuel consumption significantly increases at maximum speed of vessel, this is because of increase in wave breaking resistance. Facts established that reduction of 10-20% speed can lead to save fuel by 35 to 61% fuel. Application of proper vessel technology during construction of vessel is very important for energy optimised vessel. Operation at rated engine rpm helps in reduction in fuel consumption. Selection of right engine with proper periodic maintenance is required for effective energy optimisation. For energy optimisation, proper fleet management, resource conservation and fishery-based geo informatics system like PFZ etc are also very important. (Gulbrandson, 2012)

Environmental burden due to fishing

Global Warming Potential (GWP) is one of the environmental impacts due to which quantitatively relate the heat produced by greenhouse gas (CO_2, CH_4, N_2O, chloro-flouro carbons (CFCs), etc.) and traps in the atmosphere. Based on different levels of technological interventions in fishery the attributes of fisheries are different in different parts of world. Residence time of atmospheric gases is assumed to be 100 years. Carbon Dioxide Equivalents (CO_2-Eq) is considered as a standard for calculation of Global Warming Potential (GWP). CO_2 equivalent is a metric measure to compare the emissions of 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. In other words, it is an important indicator in the extent of damage due to environmental degradation by emitting CO_2 in atmosphere. Broadly capture fisheries has three phases; the first involves construction of fishing vessel, gear and other accessories (pre-harvest), the second involves actual fishing operation process (harvest) and the third phase deals with processing and value addition (post-harvest). Out of three phases, harvest phase contributes maximum equivalent carbon emission due to burning of fossil fuel (Ghose, et al., 2014). 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 boat construction and fuel combustion. The United Nation Framework Convention on Climate Change through its Paris convention 2015 (COP21) stressed the importance of bring down the over-exploitation and pollution for enhanced productivity and ecosystem health of ocean. In this scenario, energy analysis is relevant in relation to fisheries Life Cycle Assessment (LCA) due to the accepted importance of fuel consumption for fleet operations (Tyedmers, 2001) and associated environmental impacts (Thrane, 2006; Schau et al., 2009; Driscoll & Tyedmers, 2010). Globally marine capture landing is almost constant during past two decades however emission by fishing vessel increased by 28% during the period (WRI, 2014). According to one study the larger mechanized boats 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 all fish harvesting systems, mechanised trawling is the most energy intensive operation and traditional non-motorised gillnetting is the most energy efficient having the lowest gross energy requirement. Out of non-motorised systems, stake nets have comparatively high energy intensive. Among motorised operations, ring seines have a lower gross energy requirement per ton of fish landed. Gross energy requirement of mechanised seine was found more compared to mechanised seine, this may be due to lower fuel efficiency of outboard motors compared to inboard diesel engines. Fishing operations requires scouting of shoal/search of fishing ground which may be distantly located have relatively high gross energy requirement per t of fish landed.

LCA as a tool for energy optimisation and sustainable fishing

In the fisheries context the one of the major goals of LCA study is to assess the Global Warming Potential (GWP) as the environmental burdens associated with the fishing operations and other allied activity. Conventional fishery research, for a long time, focused mostly on individual stock assessment and management. During the recent past, in some countries research addressed the ecosystem approach to fisheries (FAO, 2003). Many authors studied and reported effect on environment by capture fisheries using life cycle assessment method. Tyedmers (2001), Ziegler *et al.* (2003), Thrane (2004, 2006), Ellingsen & Aanondsen (2006), Vázquez-Rowe *et al.* (2010a and 2010b), Ramos *et al.* (2011) and Svanes *et al.* (2011). LCA is one of the tools which address the increasing concerns regarding energy use/optimisation, inherent in the fishing and associated activities and the need to understand and minimise these impacts. LCA allows for comprehensive evaluations to be made on environmental impacts due to fishing over their whole life cycle and how to reduce at step to step. Environmental impacts resulting indirectly from fishing operations are mostly associated with the extraction and transformation of natural materials and fossil fuels used for the construction, use and maintenance of fishing units. In other words, is a widespread framework for environmental assessment of fisheries with 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., 2016). LCA takes into account of all related activities to provide idea about CO_2 emission due to construction of fishing boats (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. LCA is systematically describing and quantify the range of environmental impacts associated with the industrial aspects of fishing (Hospido & Tyedmers, 2005). Many authors reported effect of marine capture fisheries on environment using life cycle assessment method, *viz*. Tyedmers (2001), Ziegler et al. (2003), Thrane (2006), Ellingsen &

Aanondsen (2006), Ziegler & Valentinsson (2008), Vázquez-Rowe et al. (2010a and 2010b), Ramos et al. (2011) and Svanes et al. (2011). This methodology is standardized for evaluating the environmental impacts of a process/product from its entire life span which is standardized by ISO 14040 and 14044. It is widespread framework which takes an account of entire spectrum of energy consumed in each process/production stage of the material usage. Life cycle inventory (LCI) involves the collection and computation of data to quantify relevant inputs and outputs of a product, process or system, including the use of resources and emissions to air, water and soil associated to the system (ISO 14040, 2006). Several LCA software packages are used for analyzing foreground and background systems inventories along with midpoint impacts of the different inputs by means of ReCiPe 2016.

Important approaches in LCA

The Consequential Approach: The consequential approach to allocation is the theoretical model to deal with multifunctional processes and recycling. However, one need to make a lot of

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construction of fishing vessel to prepare the recipe of curry. Here fish processing waste can be used as supplements of animal feed, and their co-production means the impact of producing other sources of animal feed is avoided. After the curry is consumed, recycling of the empty packing material can mean the impact of virgin packing material production is avoided. This approach forces to make assumptions about quality, viz. do the other sources of animal feed have the same function/quality as the raw fish (in terms of nutritional value), and does the recycled packing material have the same quality as the virgin packing material?

Physical Allocation: In order to avoid such assumptions and concentrate on the life cycle of the fish curry itself, we can choose an attribution approach. In the case of multifunctional processes, one first need to classify the outputs as waste, recyclable material or marketable co-products. Then to determine an allocation key for the marketable products. This can be based on physical characteristics, such as mass, dry mass, volume, energy content and energy input associated with each co-product.

Economic Allocation: As physical allocation can be considered unfair for lower-valued by-products. To overcome this, it is common to use the price of the product and by-products to calculate the allocation keys. Although prices are often confidential and volatile; for this average price over several years can be used.

Allocation at the point of substitution: Fish processing waste are not a typical by-product, because they would be in different forms, depending on dry matter percentage. Straight from the pre-processing, waste is rather wet and have very little market value, therefore it is better not to allocate any burdens to the processing waste and only attribute the burdens from process of making recipe of curry. This approach is called allocation at the point of substitution.

Recycled content or cut-off approach: The most common approach for above situations like the wet processing waste and used packaging material is the recycled content or cut-off approach. This model allocates burdens at the point where a product is sold and applies a cut-off at the point the recyclable material leaves the product system.

Closed-loop Scenario: One situation if there is a great demand for recycled packaging material and there is limited supply also, in that case use of material will be less because of the limited availability at the production site. In this context If we apply recycled content approach, the packaging material would get a large burden from using virgin packaging material. In such situations, several LCA and carbon footprint specifications allow us to apply a closed-loop scenario. This means we assume that all the packaging material that was recycled will be used for the same purpose again. The percentage of recycled packaging material for making the packets is assumed to be equal to the percentage of packets that is recycled at the end of the life of packaging material.

Conclusion

In an ideal situation, generally we use the consequential approach. Then we can discuss our assumptions about which product is actually substituting which product in practice, rather than endlessly disagree on the allocation methods and recycling formulas we are using. Life cycles are complex and full of multifunctional processes and recycling. It takes a lot of time to go through all the options, collect the additional data of substituted life cycles. With the help of LCA technique we can determinate the energy requirement/use at each and every step in a product development or any processes. Subsequently we can reduce/minimise the quantum of that particular step in order to minimise energy consumption. LCA can account for more than just greenhouse gas emissions. In fact, this method allows consideration of other broad but significant environmental impacts that are often overlooked in other methods including toxic emissions released by food production systems such as antibiotics and pesticides, and the use of limited resources such as freshwater and oil. “ , ,

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“ ” , ( ) (sions) within the system. Thus allowing identification of stages within the system with the highest environmental impacts specially energy requirement and its optimisation.

With a growing number of LCA studies focused on seafood, new insights of current understanding of sustainability is rising. For example, the amount of fuel used to harvest an overfished stock is significantly greater than that for an abundant stock due to the extended amount of time needed to find enough fish. The type of gear used to catch fish can also make a notable difference in fuel use. Even the energy source itself is an important thing to consider, i.e. whether it comes from fossil fuels or renewables. LCA is useful in that it actually considers all of these considerations, thus amplifying our understanding of the environmental impacts of seafood production. So LCA can be used as a technique to reduction/optimisation of energy use in pre-harvest/harvest/post-harvest. Ideally standardised fisheries LCAs, should contribute to better decision making on fisheries management and seafood consumption. The decrease of environmental impacts produced by marine fisheries depends not only on technical improvement aimed at reducing adverse effects of construction, use and maintenance, but specially on the management of the fishing sector in order to decrease fishing effort on overexploited stocks and limit fishing and processing overcapacity. For instance, some of the driving factors of fuel use per landed catch, namely the selection of fishing gear and the size of fishing units, depend on design/management decisions that should be addressed by fisheries policy and management.

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