



# Gross Energy Requirement in Fishing Operations

M.R. Boopendranath<sup>1\*</sup> and M. Shahul Hameed

School of Industrial Fisheries, Cochin University of Science and Technology, Cochin - 682 016, India

## Abstract

Energy is a key input into the fish harvesting process. Efficient use of energy helps in reducing operational costs and environmental impact, while increasing profits. Energy optimisation is an important aspect of responsible fishing as enunciated in the Code of Conduct for Responsible Fisheries. Gross Energy Requirement (GER) is the sum of all non-renewable energy resources consumed in making available a product or service and is expressed in energy units per physical unit of product or service delivered. GER is a measure of intensity of non-renewable resource use and it reflects the amount of depletion of earth's inherited store of non-renewable energy in order to create and make available a product or service. In this study, GER in fish harvesting up to the point of landing is estimated in selected fish harvesting systems in the small-mechanised sectors of Indian fisheries and compared with reported results from selected non-mechanised and motorised fishing systems to reflect the situation during 1997-1998. Among the fish harvesting systems studied, GER t fish<sup>-1</sup> ranged from 5.54 and 5.91 GJ, respectively, for wooden and steel purse seiners powered by 156 hp engines; 6.40 GJ for wooden purse seiner with 235 hp engine; 25.18 GJ for mechanised gillnet/line fishing vessel with 89 hp engines; to 31.40 and 36.97 GJ, respectively, for wooden and steel trawlers powered by 99-106 hp engines.

**Keywords:** Gross Energy Requirement (GER), gillnetting, lining, trawling, purse seining

Received 05 May 2012; Revised 16 November 2012;  
Accepted 23 November 2012

<sup>1</sup>Present Address: Central Institute of Fisheries Technology, Matsyapuri P.O., Cochin - 682 029, India

\* E-mail: boopendranath@hotmail.com

## Introduction

Modern fishing is one of the most energy intensive methods of food production. FAO Code of Conduct for Responsible Fisheries (FAO, 1995) highlights the need for efficient use of energy in the fisheries sector. Information on energy requirement in different fish harvesting systems, based on the principles of energy analysis, will provide an unbiased decision making support for maximising the yield per unit of non-renewable energy use, from different fishery resource systems, by rational deployment of harvesting systems. In world capture fisheries, 50 billion litres of fuel is consumed annually, which forms 1.2% of the global fuel consumption (Tyedmers et al., 2005). Annual consumption of fuel by the mechanized and motorized fishing fleet of India has been estimated at about 1220 million litres (Boopendranath, 2000; 2006). Greenhouse emission per tonne of fish caught is 1.13 t in India (Boopendranath, 2006) and 1.7 t globally (Tyedmers et al., 2005). The need for fishing industry to become energy-smart along the entire food chain to cope with the volatility and rising trends of fuel and energy prices and to ensure food availability at accessible prices has been stressed by FAO (2011; 2012). Studies on energy analysis have been generally confined to industrial and agricultural production systems (Berry & Fels, 1973; Leach, 1976; Pimentel, 1980; Fluck, 1985; Mittal & Dhawan, 1988; EMC, 1991; Fluck, 1991). Energy Analysis Unit of the University of Strathclyde, Glasgow, Scotland, estimated the energy requirement for various fishing methods and aquaculture production systems, based on energy analysis (Edwardson, 1976a;b). Most of the available literature on energy use in fisheries deals only with the operational aspects of consumption. Large variations in energy use exist among different fishing gears.

In view of the growing significance of energy use and its impacts on environment, energy inputs in marine fishing and post-harvest operations has been studied by several authors in recent years

(Boopendranath, 2000; Thrane, 2004; Sumaila et al., 2008; Winther et al., 2009; Abernethy, 2010; Driscoll & Tyedmers, 2010; Vásquez-Rowe et al., 2011; Suuronen et al., 2012; Tyedmers & Parker 2012). Large variability of energy use in a range of fisheries types across the world has been discussed by Tyedmers (2004). Endal (1980) has given fuel consumption for different fishing methods as 1.0 kg for middle water bottom trawling, 0.6 kg for near water bottom trawling, 0.3 kg for middle water long lining, 0.2 for near water longlining and 0.1 kg for coastal fishing, per kg of fish landed. Nomura (1980) evaluated the fuel efficiency of different fishing systems, in comparison to the setnet fisheries of Japan. He found that 0.270-0.430 kg of fish was produced by high seas tuna longline; 0.530 - 0.822 kg by salmon drift net; 0.820 kg by far seas squid angling; 0.860-1.800 kg by skipjack pole and line; 0.960 kg by demersal fish trawl (East China Sea); 3.60 kg by pelagic fish purse seine; 4.80 kg by Alaska Pollack trawl (North- Pacific) and 12.50 kg by large-scale setnet, per litre of fuel. Energy analysis of non-motorised and motorised fish harvesting systems operating in Indian waters has been reported by Boopendranath (2000) and Boopendranath & Hameed (2009; 2010).

Gross Energy Requirement (GER), a measure of intensity of non-renewable resource use is the sum of all non-renewable energy resources consumed in making available a product or service. It is a convention devised by a workshop on energy analysis methodology, held under the auspices of the International Federation for Institutes of Advanced Study (IFIAS) in Sweden in 1974 (IFIAS, 1975). Renewable energy and human energy are not included in the GER. It allows for unbiased decisions in terms of energy requirement regarding the different harvesting systems, free from any of the bias which might be associated with the arguments of economists, end-users or managers. Information on GER for different fish harvesting systems will provide an unbiased decision making support for the fishery management to optimise the yield per unit of non-renewable energy spent; decide on the mix of fish harvesting systems to be employed for optimising fuel use in the capture fish production in a region; and delineate approaches for energy conservation. In this study, GER represents the intensity of non-renewable resource use per unit of the fish landed and takes into account the amount of energy used in providing all inputs into the harvesting process, including fishing vessel, fishing

gear and operational sub-systems. Objective of the present study was to estimate GER in selected fish harvesting systems operating in Indian fisheries, based on investigations conducted during 1997-1998.

## Materials and Methods

### Estimation of GER

Estimation of Gross Energy Requirement per tonne of fish landed ( $\text{GER t fish}^{-1}$ ) was carried out following the methodology recommended by IFIAS (IFIAS, 1975) and other authors (Mittal & Dhawan, 1988; Slessor, 1988; Edwardson, 1976a; Edwardson, 1976b; EMC, 1991; Boopendranath, 2000) (Fig. 1). Important inputs which go into the fish harvesting process include the fishing vessel construction, fishing gear manufacture and operational energy requirement. For each type of input, the amount of material used in one year was obtained and corresponding amount of energy used up in making the material available was determined using conversion ratios (Mittal & Dhawan, 1988; Slessor, 1988; Berry & Fels, 1973; Edwardson, 1976a; Edwardson, 1976b; ECCJ, 1997; Loftness, 1978; EMC, 1991; TERI, 1999; Boopendranath, 2000). The capital items such as fishing vessel including engine, machinery and equipment; and fishing gear were amortised over their anticipated useful lifetimes. GER per tonne of fish landed was then calculated by dividing the capital by anticipated life in years and adding other direct inputs such as annual fuel consumption and dividing the total by the quantity of fish landed in that year.

### Data sources for energy analysis

Information on mechanised vessel construction was collected from boat builders in the Vypeen-Aroor belt (Ernakulam, India). Material requirements for construction were estimated using the methods described by Fyson (1985; 1991). Useful life-time of mechanised vessels including power plants and equipment, was assumed to be 10 years for energy amortisation purposes. Data on design details and rigging of fishing gears were obtained by field survey, as per a structured survey questionnaire prepared for the purpose. Useful life-time of fishing gears estimated for amortisation purposes were one year for active fishing gears such as trawls, steel wire rope used as towing warps in trawlers; three years for surrounding nets of heavy construction for

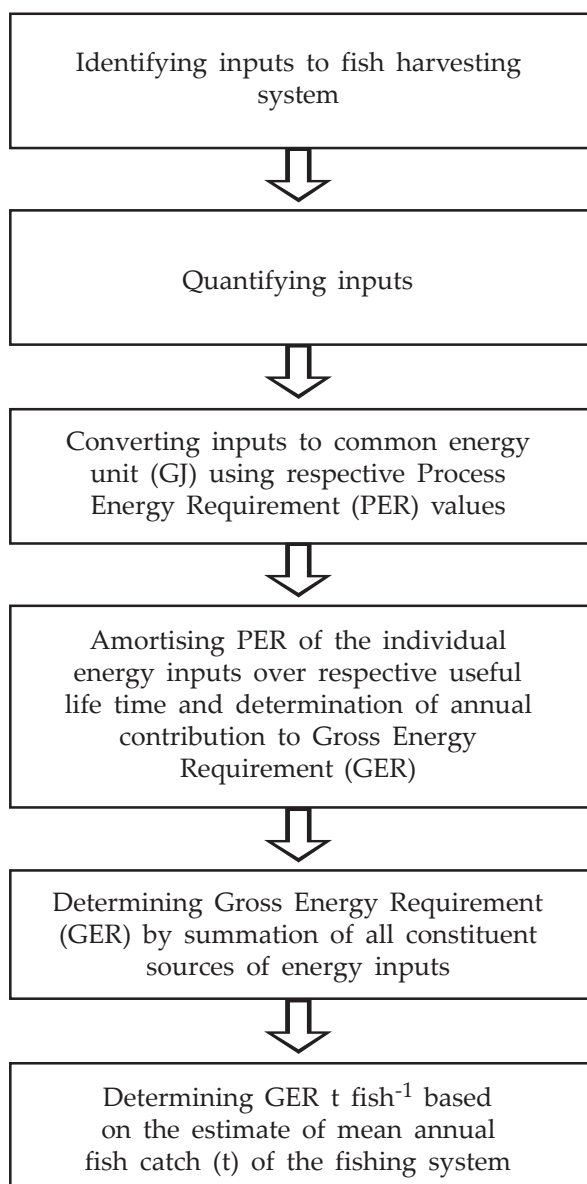


Fig. 1. Flow chart of energy analysis

mechanised purse seining, gill nets operated from mechanised vessels and for lines; and 0.5 year for otter boards, based on information sourced from fishers.

Data on fish catch by selected fish harvesting systems were collected from Cochin fisheries harbour, according to a pre-fixed sampling schedule, during 1997-98. Data on fishing operations were collected by discussions with the operators as per a structured survey questionnaire prepared for the purpose and onboard visits. Data were collected

from 5 gillnet/line fishing vessel (89 hp, 9-11 m  $L_{OA}$ ), 7 trawlers (99-106 hp, 13-14 m  $L_{OA}$ ) and 7 purse seiners (156-235 hp, 13.1-17.0 m  $L_{OA}$ ) operating from the Cochin fisheries harbour.

## Results and Discussion

Gillnet/line fishing vessels which operated from Cochin had wooden hull. The predominant length class was 9.1-10.0 m, followed by 10.1-11.0 m. Fishing vessels with 89 hp was the most common, followed by <60 hp vessels and 99 hp vessels. Gillnets used in mechanised fishing boats operated from Cochin were made of polyamide netting with a twine size of R470 tex and mesh size (stretched) of 70 - 80 mm. The hung depth of the net was usually 11 m and total length of the net ranged from 1620 to 1890 m. In addition to gillnets, two types of lines were operated from gillnetters, depending on season, availability of target resources and market demand, in order to further improve the economics of operations. Long lines were operated for large sharks and hand lines for perches, small tuna and other scombroid fishes.

Mean annual catch per gillnet/line fishing vessels was worked out to be 33 t. Tunas and bill fishes along with pelagic sharks formed 57% of the total landings. Perches belonging to the genus *Epinephelus*, *Lutjanus*, *Lethrinus* and *Pristipomoides* formed the third largest category forming 22.8% of the landings. Spanish mackerel (*Scomberomorus* spp.) and carangids contributed 9.5 and 5.7%, respectively and the rest was made up of miscellaneous fishes. Of the landings, tunas and Spanish mackerel were mostly caught by drift gillnets; sharks by drift long line and the bulk of the perches and carangids by hand line operations.

Results of energy analysis are given in Table 1 and Fig. 2. During the period of study, only wooden fishing boats were in use for gillnet and line fishing in the small scale mechanised sector, operating from Cochin. Wooden hulled boats of 10.1m  $L_{OA}$  fitted with ALM 370 engines (Ashok Leyland, India) generating a horse power of 89 hp at 2000 rpm, dominated in this category of vessels. Total energy requirement for vessel construction of this length class was estimated to be 74.3 GJ. Contribution to annual GER is estimated at 7.43 GJ.

Gillnets for pelagic fishes, long lines for pelagic sharks, multiple hook hand lines for perches and

Table 1. Results of energy analysis of Gillnetter-cum-liners operated from Cochin

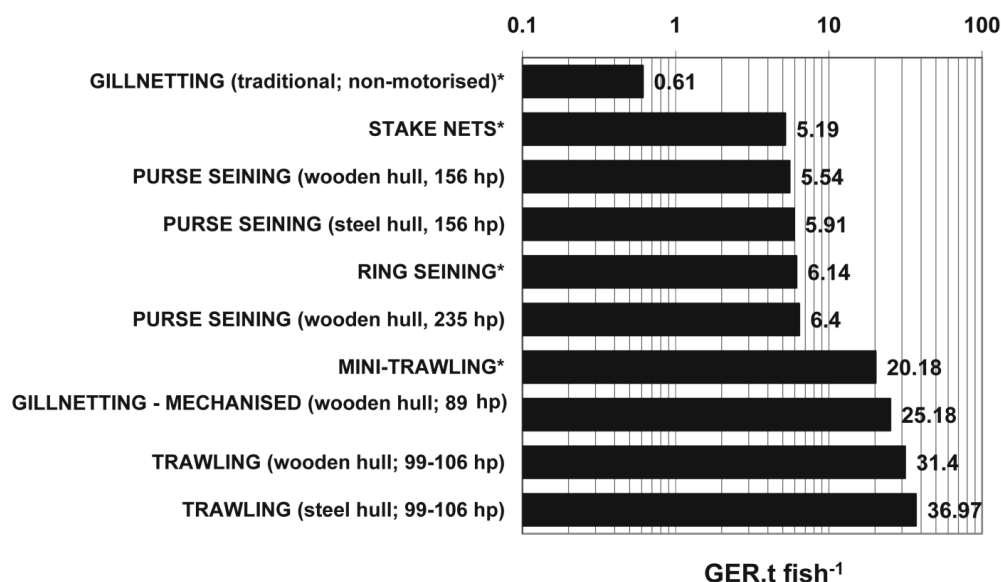
| Category                       | GJ     | Annual GER, GJ |
|--------------------------------|--------|----------------|
| Operational energy requirement |        |                |
| Diesel                         | 799.95 |                |
| Lubricating oil                | 4.64   |                |
| Ice                            | 2.83   |                |
| Sub-total                      | 807.42 | 807.42         |
| Fishing gear                   |        |                |
| Drift gillnets                 | 26.90  |                |
| Drift long line for sharks     | 28.14  |                |
| Hand line for small carangids  | 0.22   |                |
| Hand line for perches          | 0.56   |                |
| Sub-total                      | 55.82  | 18.61          |
| Vessel                         | 74.30  | 7.43           |
| Total                          |        | 833.46         |

light assisted multiple hook hand lining for small carangids were practiced by this class of vessels, during the period of study. Estimates for GER for gillnets, pelagic long lines, hand line for perch and light assisted hand line for small carangids were respectively, 26.90, 28.14, 0.558 and 0.221 GJ. Total

GER for gear aggregated to 55.82 GJ. Based on an estimated useful life span of 3 years for the gear, contribution to annual GER worked out as 18.61 GJ.

Energy for the fishing operations was contributed by consumption of diesel, lubricating oil and ice carried onboard for preservation of catch. Mean annual consumption of diesel, lubricating oil and ice by gillnet/line fishing vessels, during the period of observations were 11.9, 0.1 and 14.2 t, respectively. Fuel constituted the bulk of the energy consumed with an annual expenditure of 799.95 GJ, followed by lubricating oil, 4.64 GJ and ice 2.83 GJ. Total operational energy requirement for gillnetting and lining operations during the period of study was 807.42 GJ.

Of the operational energy requirement, fuel constituted 99.08%, lubricating oil 0.58% and ice used for preservation of catch during multi-day fishing 0.35%. Usage of ice was directly proportional to the number of days in the fishing trip which ranged from 1 to 6 days during the period of observations, with a mean number of days per trip of 4.2. Among fishing gears in use, drift long line consumed 28.14 GJ (50.41%) and drift gillnet 26.90 (48.19%). Energy requirement of hand lines was, however, comparatively very low at 0.558 and 0.221 GJ, respectively for hand line for perch and light assisted hand line



(\*Source: Boopendranath, 2000; Boopendranath & Hameed, 2009; 2010)

Fig. 2. Gross Energy Requirements (GERs) for fish harvesting systems



for small carangids. It formed 1.0 % and 0.4 % of the total energy requirement for fishing gear.

The percentage contribution of operational energy consumption, and consumption for fishing gear and fishing boat construction to the annual GER were respectively, 96.51, 2.22 and 1.27%. Fuel expended for producing unit weight of fish has been determined to be 0.364 kg fuel kg fish<sup>-1</sup>.

One-boat bottom otter trawling was conducted by small-scale trawlers of Cochin. Generally, multi-day fishing operations are undertaken, due to its economic advantages, over single day fishing. The average trip duration varied from 2 to 4 days. Normal fishing depth is up to about 110 m.

Over 80% of the trawlers belonged to the length class of 13.1-14.0 m L<sub>OA</sub> and were fitted with 99-106 hp engines. During the period of study, about 20% of the trawlers operating from Cochin had steel hulls and the rest were of wooden hull construction.

Four types of trawls are used from trawlers which are targeted at specific resources. Generally, a complement of 8 nets was carried in a small mechanised trawler. Depending on the behaviour and distribution characteristics of the target resources, each trawl had certain differences in design and rigging. Designs in use were 33.5 m demersal shrimp trawl, 41.2 m, 43.6 m squid-anchovy demersal trawl and 41.6 m demersal cuttlefish trawl. Flat rectangular otter boards of 1474x737 mm (70 kg), 1524x762 mm (75 kg), and 1626x813 mm (82 kg) were used by vessels powered by 99 hp, 106 hp and 156 hp engines, respectively. V-type boards of size 1370x760 mm of 65 and 70 kg weight, were used by vessels powered by 99 hp and 106 hp, respectively. About 35% of the trawlers operating from the Cochin fisheries harbour were using V-shaped steel otter boards.

Mean catch per year of trawlers was 53 t and major catch components were threadfin breams 22.9%, perches 17.7%, carangids 9.9%, lizard fish 2.8%, sciaenids 1.7%, crustaceans 8.8%, cephalopods 12.2% and miscellaneous fish 24.0%. Catches ranging from 303-383 kg trawler<sup>-1</sup> day<sup>-1</sup> were obtained during April- September. During other months of the year, it ranged from 145-153 kg trawler<sup>-1</sup> day<sup>-1</sup>. During these months the trawlers diversified into line fishing, due to the paucity of trawl resources and the resultant economic reasons. Fishing operations were suspended during a period of 45 days from

15<sup>th</sup> June to the end of July, during the period of study, due to the monsoon trawl ban imposed by the State Government.

Energy analysis was performed separately for wooden and steel hulled trawlers. Results of energy analysis are given in Table 2 and Fig. 2. Total energy inputs for trawling with wooden trawler, was estimated to be 1624.33 GJ. Percentage contribution of operational and capital energy inputs to GER in respect of wooden trawlers were 85.7% for diesel, 0.3% for lubricating oil, 0.4% for ice, 11.8% for fishing gear and 1.8% for fishing vessel. Gross non-renewable energy requirement per tonne of fish landed by this category of trawlers worked to be 31.40 GJ.

Table 2. Results of energy analysis of trawlers

| Category                               | Wooden trawlers |                | Steel trawlers |                |
|----------------------------------------|-----------------|----------------|----------------|----------------|
|                                        | GJ              | Annual GER, GJ | GJ             | Annual GER, GJ |
| Operational energy requirement         |                 |                |                |                |
| Diesel                                 | 1392.66         |                | 1684.65        |                |
| Lubricating oil                        | 4.86            |                | 5.64           |                |
| Ice                                    | 6.26            |                | 6.40           |                |
| Sub-total                              | 1403.77         | 1403.77        | 1696.69        | 1696.69        |
| Fishing gear                           |                 |                |                |                |
| Trawls with appurtenances              | 35.28           | 35.28          | 35.28          | 35.28          |
| Towing warp                            | 147.83          | 147.83         | 147.83         | 147.83         |
| Otter boards                           | 4.114           | 8.23           | 4.114          | 8.23           |
| Line fishing gear                      | 0.558           | 0.56           | 0.558          | 0.56           |
| Fishing vessel with engine & equipment | 286.6           | 28.66          | 1052.7         | 105.27         |
| Total                                  |                 | 1624.33        |                | 1993.86        |

Total energy inputs of steel trawlers were estimated to be 1993.86 GJ which was 22.8% higher than that for wooden trawlers. Percentage contribution of operational and capital energy inputs to GER of steel trawlers were 84.5 % for diesel, 0.3% for lubricating oil, 0.3% for ice, 9.6% for fishing gear and 5.3% for fishing vessel. GER per tonne of fish landed by steel trawlers was estimated to be 36.97 GJ which was 17.7% higher than that for wooden trawlers. The GER values for trawling ranging from 31.4 to 36.97 GJ t fish<sup>-1</sup> were the highest among the various harvesting systems covered under the present study. Mean fuel consumption per trawler during the period of study has been 0.38 kg fuel kg fish<sup>-1</sup>,

ranging from 0.28 to 0.53 kg fuel kg fish<sup>-1</sup>, during different months.

Purse seines were operated from Cochin throughout the year, excluding three months from June to August, during which period their operations are banned under regulations originating from the provisions of Kerala Marine Fisheries Regulation Act 1980. Main gear handling equipment onboard purse seiners was purse line winch. A skiff towed behind the small-scale seiners rendered assistance during the encircling and fish brailing. Net brailers were used for transferring the catch from the bunt to the fish hold. Modern equipment such as net haulers and acoustic fish detection equipment were not used in the small-scale purse seiners. Net hauling was done manually while pursing operation was mechanically assisted.

Purse seiners were either wooden or steel hulled. Wooden vessels constituted 78.3% of the purse seine fleet and the rest 21.7% constituted steel vessels. The length overall varied from 13.7 to 19.8 m. The horse power of the diesel engine depending on the size of the vessel varied from 90 to 272. The skiff which was towed behind the purse seiner was not powered and its size varied from 3 to 3.7 m. The length of the purse seine varied from 768 to 823 m and its hung depth varied from 65 to 73 m depending on the size of the vessel. Polyamide netting of R310 tex with a stretched mesh size of 22 mm, is used in the bunt placed at one end of the purse seine net. Polyamide netting of R230 tex of 22 mm stretched mesh size is used for fabrication of the main body

of purse seine net. Sixty-two purse rings of 100 mm dia, made of brass weighing 800 g each, are attached along the lead line. Cylindrical expanded PVC (Polyvinyl Chloride) floats were used in purse seines. About 5400 lead sinkers of 200 g each were attached to the lead line to attain 1.5 kg m<sup>-1</sup> and 3960 expanded PVC floats with a buoyancy of 610 gf each, were attached along the float line, to attain a buoyancy rate of 3.4 kgf m<sup>-1</sup>.

Mean number of fishing days were 124 for 235 hp wooden purse seiners and 181 for 156 hp steel and wooden seiners. Mean catch per year were 325 t, 340.5 t and 278 t, respectively for 156 hp wooden seiner, 156 steel seiner and 235 hp wooden seiner. The catch was constituted by sardines 54.30%, mackerel 44.5%, tunnies 0.23%, pomfrets 0.08% and miscellaneous fish 0.89%.

Results of energy analysis are given in Fig. 2 and Table 3. GER values were estimated separately for 156 hp wooden seiners, 156 hp steel seiners and 235 hp wooden seiners. Total energy inputs for 156 hp wooden seiners was 1802.46 GJ, contributed by diesel (90.08%), lubricating oil (0.40%), gear (6.39%) and vessel and skiff (3.12%). Gross non-renewable energy per tonne of fish landed for this category of purse seiners was estimated to be 5.54 GJ. Total energy inputs for 156 hp steel seiners was 2019.60 GJ, which was 12.05% higher than that for wooden vessels with the same installed horsepower. Percentage contribution to total energy inputs was 85.95% for diesel, 0.35% for lubricating oil, 5.71% for gear, 7.99% for steel vessel and wooden skiff. GER was

Table 3. Results of energy analysis of purse seiners

|                                                  | Steel Purse seiners,<br>156 hp |                   | Wooden Purse<br>seiners, 156 hp |                   | Wooden purse<br>seiners, 235 hp |                   |
|--------------------------------------------------|--------------------------------|-------------------|---------------------------------|-------------------|---------------------------------|-------------------|
|                                                  | GJ                             | Annual<br>GER, GJ | GJ                              | Annual<br>GER, GJ | GJ                              | Annual<br>GER, GJ |
| Operational energy requirement                   |                                |                   |                                 |                   |                                 |                   |
| Diesel                                           | 1735.90                        |                   | 1623.70                         |                   | 1602.26                         |                   |
| Lubricating oil                                  | 7.14                           |                   | 7.27                            |                   | 3.21                            |                   |
| Sub-total                                        | 1743.04                        | 1743.04           | 1630.97                         | 1630.97           | 1605.46                         | 1605.47           |
| Fishing gear                                     |                                |                   |                                 |                   |                                 |                   |
| Purse seine with appurtenances                   | 345.75                         | 115.25            | 345.75                          | 115.25            | 345.75                          | 115.25            |
| Fishing vessel with engine,<br>equipment & skiff | 1613.08                        | 161.31            | 562.36                          | 56.24             | 562.36                          | 56.24             |
| Total                                            |                                | 2019.60           |                                 | 1802.46           |                                 | 1776.96           |

estimated to be  $5.91 \text{ GJ t fish}^{-1}$  for steel seiners. For 235 hp wooden seiners, the total energy inputs was 1776.95 GJ. Total energy inputs for 235 hp wooden vessels, was the lowest among the three classes of seiners, due to the lower number of fishing days and consequent lower annual operational energy expenditure of this class of vessels, during the period of study. The gross energy requirement for this class of seiners was estimated to be  $6.40 \text{ GJ t fish}^{-1}$ , which was the highest among the three classes of seiners due to the relatively high fuel consumption of the power plant. Percentage contribution to the total energy inputs was 90.17% for diesel, 0.18% for lubricating oil, 6.49% for gear and 3.17% for vessel and skiff. Mean GER for all classes of seiners worked out to be  $5.94 \text{ GJ t fish}^{-1}$ , which was the lowest among the different mechanised vessel-gear combinations, covered under the present study. Mean energy inputs for purse seiners was 1866.35 GJ contributed by diesel 88.6%, lubricating oil 0.3%, fishing gear 6.2% and fishing vessel 4.9%. As purse seining is conducted on a daily basis, ice for preservation of catch does not form a part of energy inputs for purse seiners, unlike mechanised gillnet/line fishing vessel and trawlers.

The results of energy analysis of the non-motorised, motorised fishing systems reported earlier from Indian waters (Boopendranath, 2000; Boopendranath & Hameed, 2009; 2010) and the results of the energy analysis of mechanised fishing systems during the present study are summarized in Fig. 2. Among the fish harvesting systems, traditional non-motorised gillnetting was the most energy efficient having the lowest GER and energy intensity values and highest efficiency ratio, producing more energy than the amount of non-renewable energy consumed. Mechanised trawling was the most energy intensive fish harvesting system with GER  $\text{t fish}^{-1}$  values ranging from 31.40 to 36.97 GJ, indicating an overall consumption of 0.73-0.86 t of fuel for every tonne of fish produced. Among the non-motorised systems, stake nets have relatively high energy intensity, as the annual landings were lowest and the economic viability of the operation was due to the catch of high value prawns. In the motorised operations, ring seines have a lower GER  $\text{t fish}^{-1}$  value than mini-trawling. For a fishing system, which is restricted in its operation, to shallow coastal waters, the energy cost of mini-trawling is adjudged to be high. Economic viability of the mini-trawling could be derived from high value landings of prawns during its seasonal operation. GER value

of ring seines was higher compared to 156 hp mechanised purse seiners, probably due to lower fuel efficiency of outboard motors compared to inboard diesel engines. Mechanised gillnetting and lining operations were conducted at comparatively distant fishing grounds due to scarcity of resources in the inshore waters, which explains the relatively high GER  $\text{t fish}^{-1}$  values obtained for a system, operating passive fishing gears. Steel vessels generally gave higher GER  $\text{t fish}^{-1}$  values compared to wooden vessels used in purse seining and trawling, due to larger inputs in terms of energy into vessel construction.

Gulbrandson (1986) reported that trawling consumed 0.8 kg of fuel while longlining and gillnetting consumed between 0.15 and 0.25 kg of fuel and purse seining required 0.07 kg of fuel, to catch one kilogram of fish, in Scandinavian fisheries. During 1979-86, Endal (1989) had determined the fuel consumption ranges in Norwegian fisheries, as 0.51-0.75 kg for offshore trawling, 0.045-0.07 kg for offshore purse seining, 0.32-0.46 kg for offshore longlining and 0.18-0.34 kg for coastal fishing, per kg of fish landed. Aegisson & Endal (1993), based on their studies in the states of Kerala and Karnataka in India, found that trawling produced 1.95 kg fish  $\text{kg fuel}^{-1}$ , purse seining 12.72 kg fish  $\text{kg fuel}^{-1}$  and gillnetting 3.50 kg fish  $\text{kg fuel}^{-1}$ .

Edwardson (1976a) estimated that 0.076 kg fuel was consumed by coastal fishing using net and long line in north Norway, 0.140 by long line in the continental shelf and 0.290 kg by factory vessels, per kg of fish. Energy inputs in seafood harvesting in the US have been estimated as 580 kcal for sardines, 4560 kcal for salmon, 4280 kcal for cod, 16,100 kcal for tuna and 74,800 kcal for shrimp per kg of fish (Mayor & Rawitscher, 1978).

For coastal pelagic shoaling resources, mechanised purse seining with 156 hp vessels was most efficient in terms of GER values, and this category of seiners need to be promoted, subject to the maximum sustainable yield of the target resource. Mechanised gillnetting and lining depending on deep sea pelagic and demersal resources, has GER values which is higher than coastal purse seining but lower than mechanised trawling. However, as there are no competing harvesting systems targeted at these resources, gillnetting and lining could be encouraged. Mechanised trawling has the highest energy requirement and in addition is known to have

negative ecological impacts on the resource systems. However, trawling being one of the most effective fishing method for shrimps, a trade-off would be to control their number at a rational level according to the maximum sustainable yield of shrimp stocks, and encourage diversification of excess capacity into low energy fishing methods.

## Acknowledgements

The first author thanks Cochin University of Science and Technology, Cochin, for the facilities provided for this study at the School of Industrial Fisheries; Director, Central Institute of Fisheries Technology, for granting the sabbatical, during which this work was undertaken; and mechanised fishing vessel operators of Ernakulam, for their cooperation and assistance, during the course of collection of materials for this study.

## References

- Abernethy, K.E., Trebilcock, P., Kebede, B., Allison, E.H., Dulvy, N.K. (2010) Fuelling the decline in UK fishing communities? ICES J. Mar. Sci. 67: 1076-1085
- Aegisson, G. and Endal, A. (1993) Energy Conservation Programme in Indian Fisheries - Report from the Preparatory Phase. Report No. 402009.00.01.93. MARINTEK, Norwegian Marine Technology Research Institute, Trondheim, Norway, 45 p
- Berry, R. and Fels, M.F. (1973) The Production and Consumption of Automobiles - An Energy Analysis of the Manufacturing, Discard, and Reuse of the Automobile and its Component Materials. Department of Chemistry, University of Chicago, University of Chicago Press, Chicago, IL
- Boopendranath, M.R. (2006) Energy conservation in fishing operations. Fish Technology Newsletter 17(3): 2-4
- Boopendranath, M.R. (2000) Studies on Energy Requirement and Conservation of Selected Fish Harvesting Systems. Ph.D. Thesis. Cochin University of Science and Technology, Cochin, India, 273 p
- Boopendranath, M.R. and Hameed, M.S. (2009) Energy analysis of traditional non-motorised gill net operations in Vembanad lake, Kerala, India. Fish. Technol. 46: 15-20
- Boopendranath, M.R. and Hameed, M.S. (2010) Energy Analysis of stake net operations in Vembanad lake, Kerala, India. Fish. Technol. 47: 35-40
- Driscoll, J., Tyedmers, P. (2010) Fuel use and greenhouse gas emission implications of fisheries management: the case of the New England Atlantic herring fishery. Mar. Policy 34: 353-359
- ECCJ (1997) Japan Energy Conservation Handbook 1997. The Energy Conservation Centre, Japan
- Edwardson, W. (1976a) The energy cost of fishing. Fishing News Int. 15(2): 36-39
- Edwardson, W. (1976b) Fish Farming. Report No. 6. Energy Analysis Unit, University of Strathclyde, Glasgow, Scotland, 29 p
- EMC (1991) Energy Conservation in Selected Government Farms. Energy Management Cell, New Delhi, 85 p
- Endal, A. (1980) Fuel saving. Fishing News International 19(10): 16-17
- Endal, A. (1989) Energy fishing - challenge and opportunities. In: Proceedings of the World Symposium on Fishing Gear and Fishing Vessel Design 1988, pp. 74-78, Marine Institute, St. John's, Newfoundland, Canada
- FAO (1995) Code of Conduct for Responsible Fisheries, FAO, Rome
- FAO (2011) Energy Smart Food for People and Climate. FAO, Rome, 66 p
- FAO (2012) Energy-Smart Food at FAO: An Overview. Environment and Natural Resources Working Paper. FAO, Rome, 71 p
- Fluck, R.C. (1985) Energy sequestered in repairs and maintenance of agricultural machinery, Trans. ASAF 28: 738-744
- Fluck, R.C. (1991) Input-output energy analysis for agriculture, In: Analysis of Agricultural Energy Systems, Energy in World Agriculture 5 (Peart, R.M., Ed.) pp 83-88, Elsevier, Amsterdam
- Fyson, J.F. (Ed.) (1985) Design of Small Fishing Vessels. Fishing News Books Ltd, Farnham, Surrey, England
- Fyson, J.F. (1991) Fishing Boat Designs 3 Small Trawlers. FAO Fish. Tech. Paper 188. FAO, Rome
- Gulbrandson, O. (1986) Reducing the Fuel Costs of Small Fishing Boats, BOBP/WP/27, Bay of Bengal Programme, Madras, 15 p
- IFIAS (1975) Energy Analysis Workshop on Methodology and Conventions, Guildmedshytten, Sweden, August 1974. International Federation of Institutes of Advanced Study, Ontario, Canada
- Leach, G. (1976) Energy and Food Production. IPC Business Press, Guildford
- Loftness, R. (1978) Energy Handbook. Van Nostrand Reinhold Company, New York
- Mayor, J. and Rawitscher, M. (1978) Energy Use in U.S. Seafoods: Final Report for the U.S. Energy Research and Development Administration. Tufts University, Medford, Massachusetts



- Mittal, J.P. and Dhawan, K.C. (1988) Research Manual on Energy Requirements in Agricultural Sector. College of Agricultural Engineering, Punjab Agricultural University, Ludhiana, 150 p.
- Nomura, M. (1980) Influence of fish behaviour on use and design of set nets, In: Fish Behaviour and its Use in the Capture and Culture of Fishes. (Bardach, J.E., Magnuson, J.J., May, R.C. and Reinhart, J.M. Eds), pp 446-472, ICLARM Conference Proceedings 5. International Centre for Living Aquatic Resources Management, Manila, Philippines
- Pimentel, D. (1980) Handbook of Energy Utilisation in Agriculture, CRC Press Inc., Boca Raton, Florida.
- Slessor, M. (Ed.) (1988) Macmillan Dictionary of Energy, 2<sup>nd</sup> edn., The Macmillan Press Ltd., London and Basingstoke
- Sumaila, U.R., Teh, L., Watson, R., Tyedmers, P. and Pauly, D. (2008) Fuel price increase, subsidies, overcapacity, and resource sustainability. ICES J. Mar. Sci. 65: 832-840
- Suuronen, P., Chopin, F., Glass, C., Løkkeborg, S., Matsushita, Y., Queirolo, D. and Rihan, D. (2012) Low Impact and Fuel Efficient fishing - Looking beyond the horizon. Fish. Res. 119-120: 135-146
- TERI (1999) TERI Energy Data Directory and Yearbook 1999/2000. Tata Energy Research Institute, New Delhi
- Thrane, M. (2004) Energy consumption in the Danish fishery: Identification of key factors. J. Ind. Ecol. 8: 223-239
- Tyedmers, P. (2004) Fishing and Energy Use. In: Encyclopedia of Energy. Vol. 2, pp. 683-693, Elsevier, Amsterdam
- Tyedmers, P. and Parker, R. (2012) Fuel consumption and greenhouse gas emissions from global tuna fisheries: A preliminary assessment. ISSF Technical Report 2012 03. International Seafood Sustainability Foundation, McLean, Virginia, USA
- Tyedmers, P.H., Watson, R. and Pauly, D. (2005) Fueling global fishing fleets. AMBIO 34: 635-638
- Vásquez-Rowe, I., Moreira, M.T. and Feijoo, G. (2011) Life cycle assessment of fresh hake fillets captured by the Calician fleet in the Northern Stock. Fish. Res. 110: 128-135
- Winther, U., Ziegler, F., Skontorp Hognes, E., Emanuelsson, A., Sund, V. and Ellingsen, H. (2009) Carbon footprint and energy use of Norwegian seafood products. SINTEF Report No. SHF80 A096068, 91 p