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Oil for Fish: An Energy Return on Investment Analysis of Selected European Union Fishing Fleets

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Abstract :

World food production has increased substantially in the past century, thanks mostly to the increase in the use of oil as input in the production processes. This growing use of fossil fuels has negative effects, both on the environment and the production costs. Fishing is a fuel consuming food production activity, and its energy efficiency performance has worsened over time. World-wide fisheries are also suffering from overexploitation, which contributes to the poor efficiency performance, adding more pressure and criticism on this economic activity. In this paper we analyzed the energy efficiency performance of more than 20,000 European Union (EU) fishing vessels for the period 2002-2008, using the edible energy return on investment (EROI) indicator. The vessels analyzed, grouped in 49 different fleets, represented 25% of the vessels and 33% of the landings of the EU fishing sector. These EU fishing fleets' average EROI for 2008 was 0.11, which translates to an energy content of the fuel burned that is 9 times greater than the edible energy content of the catch. Hence, the significance of this study arises from the use of time-series data on a relevant part of the EU fleet that showed stable or even slight improvements on the EROI over time. Moreover, results showed that the energy efficiency of the different fleets varied significantly (from 0.02 to 1.12), mainly depending on the fishing gear and the vessel length. The performance of the most efficient fleets, such as large pelagic trawlers and seiners, was comparable to many agricultural production activities. The plausible drivers behind these trends are further considered.

Keywords : energy efficiency, energy return on investment (EROI), fisheries, fishing fleet, fuel consumption, industrial ecology

Introduction

World food production has increased substantially in the past century, as has calorie intake per capita (Nellemann et al. 2009). But this has happened at the cost of increasing the use of oil as input in the food production process. “Eating Oil” is the title of a book published in 1978 that investigates the extent to which food supply in industrialized countries relies on fossil fuels (Green 1978). Not surprisingly, most studies on energy efficiency for food production were realized during the 70s and 80s, after the first oil crisis in 1973 (i.e. Leach 1976; Pimentel and Pimentel 1979; Pimentel et al. 1983; Cleveland et al. 1984; Hall et al. 1986). Nowadays, food supply worldwide is even more dependent on oil, and a lot more studies have populated the scientific literature (i.e. Dutilh and Kramer 2000; Tyedmers 2001, 2004; Pelletier and Tyedmers 2007; Pelletier 2008; Schau et al. 2009; Fet et al. 2010, Pelletier et al. 2010a, 2010b).

The energy return on investment (EROI) is the ratio of the energy delivered by a process to the energy used directly and indirectly in that process (Leach 1976; Pimentel and Pimentel 1979; Pimentel et al. 1983; Cleveland et al. 1984; Hall et al. 1986). The EROI is generally used for measuring the efficiency of different technologies and sources of energy, expressed as the ratio of the gross energy return to the amount of energy invested (Mulder and Hagens 2008). Other names used for this concept are energy profit ratio, energy efficiency, energy gain (Tainter et al. 2003), net energy (Odum 1973) and energy payback (Keoleian 1998).

Although originally the EROI indicator was a measure of the efficiency of different energy sources, the EROI ratio has also been used in food production processes to compare the energy extracted from the edible content of the food and the energy in the form of input requested for their production. The EROI analysis provides a quantitative result that can be easily compared with other similar calculations (Murphy et al. 2011). Therefore, the EROI indicator provides an objective measurement of the nourishment that can be produced by unit of energy spent (i.e. fuel combustion). This allows to compare the energy efficiency of different fleets without dependence on landing weights (that can provide partial vision due to large non edible contents, i.e. in mussels) or on their monetary values, and consequently, results can be objectively compared worldwide. It also allows comparison of the fishing sector with other sectors, such as livestock or aquaculture (i.e. Tyedmers 2004; Tyedmers et al. 2005). Indeed, the ratio has been used in agriculture (i.e. Pimentel and Pimentel 1979; Pimentel et al. 1983), cattle farming (i.e., Pelletier 2008), fisheries (i.e. Tyedmers 2001, 2004) and aquaculture (i.e. Pelletier and Tyedmers 2007).

Fisheries have often been considered one of the less efficient food production activities (Wilson 1999); however, this generalization is not supported by the work of several authors (i.e. Tyedmers et al. 2005). It has been estimated that fishing fleets around the world burn between 38 and 42.5 million tons of oil per year, accounting for about 1.2% of global oil consumption (Tyedmers et al. 2005; World Bank and FAO 2008). Moreover, a general tendency of energy performance becoming poorer over time is evident from a number of fisheries around the world (i.e. Tyedmers 2001, 2004). Fisheries are suffering from poor profitability, mainly due to increasing fuel costs, as well as the increasing stocks overexploitation (i.e. Csirke 2005; Abernethy et al. 2010). This implies that in order to extract the same amount of fish it is necessary to consume more oil. The energy efficiency of the different existing fleet segments varies significantly. Both the fishing gear/technique and the vessel length that characterize each fleet segment affect the energy performance of the fleets (Thrane 2004; Ziegler and Valentinsson 2008; Driscoll and Tyedmers 2010).

Because fuel combustion has adverse environmental impacts and also raises production costs, it is advisable to reduce fuel consumption, or at least consume it in the most efficient way possible. This is also valid for fisheries, where fuel often is the most important cost (FAO 1995; Dahou et al. 2001; Reddy 2004; FERM 2004; Sumaila et al. 2007; STECF 2010; Sumaila et al. 2010). Under the Europe 2020 Strategy for smart, sustainable and inclusive growth (EC 2010), EU Member States have committed themselves to reducing greenhouse gas emissions (GHG) by 20% compared to 1990 levels , increasing the share of renewable sources in the EU's energy mix to 20%, and achieving a 20% increase in energy efficiency by 2020.

In this paper, by using public and comprehensive time series data we analyze the energy profiles of different EU fishing fleets with the edible Energy Return on Investment ratio. By doing this we do not just estimate the evolution of the EROI for different EU fleets, but we are in a position to identify the most efficient fishing techniques from the nourishment perspective. Besides the obvious economic incentives, the use of more efficient fishing gears can contribute to the environmental sustainability.

Materials & Methods

Data included in the 2010 Annual Economic Report (AER) on the EU fishing fleet (STECF 2010) was used for this analysis. The AER provides the most complete compilation of statistics on the economic performance of the EU Member States fishing fleets. The report contains an economic and structural analysis of the European Union fishing fleets with data collected under the Data Collection Framework (DCF) (EC 2008). To the authors knowledge, there is no other publication worldwide that periodically reports fisheries production and cost data at such levels of detail.

For the current analysis, we considered only data for those fleet segments (a group of vessels belonging to the same length class and having the same predominant fishing gear during the year) for which full time series data for all the relevant variables (fuel consumption and weight of landings per species by fleet) were available. The analysis was performed at the fleet segment level and data from different countries were aggregated together. All main fleet segments were covered by the study: trawls and seines (demersal and pelagic), dredges, hooks, nets, pots and traps. The fleet segmentation follows the EU segmentation (EC 2001) by fishing technique and vessel length class (the codes used can be found below the table 2 and figures).

Fuel consumption and landing weights by species covering the years 2002 to 2008, were used for the calculation of the EROI. Data used originated from more than 20,000 fishing vessels grouped in 49 fleet segments of seven countries (Belgium, Germany, Denmark, France, Italy, Netherland and Sweden), representing 25% in terms of number of vessels and 33% in terms of landings' weight of the EU-27 for the time period studied.

For the calculation of the edible EROI we divided the energy extracted from the edible content of the fish[i] by the energy consumed in the production process (equation 1). The former is calculated by multiplying the landings from each fleet by the energy content and the edible content of each fish species. The energy content of fresh seafood per species was assigned according to Dorosz (2010) and when no value for a species was reported, the value of 1,116 Kcal/kg was used as the average energy content (MAPA 1999). Because not all the parts of a fish are edible, different edible fractions by species have been applied (Tyedmers, personal communication, 2010[ii]). Therefore, the boundary of this study is the $EROI_{1,d}$ as classified in Murphy et al. (2011)[iii].

The edible EROI for a fleet on a given year is calculated according to the following formula:

$$EROI_{ft} = \sum_{s=1}^{S} \frac{LW(Kg)_{fst}}{FC(L)_{ft}} \times EC_{fst}(Kcal/Kg) \times EdC_{fst} \times \frac{1\,L}{38.66\,mJ} \times \frac{4.187\,KJ}{1\,Kcal} \times \frac{1000mJ}{1KJ}$$

(1)

Where LW stands for the landings weight in Kg, FC for the fuel consumption in liters, EC for the energy content in Kcal per kg, EdC for the edible content of the fish expressed as a percentage, f indexes the fishing fleet, s the species and t the year. One liter of fuel is estimated to contain around 38.66 MJ (Schau et al. 2009), and one Kcal is approximately 4.187 kJ.

Only the energy content of the edible content of fresh seafood has been accounted for in this study. This implies that co-product allocation (the use of fish parts not suitable or edible for human consumption, i.e. use in animal feeds) has not been taken into account. This is because data on the different consumption and processing patterns depend mostly on country/region and fleet (i.e. consumer preferences to buy the whole fish or fillets), as well as the processes co-products are exposed. Consequently this data is rather difficult to obtain for such a diverse number of fleets. Therefore, the EROI estimated in this study corresponds to the EROI measure related to human-edible food energy return on industrially-mediated energy investment specified in Pelletier et al. (2011).

Indirect energy use was excluded from the analysis due to the lack of data and only direct fuel consumption was used to calculate the relevant indicator. This is not a major shortcoming as direct fuel use in fisheries account between 75 and 90%, regardless of the fishing gear used or the species targeted (Ziegler et al. 2003; Tyedmers 2004; Hospido and Tyedmers 2005; Pelletier et al. 2011). Depending on the fishery, the remaining 10 to 25% is generally composed of other energy inputs associated with vessel construction and maintenance, the provision of labor, fishing gear, bait and ice, fish processing and transportation to the market (Rawitscher 1978; Watanabe and Uchida 1984; Tyedmers 2000; Andersen 2002; Ziegler et al. 2003; Fet et al. 2010). Moreover, we are interested in the comparison between fishing fleets and especially in trends in energy use and efficiency over time. Thus, the exclusion of indirect energy should not bias the results, but it should be noted that the estimated indicators are conservative with respect to the studies that consider also indirect energy use, by a magnitude of 10 to 25%.

Results

For the analyzed fleet segments, the landings weight and the fuel consumption have been decreasing over time, reaching in 2008 almost two thirds of the values recorded in 2002 (Figure 1). The decrease in the fuel consumption is almost monotonic, whereas in the weight of landings the decreasing trend appears more scaled. The distribution of the landings and fuel consumption by fishing technique for the studied fishing fleets for the year 2008 are presented in Figures 2 and 3.

An overview of the EROI estimated for the different fleets is presented in Table 1. The weighted average edible EROI for 2008 was 0.11, ranging between 0.09 and 0.11 for the period of the analysis. That is to say that the average energy content of the fuel burned by the studied

European fleets was nine times greater than the edible energy content of the resulting catch in 2008.

The different EU fishing fleets analyzed demonstrated important differences in the EROI levels (see table 2). Gears using hooks (0.04 in 2008), and beam trawlers between 24 and 40 meters and larger than 40 meters (0.02) had the lowest EROI values, followed by polyvalent passive gears (0.04), demersal trawls and seiners (0.05), and driftnets and fixed nets (0.07). Pelagic trawlers and seiners larger than 40 meters (1.12) had the highest EROI values estimated. High values were also observed for dredges lower than 12 meters (0.20) and small vessels equipped with passive gears (0.38).

These important differences in the ratio between fishing gears and vessel lengths was in accordance with Thrane (2004), who presented different energy consumption levels for nine Danish fleets. The edible EROI values were in line with those reported in Tyedmers (2004) for 29 North Atlantic and Pacific fisheries from several studies. The values varied from 0.019 for the trawl fishing targeting shrimps and the trawl fishing targeting flatfish to an EROI of 0.56 for the purse seine fishing for herring and mackerel. Similarly, beam trawlers between 24 and 40 meters and beam trawlers larger than 40 meters had an EROI for 2008 of 0.020 and 0.016, respectively. These fleets target mainly sole, plaice (flatfishes) and shrimps which are species with high commercial value. On the other hand, pelagic trawlers and seiners larger than 40 meters, targeting low-value species such as herring, mackerel, sand-eels and sprat, had an EROI of 1.12.

From the results it can also be concluded that for each fishing technique, there was an optimal vessel length class, as can be seen in table 2. For pelagic and demersal trawlers and seiners, the larger vessels were more energy efficient; whereas the opposite was occurring for beam trawlers and dredges.

Discussion

The reduction of greenhouse gas emissions and the efficient use of resources have become important political objectives in the agenda of the European Union. Clear incentives to reduce fuel consumption, or at least consume it in the most efficient way possible, start to appear in many sectors, including fisheries and food production.

Continued technological advances in fishing fleets increase catch efficiency directly affecting fish stocks. It is commonly perceived that with the advent of modern fish-catching technologies, fleets would become more catch efficient. This phenomenon known also as technological creep or, simply, creep of the fleet is usually positively related to the increase in skipper skills, investments in auxiliary equipment, more efficient gear and materials, replacement of old vessels by new ones and, to a lesser extent, upgraded engines (Rijnsdorp et al. 2006). Creep has been estimated to be as much as 10% per year (i.e. Ellis and Wang 2007; Marchal et al. 2007). Meanwhile, many fish stocks are at a very low level in relation to the sustainability criteria. Worm et al. (2009) estimated that 63% of assessed fish stocks worldwide are overexploited, and so, they require rebuilding. In the EU, 88% of assessed stocks are overexploited, 30% of these stocks being outside safe biological limits (EC 2009). The European fishing industry is experiencing smaller catches and facing an uncertain future. As a result, changes in fleet catch efficiency may reflect shifts in effort and or trends in fish abundance. But in comparison to the beginning of the study, the decrease observed lately in the fuel consumption

(-33%) is proportional to the one observed in the landings (-34%). The poor situation of the fish stocks is probably prevailing over advances in technology.

A general tendency for poorer outcomes on the energy performance of the fishing fleets over time has been documented (Tyedmers 2001, 2004). Mitchell and Cleveland (1993), for the New Bedford fishery, studied the evolution of the EROI ratio in 20 years (between 1968 and 1988) and concluded that it went from 0.18 down to 0.03. Instead, our results show that the selected EU fleets efficiency remained practically stable or even had a slight increase[iv].

Tyedmers et al. (2005) estimated the energy content of the fuel burned by the fisheries globally to be 12.5 times greater than the edible energy content of the catch. The European fishing fleet seems to be relatively more fuel efficient than the global fisheries, with an estimated energy content of the fuel burned nine times greater than the edible energy content of the resulting catch[v]. The difference between the two estimations could be attributed either to different energetic performances of the fishing fleets, or a different composition of the fishing fleets represented in the datasets herein and worldwide. This is an interesting topic that needs to be further investigated; one could deduce that given the current overexploitation of most EU fish stocks (EC 2009) the energy performance of the fleets exploiting them should be worse than the global one. This can at least in part be explained by the high fuel prices in the EU that works as an incentive to improve the energy efficiency (Cheilari et al. 2013).

Although fisheries have been considered a fuel intensive food production process as stated by Wilson (1999), our results confirm Tyedmers (2004) and Tyedmers et al. (2005) conclusions that fisheries are not among the less fuel efficient food production activities. This conclusion does not change even if we consider a potential 25% overestimation on our results due to not accounting for the indirect energy uses (Pelletier et al. 2007). Comparing to other food production activities (table 3), fisheries EROI ratios tend to be lower. However, certain fleet segments (i.e., pelagic trawlers and seiners larger than 40 meters, pelagic trawlers and seiners between 24 and 40 meters and vessels smaller than 12 meters using passive gears), are more energy efficient than some agricultural processes. While compared to livestock and aquaculture production EU fishing fleets show a better energy performance, as they have on average a higher EROI, even if the results from this study are underestimated compared to studies that consider embodied energy.

Different fleets have different energy profiles. Pelagic trawls and seiners targeting pelagic fish can be among the most energy efficient production systems. Based on these results one could be tempted to incentivize pelagic trawls and seiners in detriment of less efficient fishing gears. However, not all fishing gears target the same species. Thus, comparison could only be feasible for those gears with same target species, such as demersal trawlers versus beam trawlers or pelagic trawlers versus pelagic purse seiners. Unfortunately, these data is not yet available in detail, but improvements in the data availability have been achieved during the last years and the European Union publishes data on fuel consumption and landings' weights per fleet and country (i.e. STECF 2010). Data by vessel could prove very important to determine what factors can help to improve energy efficiency (i.e. particular investments or fishing strategies), however, such studies require a more limited sample than the one used in this study. Currently data on landings and fuel consumption by vessel can only be available at the national and regional administrations. Similarly, data on material and energetic demands of fishing fleets (Pelletier et al. 2007) for such a large number of fleets is also lacking (except on direct energy use). More efforts should be allocated to collect these data at a larger scale, and not only on a case study basis, in order to be able to extract sound conclusions and recommendations for fisheries practices and management.

Nevertheless, we should not ignore that fishing is an economic activity, and fishers decide to use a fishing technique based on economic incentives. Because fuel costs are an important part of the total costs, fishers are also interested in energy efficiency. But fuel costs are not the only driver to this decision. Other important factors, such as the relative price of potential target species, catchability between techniques (selectivity), other costs and previous investments in vessel and gears, may define the choice, at least in the short term and should be taken into consideration during the development of management strategies that can reduce the fuel consumption of the fishing industry.

The proposal for the financial tool of the EU's Common Fisheries Policy (CFP), the European Maritime and Fisheries Fund (EMFF), has made provisions for supporting measures that will increase energy efficiency, reduce emissions and contribute to the Europe 2020 target on climate change. However, it is not clear yet which specific innovations will be eligible for funding within the new EMFF. A non-exhaustive list could include areas such as: engines with reduced emissions (e.g. hybrid engines); bio-fuels; vessel design and technology; vessel operation (maintenance of hulls and engines); use of alternative/renewable energy sources (wind, H2 fuel cells); efficient fishing gears (e.g. reduced gear drag); fishing tactics and techniques; fuel management systems; energy audits. Energy audit can serve as a tool for assessing the performance of the fleets as well as the success of the innovative techniques applied (Notti et al. 2012). So far energy audits have proven to be quite effective in reducing consumption and increasing efficiency (Danish Ministry of Food, Agriculture and Fisheries 2011; Sala et al. 2011). Other more hypothetical measures to improve energy efficiency not related with this fund could be the inclusion of fisheries in a carbon emission quota system (i.e. the European Union Emissions Trading System) or changes in the taxation of fuel for fisheries. Then, the EROI indicator could be a good measure to monitor energy efficiency performance for vessels and fleets (when targeting different species), as well as one of the criteria to allocate funds.

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Tables

Table 1. EROI values by fleet (main gear) for the period 2002-2008 (Source: own calculations from STECF 2010 data).

Fleet (gear)	2002	2003	2004	2005	2006	2007	2008
Drift nets and Fixed Nets	0.058	0.052	0.055	0.047	0.042	0.060	0.067
Dredges	0.126	0.092	0.120	0.106	0.083	0.087	0.071
Demersal Trawl and demersal Seiner	0.036	0.037	0.039	0.046	0.047	0.045	0.051
Pots and traps	0.105	0.124	0.163	0.119	0.095	0.084	0.122
Gears using hooks	0.013	0.014	0.023	0.019	0.025	0.034	0.041
Passive gears	0.285	0.391	0.317	0.276	0.288	0.392	0.376
Polyvalent passive gears	0.038	0.040	0.040	0.045	0.051	0.050	0.044
Combining mobile & passive gears	0.078	0.082	0.081	0.205	0.154	0.134	0.111
Pelagic Trawls and Seiners	0.534	0.417	0.461	0.541	0.560	0.536	0.617
Beam Trawl	0.021	0.021	0.022	0.022	0.023	0.024	0.027
Total Average	0.102	0.091	0.097	0.110	0.111	0.103	0.114

Table 2. EROI values by fleet segment for the period 2002-2008 (Source: own calculations from STECF 2010 data).

Fleet segment	2002	2003	2004	2005	2006	2007	2008
DFN VL0012	0.030	0.032	0.035	0.026	0.028	0.042	0.048
DFN VL1224	0.083	0.070	0.072	0.073	0.061	0.082	0.094
DRB VL0012	0.411	0.359	0.340	0.205	0.143	0.178	0.201
DRB VL1224	0.092	0.065	0.089	0.083	0.069	0.070	0.047
DTS VL0012	0.022	0.035	0.045	0.047	0.045	0.041	0.049
DTS VL1224	0.031	0.032	0.035	0.042	0.040	0.038	0.047
DTS VL2440	0.042	0.043	0.045	0.053	0.059	0.056	0.056
DTS VL40XX	0.078	0.075	0.061	0.061	0.088	0.083	0.081
FPO VL0012	0.105	0.124	0.163	0.119	0.095	0.084	0.122
HOK VL0012	0.013	0.014	0.023	0.019	0.025	0.034	0.041
PG VL0012	0.285	0.391	0.317	0.276	0.288	0.392	0.376
PGP VL0012	0.033	0.036	0.036	0.040	0.047	0.047	0.041
PGP VL1224	0.129	0.111	0.135	0.135	0.120	0.151	0.150
PMP VL0012	0.094	0.101	0.155	0.221	0.164	0.159	0.112
PMP VL1224	0.076	0.078	0.069	0.203	0.152	0.128	0.111
PTS VL1224	0.169	0.140	0.175	0.183	0.221	0.209	0.208
PTS VL2440	0.533	0.419	0.428	0.562	0.496	0.459	0.470
PTS VL40XX	0.941	0.813	0.800	0.912	1.029	1.024	1.125
TBB VL1224	0.045	0.047	0.052	0.060	0.053	0.052	0.059
TBB VL2440	0.016	0.014	0.016	0.014	0.013	0.016	0.020
TBB VL40XX	0.016	0.015	0.015	0.014	0.017	0.017	0.016
Total Average	0.102	0.091	0.097	0.110	0.111	0.103	0.114

Active gears: DTS: Demersal trawl and demersal seiner, PTS: Pelagic trawls and seiners, TBB: Beam trawl, DRB: Dredges.

Passive gears: HOK Gears using hooks, DFN: Drift nets and fixed nets, FPO: Pots and traps, PGP: Polyvalent passive gears, PG: Passive gears (applicable only to vessels with length lower than 12 m).

Polyvalent gears: PMP: Combining mobile & passive gears.

VL0012: vessels less than 12 m in length, VL1224: vessels between 12-24 m in length, VL2440: vessels between 24-40 m in length, VL40XX: vessels greater than 40 m in length.

Table 3. EROI values from other studies.

Product	EROI	Source
Soy bean	4.92	Pelletier (2008)
Corn	0.81	Pelletier (2008)
Wheat	0.89	Pelletier and Tyedmers (2007)
Swine	0.071	Pimentel (2004)
Beef (pasture-based)	0.05	Pimentel (2004)
Beef (feedlot)	0.025	Pimentel (2004)
Lamb	0.018	Pimentel (2004)
Broiler poultry	0.177	Pelletier (2008)
Farmed salmon	0.114	Pelletier and Tyedmers (2007)
Carp (aquaculture)	1.00 - 0.084	Troell et al. (2004)
Mussels (aquaculture)	0.10 - 0.05	Troell et al. (2004)
Tilapia (aquaculture)	0.13 - 0.025	Troell et al. (2004)
Catfish (aquaculture)	0.04	Troell et al. (2004)
Atlantic salmon (aquaculture)	0.025 - 0.02	Troell et al. (2004)
Chinook salmon (aquaculture)	0.02	Troell et al. (2004)
Shrimps (aquaculture)	0.025 - 0.014	Troell et al. (2004)
Sea bass (aquaculture)	0.015	Troell et al. (2004)
Redfish spp. (trawl)	0.11	Tyedmers (2004)
Cod/flatfish spp. (Danish seine)	0.10	Tyedmers (2004)
Cod/haddock (longline)	0.091	Tyedmers (2004)
Cod/saithe (trawl)	0.084	Tyedmers (2004)
Flatfish spp (trawl)	0.019	Tyedmers (2004)
Herring/mackerel (purse seine)	0.56	Tyedmers (2004)
Herring/saithe (Danish seine)	0.35	Tyedmers (2004)
Swordfish/tuna (longline)	0.042	Tyedmers (2004)
Crab (trap)	0.057	Tyedmers (2004)
Scallop (dredge)	0.027	Tyedmers (2004)
Shrimp (trawl)	0.058	Tyedmers (2004)
Norway lobster (trawl)	0.026	Tyedmers (2004)
Shrimp (trawl)	0.019	Tyedmers (2004)

Supplementary information file

Table 1 Supplementary. EROI values by fleet segment for the period 2002-2008, taking into account the indirect energy use.

Fleet segment	2002	2003	2004	2005	2006	2007	2008
Drift nets and Fixed Nets	0.044	0.039	0.042	0.036	0.032	0.045	0.051
DFN VL0012	0.023	0.024	0.027	0.020	0.021	0.032	0.036
DFN VL1224	0.063	0.053	0.055	0.055	0.046	0.062	0.071
Dredges	0.096	0.070	0.091	0.080	0.063	0.066	0.054
DRB VL0012	0.312	0.272	0.258	0.155	0.108	0.135	0.152
DRB VL1224	0.070	0.049	0.067	0.063	0.052	0.053	0.036
Demersal Trawl and demersal Seiner	0.027	0.028	0.030	0.035	0.036	0.034	0.039
DTS VL0012	0.017	0.027	0.034	0.036	0.034	0.031	0.037
DTS VL1224	0.023	0.024	0.027	0.032	0.030	0.029	0.036
DTS VL2440	0.032	0.033	0.034	0.040	0.045	0.042	0.042
DTS VL40XX	0.059	0.057	0.046	0.046	0.067	0.063	0.061
Pots and traps	0.080	0.094	0.124	0.090	0.072	0.064	0.092
FPO VL0012	0.080	0.094	0.124	0.090	0.072	0.064	0.092
Gears using hooks	0.010	0.011	0.017	0.014	0.019	0.026	0.031
HOK VL0012	0.010	0.011	0.017	0.014	0.019	0.026	0.031
Passive gears	0.216	0.296	0.240	0.209	0.218	0.297	0.285
PG VL0012	0.216	0.296	0.240	0.209	0.218	0.297	0.285
Polyvalent passive gears	0.029	0.030	0.030	0.034	0.039	0.038	0.033
PGP VL0012	0.025	0.027	0.027	0.030	0.036	0.036	0.031
PGP VL1224	0.098	0.084	0.102	0.102	0.091	0.114	0.114
Combining mobile & passive gears	0.059	0.062	0.061	0.155	0.117	0.102	0.084
PMP VL0012	0.071	0.077	0.117	0.168	0.124	0.121	0.085
PMP VL1224	0.058	0.059	0.052	0.154	0.115	0.097	0.084
Pelagic Trawls and Seiners	0.405	0.316	0.349	0.410	0.425	0.406	0.468
PTS VL1224	0.128	0.106	0.133	0.139	0.168	0.158	0.158
PTS VL2440	0.404	0.318	0.324	0.426	0.376	0.348	0.356
PTS VL40XX	0.713	0.616	0.606	0.691	0.780	0.776	0.853

Beam Trawl	0.016	0.016	0.017	0.017	0.017	0.018	0.020
TBB VL1224	0.034	0.036	0.039	0.045	0.040	0.039	0.045
TBB VL2440	0.012	0.011	0.012	0.011	0.010	0.012	0.015
TBB VL40XX	0.012	0.011	0.011	0.011	0.013	0.013	0.012
Total Average	0.077	0.069	0.074	0.083	0.084	0.078	0.086

Active gears: DTS: Demersal trawl and demersal seiner, PTS: Pelagic trawls and seiners, TBB: Beam trawl, DRB: Dredges.

Passive gears: HOK Gears using hooks, DFN: Drift nets and fixed nets, FPO: Pots and traps, PGP: Polyvalent passive gears, PG: Passive gears (applicable only to vessels with length lower than 12 m).

Polyvalent gears: PMP: Combining mobile & passive gears.

VL0012: vessels less than 12 m in length, VL1224: vessels between 12-24 m in length, VL2440: vessels between 24-40 m in length, VL40XX: vessels greater than 40 m in length.

Figures

Figure 1. Evolution in landings weight, fuel consumption and the ratio between them, for the studied EU fleets for the period 2002-2008. Landings weight and fuel consumption are represented on the primary axis (left) and the ratio between fuel consumption and fish landed are represented on the secondary axis (right).

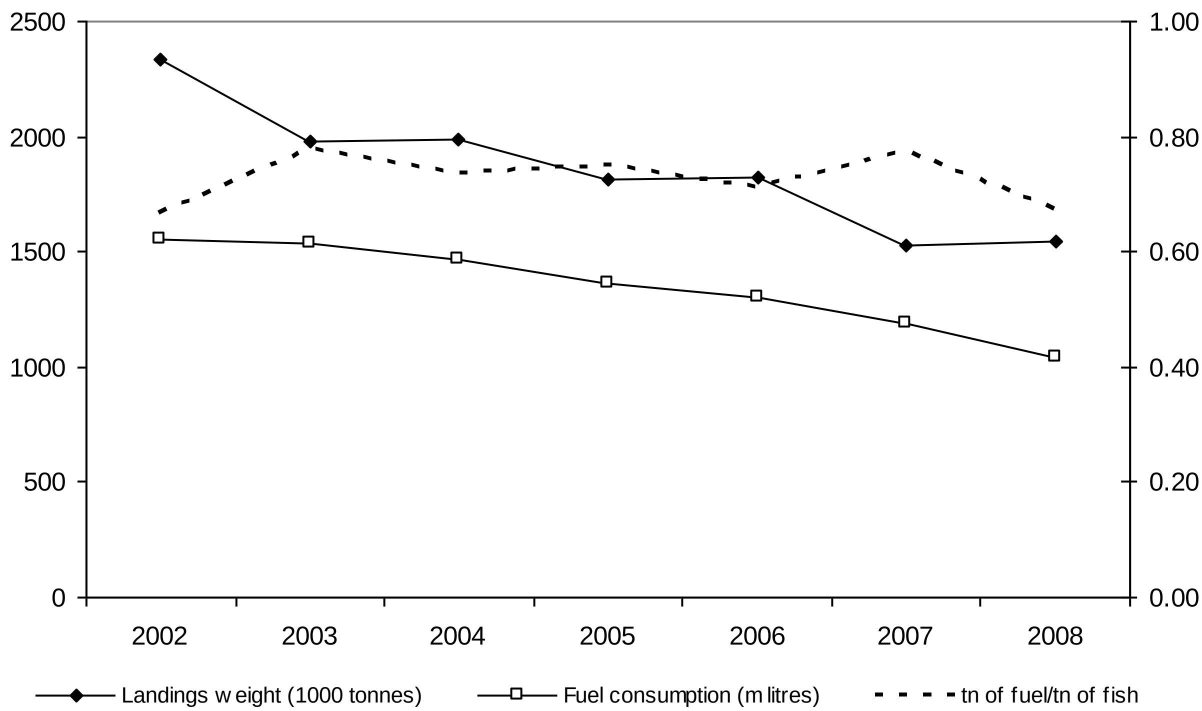
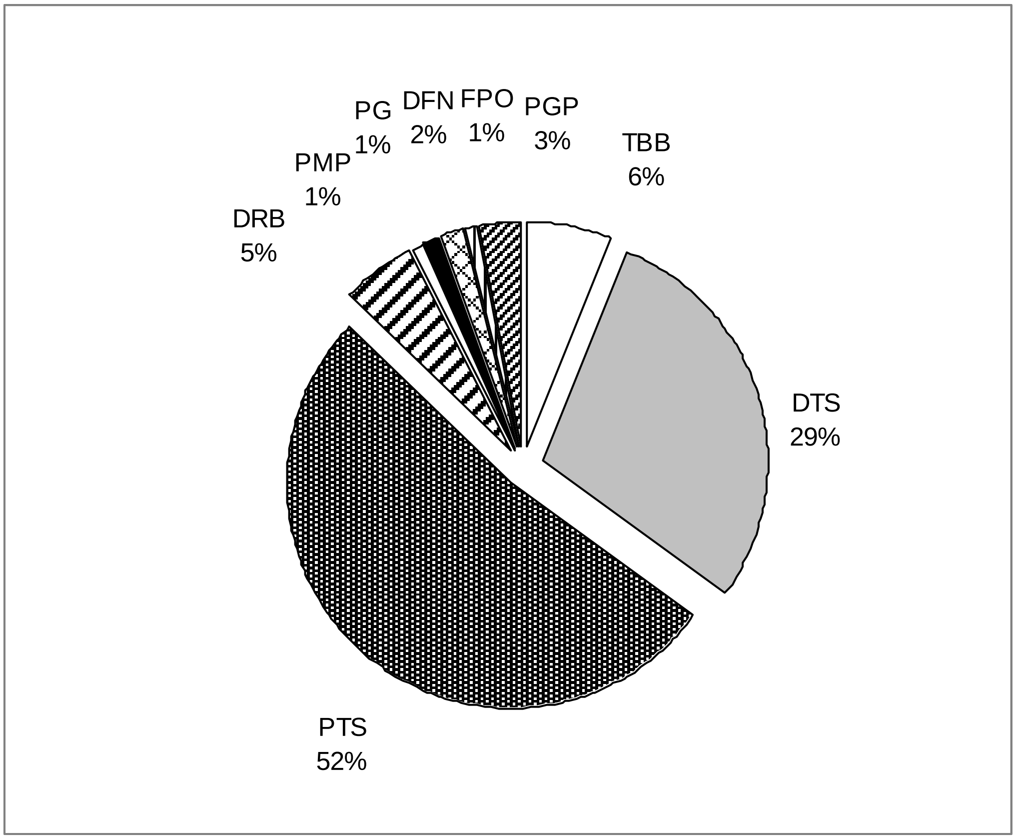


Figure 2. Distribution of the landings by fishing technique for the studied EU fishing fleets in the year 2008.

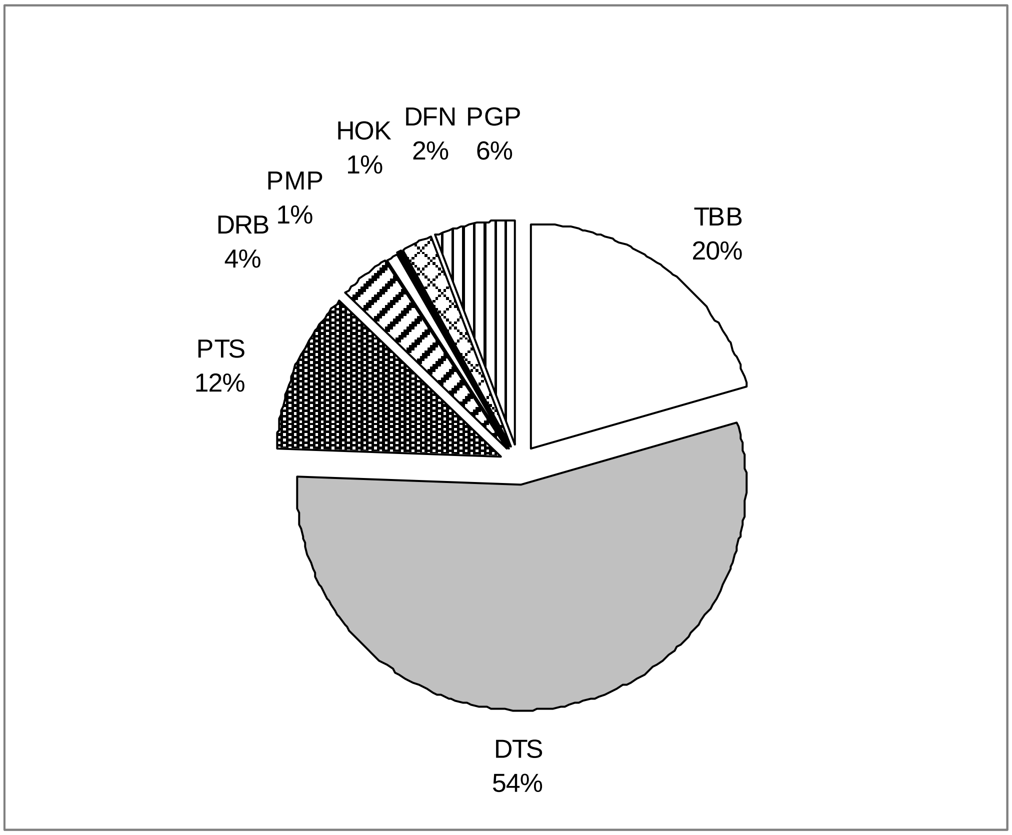


Active gears: DTS: Demersal trawl and demersal seiner, PTS: Pelagic trawls and seiners, TBB: Beam trawl, DRB: Dredges.

Passive gears: DFN: Drift nets and fixed nets, PGP: Polyvalent passive gears FPO: Pots and traps, PG: Passive gears (applicable only to vessels with length lower than 12 m).

Polyvalent gears: PMP: Combining mobile & passive gears.

Figure 3. Distribution of fuel consumption by fishing technique for the studied EU fishing fleets in the year 2008.



Active gears: DTS: Demersal trawl and demersal seiner, PTS: Pelagic trawls and seiners, TBB: Beam trawl, DRB: Dredges.

Passive gears: HOK Gears using hooks, DFN: Drift nets and fixed nets, PGP: Polyvalent passive gears.

Polyvalent gears: PMP: Combining mobile & passive gears.

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[i] The term fish refers to all aquatic organisms harvested by the fisheries: fish, mollusks, crustaceans.

[ii] Includes data from Wiviot and Mathews 1975, Bykov 1985, Torry Research Station 1989, and Crapo, Paust and Babbit 1993.

[iii] Boundary for energy inputs is direct energy and material inputs, while the boundary for energy outputs is extraction.

[iv] A 2.6% annual increase of the overall EROI is statistically significant at a 10% level, but not at a 5% level.

[v] EROI values of the EU fleet taking into account the indirect energy use, which refers to the cumulative energy required in upstream processes associated with the production and delivery of such inputs, are

24% lower than the ones reported in this study considering only direct energy use. When estimating a life cycle energy demand factor applying the cumulative energy demand method of the EcoInvent process for "Heavy fuel oil, at regional storage" (51 MJ/kg) replaces the energy that a liter of fuel contains (38.66M/J). The values of the EROI considering the indirect energy use are reported in the supplementary information file.