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Linking fuel consumption and eco-efficiency in fishing vessels

A brief case study on selected Galician fisheries

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Abstract— **In recent years fishing vessels are suffering due to an important increase in fuel prices. This is due mainly to the fact that most fishing fleets have a high energy consumption rate (up to 45% of the total costs), with a consequent increased environmental impact.**

This paper describes a methodology that combines Life Cycle Assessment (LCA, an environmental management tool) and Data Envelopment Analysis (DEA, an economic management tool). By doing so, the operational and environmental performances of a set of multiple similar entities can be jointly discussed.

The "five-step LCA+DEA method" is here applied to a wide range of vessels for selected Galician fisheries, including deep sea and coastal fleets. The link between operational efficiency and environmental impacts is revealed, and the environmental consequences of operational inefficiencies quantified. Operational inefficiencies were detected and target performance improvement values were consequently defined for the inefficient vessels. In particular, the benchmarking of fuel consumption levels for vessel operation was used to determine an average value for the amount of fuel which is wastefully consumed given the current operational patterns.

Furthermore, comparison between the optimization of fuel consumption and other major inputs to the system was established. Results demonstrated the total dependence of environmental impacts on this important operational input. The optimization of energy resources was greater for the more intensive fuel consuming fleets, such as deep sea trawling. This case study proved the usefulness of this method as an eco-efficiency verification tool.

Keywords- commercial fishing; Data Envelopment Analysis; eco-efficiency; fishing fleets; Life Cycle Assessment

I. INTRODUCTION

The Galician fishing sector is responsible for 10% of the regional GDP (Sainz et al., 2008). Furthermore, 42.6% of the Spanish fleet is based in Galician ports, where over 17% of the countries captures are landed. The primary activities linked to this sector can be divided in two main groups. On the one hand, commercial fishing, that includes the coastal, offshore and deep-sea fishing of all major marine species. On the other hand, fish farming (aquaculture) includes extensive aquaculture, marine intensive aquaculture and continental intensive aquaculture (Xunta de Galicia, 2009).

Despite the robustness of the Galician fishing sector, its fishing fleet does not evade the threats linked to the depletion and over-exploitation of fisheries worldwide (SOFIA, 2008). In fact, the direct ecological impact that fishing effort produces on target and non-target species, including excessive by-catch (Glass, 2000; Davies et al., 2009) or increased alteration of trophic dynamics (Jackson et al., 2001), is the main problem that the fishing fleets have to face nowadays (Pauly et al., 2002; Myers and Worm, 2003). However, fishery analysis must also focus on the impacts related to the operations of the fishing vessels (Hospido and Tyedmers, 2005), especially taking into account that some of the operations, such as fuel consumption, account for up to 45% of the total costs of an average Spanish fishing vessel (FEOPE, 2009).

In this context, Life Cycle Assessment (LCA), which is recognized worldwide as a useful tool for assessing environmental aspects and potential impacts associated with products or processes (ISO 2006a, 2006b), can be a suitable methodology for the analysis of the environmental performance of fisheries (Pelletier et al., 2007). However, LCA in fisheries presents a series of shortages when it comes to study the social and economic factors linked to the product or process. In this sense, the inclusion of Data Envelopment Analysis (DEA), a performance measurement methodology used to calculate the efficiency of multiple similar installations –named Decision Making Units (DMUs) (Cooper et al., 2007)– has been recommended in LCA studies in order to link environmental and economic issues in fisheries (Lozano et al., 2009; Vázquez-Rowe et al., 2010a, 2010b).

The joint implementation of LCA and DEA provides a number of promising characteristics that include: (i) avoiding large standard deviations; (ii) facilitating result interpretation; (iii) adding an economic dimension to the LCA study; and (iv) benchmarking the operational and environmental performance of the different entities as a path for eco-efficiency verification (Vázquez-Rowe et al., 2010a).

The purpose of this paper is the use of a varied set of relevant Galician fishing fleets in order to apply the LCA+DEA methodology, obtaining, therefore, operational benchmarking and eco-efficiency verification. Furthermore, the link between fuel usage and potential environmental impacts as compared to other inputs is studied.

II. MATERIALS AND METHODS

A. *Fishing fleet selection*

In this study a total of six Galician fishing fleets underwent LCA+DEA implementation (Vázquez-Rowe et al., 2010b). The analyzed fleets were chosen in order to include coastal, offshore and deep-sea fisheries and varying the gear type. Specifically, the assessed fleets corresponded with auxiliary mussel raft vessels, coastal purse seining, coastal trawling, offshore long lining, deep-sea trawling and deep-sea purse seining.

B. *Goal and scope of the study*

The combination of the operational benchmarking of the fishing vessels with their environmental performance assessment through the use of LCA+DEA methodology is the main goal of this paper. The specific objectives that are considered in this study are (i) identification of operational inefficiencies and resource usage optimization in fishing vessels; (ii) assessment of the environmental performance of the benchmarked vessels, (iii) evaluation of the role played by fuel efficiency, and (iv) comparison of the results between the included fleets.

The functional unit (FU) used for the LCA of all fishing fleets was 1 ton of landed fish. Despite the fact that most of the fishing fleets analyzed work in multispecies fisheries, this FU was chosen rather than a product perspective so as to focus on the operational performance of the individual vessels. The system boundaries included all the different operational stages of fish extraction till landing in Galician ports, constituting a "cradle to gate" analysis (Guinée et al., 2001). Vessel construction activities were also taken into account.

DEA analysis does not involve the inclusion of all the inputs and outputs from the Life Cycle Inventory (LCI). For this study, a total of three inputs and one output were considered for the six analyzed fleets (Table I). All the fleets met minimum sample size requirements (Boussofiane et al., 1991; Cooper et al., 2007).

TABLE I. INPUTS AND OUTPUT SELECTION FOR DEA MATRIX

Fishing fleet	**Input 1** *(l/year)*	**Input 2** *(kg/year)*	**Input 3** *(l/year or kg/year)*	**Output** *(€/year)*
F1-Auxiliary mussel raft vessels	Diesel	Hull material	Anti-fouling	Catch value
F2-Coastal purse seining	Diesel	Hull material	Net	Catch value
F3-Coastal trawling	Diesel	Hull material	Net	Catch value
F4-Offshore long lining	Diesel	Hull material	Anti-fouling	Catch value
F5-Deep-sea trawling	Diesel	Hull material	Net	Catch value
F6-Deep-sea purse seining	Diesel	Hull material	Anti-fouling	Catch value

C. *Methodology specifications. The five-step LCA+DEA method*

The proposed LCA+DEA methodology, as explained briefly in Figure 1, is made up of five steps:

I) Development of the LCI based on the data collection, for each of the similar units (DMUS) analyzed.

II) Individual Life Cycle Impact Assessment (LCIA) for the DMUs included in the study, in order to determine the environmental performance of the current vessels.

III) Operational efficiency determination for individual vessels through DEA implementation using selected data from the LCIs.

IV) Environmental characterization of target vessels by using LCIA with the projected data calculated in the previous step.

V) Potential environmental impacts analysis for virtual vessels as compared to the current vessels.

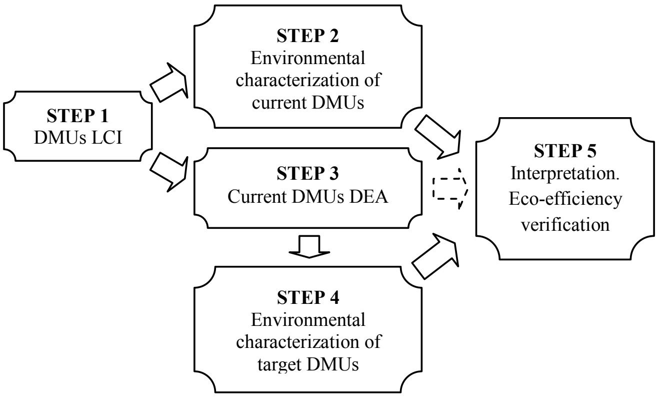

Figure 1. Five-step LCA+DEA method for fisheries.

For a detailed description of the method, please refer to Lozano et al. (2009), Iribarren (2010) or Vázquez-Rowe et al. (2010a).

III. RESULTS

A. Step I. Data obtention and current LCIs

Five commercial fishing fleets, using several types of fishing gears and operating in diverse geographical areas were considered in this study. Additionally, a sixth fleet was included in the scope of the research, comprising auxiliary vessels for mussel cultivation on rafts (Table II). Primary data were gathered through questionnaires filled out by Galician skippers, whereas the background processes (secondary data) for LCA were retrieved from the ecoinvent database (Frischknecht et al., 2007) or from specific data regarding the Galician fishing context (Costa, personal communication; Hempel, 2009).

TABLE II. MAIN CHARACTERISTICS OF SELECTED GALICIAN FISHING FLEETS

	F1	F2	F3	F4	F5	F6
Sample size	12	15	20	12	8	9
Percentage over fleet	1.1	31.9	19.8	20.3	29.6	14.3
Reference year	2007	2008	2008	2008	2009	2000-2004
Landings (tons)	3,703	7,500	12,093	3,416	5,000	72,000
Catch value (€*10^3/year)	22,443	4,913	17,310	10,534	13,054	371,320
Main species	Mussel	Sardine	Mackerel	Hake	Octopus	Tuna

Emissions linked to fuel combustion were calculated using the EMEP-Corinair Emission Inventory Handbook of 2006 (EMEP-Corinair, 2006). Anti-fouling loss to marine waters was considered to be two thirds of the total (Hospido and Tyedmers, 2005).

B. Step II. Environmental characterization

The impact assessment phase was developed through the use of the CML baseline 2000 method (Guinée et al., 2001). Five impact categories were included: Abiotic Depletion Potential (ADP), Acidification Potential (AP), Eutrophication Potential (EP), Global Warming Potential (GWP) and Marine aquatic Eco-Toxicity Potential (METP). Additionally, the Cumulative Energy Demand (CED) indicator was also taken into account in the scope of the study (VDI-Richtlinien, 1997). The software used for the implementation of the inventories was SimaPro 7 (Goedkoop et al., 2008). Results relating to this step are discussed in the interpretation stage (step V), comparing them to those results obtained in step IV.

C. Step III. Efficiency scores and target value determination for current vessels

The DEA matrix is constituted with the most relevant data gathered from the LCI. DEA-Solver Professional Release 6.0 software (Saitech, 2009) was used in order to solve a DEA optimization model that directs to an efficiency score and to the definition of operational targets. For this specific research, an input-oriented Slacks-Based Measure model (SBM-I) was chosen. Aiming to exemplify matrix formulation, Table III presents the DEA matrix for F4 (offshore long lining fleet).

TABLE III. DEA MATRIX FOR OFFSHORE LONG LINING VESSELS

DMU	Input 1	Input 2	Input 3	O
F4-1	680,000	3,138	298	1,633,578
F4-2	654,000	3,450	290	1,583,310
F4-3	952,000	6,320	340	945,792
F4-4	349,550	4,067	250	472,936
F4-5	315,000	3,983	273.6	726,600
F4-6	300,000	4,240	273.6	691,900
F4-7	340,000	4,182	290	690,700
F4-8	325,000	2,829	220.8	792,410
F4-9	320,000	2,954	233	643,910
F4-10	258,400	5,000	320	771,328
F4-11	163,200	2,819	156.4	732,448
F4-12	353,600	5,067	325	849,152

Not only efficiency scores for each vessel within each fleet were computed by means of DEA implementation, but also target values for those units deemed inefficient. These target (virtual) vessels mean vessels, that in order to become efficient, suffer a minimization of input consumption while output production is maintained. In this sense, as an example, Table IV presents the efficiency scores (Φ) calculated for each individual vessel within F4, together with the potential reduction in input consumption.

TABLE IV. EFFICIENCY SCORES (Φ) OF LONG LINING VESSELS

DMU	Input 1 (%)	Input 2 (%)	Input 3 (%)	Efficiency (Φ)
F4-1	0.00	0.00	0.00	100.00
F4-2	0.00	10.38	0.12	96.50
F4-3	58.65	71.25	49.26	40.28
F4-4	43.68	77.66	65.49	37.72
F4-5	48.60	29.79	43.29	59.44
F4-6	48.61	37.19	46.00	56.06
F4-7	54.74	36.43	49.14	53.23
F4-8	0.00	44.48	34.18	73.78
F4-9	16.24	58.13	49.59	58.68
F4-10	33.49	40.63	48.53	59.12
F4-11	0.00	0.00	0.00	100.00
F4-12	46.49	35.50	35.50	57.93

Results related to the efficiency score for the average vessel of each fleet can be observed in Figure 2. The efficiency scores for the average vessel of the two deep-sea fleets were the highest obtained, above 65% in both cases. Offshore long liners presented an average vessel efficiency of around 62%, while coastal fleets had lower values: 46.04% for coastal trawlers and 44.26% for coastal purse seiners. Finally, auxiliary vessels for mussel rafts had the lowest result (30.05%).

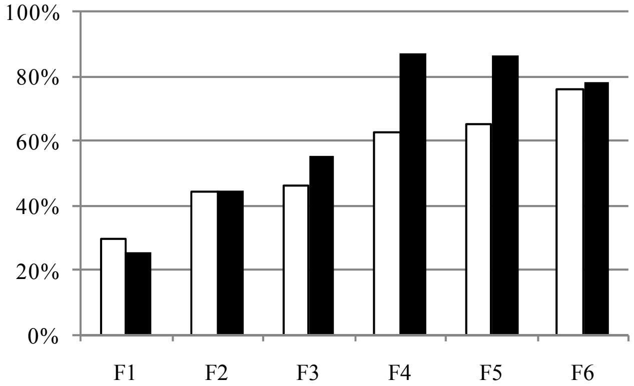

Figure 2. Average vessel diesel input efficiency (black bar) as compared to the efficiency score (white bar).

When exclusively assessing the fuel efficiency of the average vessel, this efficiency was found to be higher than the total efficiency score of the average vessel for each fleet, except for the auxiliary vessels (Figure 2). The highest values related to diesel input efficiency were found in the average vessels of offshore long liners (87.51%) and deep-sea trawlers (86.92%).

D. Step IV. Environmental characterization of target values

The vessels that were regarded as inefficient after the DEA analysis underwent a new LCIA with the new target values obtained. This approach leads to the calculation of a new potential environmental impact of each vessel if operated in an efficient manner. For instance, Figure 3 shows a comparison between the average global warming potential for current and target vessels for each fleet. A decrease ranging from 13 (F4) to 74% (F1) was achieved.

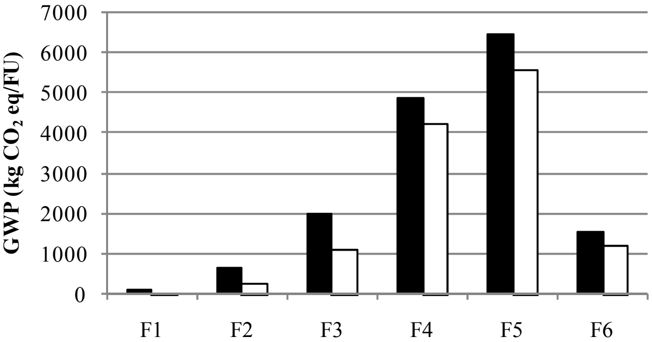

Figure 3. Original vessels (black bar) and virtual vessels (white bar) average global warming potential per FU.

E. Step V. Result interpretation and eco-efficiency verification

According to the World Business Council for Sustainable Development (WBCSD), the term eco-efficiency is referred to the production of competitively priced goods and services that satisfy human needs and bring quality of life while reducing environmental impacts of goods and resource intensity throughout the entire life-cycle to a level not higher than the Earth's estimated carrying capacity. In this line, the proposed methodology reveals the environmental consequences related to operational inefficiencies thanks to resource minimization (as previously exemplified for the global warming category in Figure 3). Thus, the link between environmental impacts and operational efficiency was proved for each of the fleets.

Auxiliary vessels for mussel rafts would benefit the most from operational optimization, obtaining environmental improvements of up to 74%. On the opposite side, deep-sea fleets would only advance by 22% (purse seiners) and 14% (trawlers).

IV. CONCLUSIONS AND PERSPECTIVES

Six different Galician fleets were analyzed in order to determine their operational efficiency. In this sense, a series of clear patterns were identified.

The deep-sea and offshore fleets analyzed showed a significant increased operational efficiency for the average vessel when compared to coastal fleets. Moreover, the proportion of vessels that were identified as efficient was highest in the deep-sea fleets.

Environmental impacts were found to depend mainly on fuel consumption. Other issues related to vessel operation besides fuel usage (e.g. vessel construction or net consumption) showed minimal influence respect to the potential environmental improvement. Nevertheless, the reduction of these secondary inputs through operational benchmarking may translate in significant savings in economic costs.

To sum up, the five-step LCA+DEA methodology demonstrated to be a highly useful procedure to quantify operational and environmental targets. Furthermore, the use of this eco-efficiency verification tool is recommended to strengthen the individual results provided by LCA or DEA as single techniques when assessing a set of similar multiple entities. In addition, the firmness of the results presented in this paper certifies that this methodology can be used as a regular practice in LCA for fisheries.

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