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Environmental Policies in Maritime Transport: A Case Study of Solar Ship in Galapagos Islands

Beatriz Rivela[1], Andrés Montero[2], Byron Criollo[2], Diego Vaca[2] and Jesús López-Villada[2]

[1] Prometeo Researcher. National Institute of Energy Efficiency and Renewable Energy, Quito (Ecuador)

[2] National Institute of Energy Efficiency and Renewable Energy, Quito (Ecuador)

Abstract

The Galapagos Islands are one of the most biodiverse areas on the planet. Maritime transport there has serious effects, as occurred with the fuel tanker Jessica grounded on Shiavioni reef at the entrance of Wreck Bay, Isla San Cristóbal, on 16 January 2001. The vessel oil spilled approximately 240,000 gallons of fuel oil consisting of 160,000 gallons of Diesel Oil #2 (DO#2) and 80,000 gallons of Intermediate Fuel Oil 120 (IFO 120, or bunker fuel), jeopardizing the ecosystem of these islands. In order to reduce this impact, Ecuador authorities are driving the development of alternatives through initiatives such as the "National Plan for Good Living" and the "Galapagos Zero Fossil Fuels in the Galapagos" initiative. One remarkable initiative is the project of a solar powered catamaran. This study intends to assess the environmental effects related to the use of this boat as well as to compare the environmental performance of two main scenarios: solar and conventional boat operations. The results obtained show a significant improvement in the environmental performance when the solar boat is considered.

Key words: maritime transport, environmental performance, photovoltaics, autonomous ship

1. Introduction

Maritime transport has been a catalyst of economic development and prosperity throughout its history. It enables trade and contacts, ensures the security of supply of energy, food and commodities, benefiting other economic sectors. Moreover, the quality of life on islands and in peripheral maritime regions depends on good maritime transport service.

The Galapagos Islands, one of the most biodiverse areas on the planet, faces serious environmental problems, which are largely attributable to the scale of maritime transportation in the area. In the Itabaca Channel, located between Baltra and Santa Cruz islands, 4 boats move about 146,000 people per year between tourists and residents. As a consequence, oil spills, motor noise, exhaust gas emissions, etc. are serious threats to the environment. One way to minimize this impact is to use highly efficient solar boats. For that reason, the Ministry of Electricity and Renewable Energy of Ecuador (MEER) requested to the National Institute of Energy Efficiency and Renewable Energy (INER) to evaluate the technical, environmental and economic feasibility of using solar electric boats in Galapagos Islands. The first step of this evaluation was the design of a solar electric catamaran. At present, the catamaran is under construction and will be in operation next November 2014. The catamaran will replace one of the conventional boats that consume, on average, 5,000 gallons of fuel and emit 50 Tm of CO_2 per year. This project reinforces the "Galapagos Zero Fossil Fuels" initiative supported by MEER and funded by the Secretary of Higher Education, Science, Technology and Innovation (SENESCYT).

2. Methods

Considering the solar powered catamaran is under construction, in a first step hydrodynamic behavior was analyzed using Rhino3D and Orca3D software packages (Rhino 3D, 2014; Orca•3D, 2014) to estimate and

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minimize the energy consumption during the navigation of the ship. The daily energy consumption was estimated assuming that the boat will cross the Itabaca Channel 8 times a day. Then the energy performance of the PV system was designed and estimated using the simulation software PVSyst 6.0 (Mermoud and Wittmer, 2014) considering the meteorological data of Galapagos Islands obtained from NASA climate website based on satellite data from July 1983 to June 2005.

The Life Cycle Assessment (LCA) methodology has proved to be a valuable tool for documenting and analyzing environmental considerations of product and service systems that need to be part of decision-making process towards sustainability. For the purpose of the present work, the impact assessment was conducted using the CML 2000 methodology (Guinée et al., 2002). It is remarkable that the environmental indicators used have been chosen on the basis that there are agreed calculation methods for their quantification (Table 1).

Tab. 1: Indicators describing environmental impacts.

Indicator	Unit
Global warming potential (**GW**)	kg CO_2 equiv.
Depletion potential of the stratospheric ozone layer (**O**)	kg CFC-11 equiv.
Acidification potential of land and water (**A**)	kg SO_2 equiv.
Eutrophication potential (**E**)	kg $(PO_4)^{3-}$ equiv.
Formation potential of tropospheric ozone photochemical oxidants (**PO**)	kg Ethene equiv.
Abiotic resource depletion potential for elements (**AD**)	kg Sb equiv.
Abiotic resource depletion potential of fossil fuels (AD_fossil fuels)$^{(*)}$	MJ, net calorific value

$^{(*)}$There is no scientifically agreed calculation method for this impact category, so it has not been considered for the purpose of the present work.

3. Results and Discussion

3.1. Goal definition and scope

The goals of this study were to assess and compare the environmental impacts of both conventional and solar ship -identification and quantification of the most important environmental burdens related to the alternatives under analysis- as a basis to discuss the replacement of conventional ships in Galápagos Islands.

Fig. 1 shows both scenarios under study, the conventional ship and the proposed solar powered catamaran.

Fig. 1: Conventional ships operating in the Itabaca Channel (left) and solar powered catamaran designed to operate between Baltra and Santa Cruz islands (right).

Scenario A comprises the construction and operation of the conventional ship (barge). At present, inhabitants and tourists of Galapagos Islands require to take one of the four existing barges in order to take them through the Itabaca Channel (10 minutes trip). One of the barges belongs to the Santa Cruz Municipality and it will be replaced by the solar powered catamaran. This monohull ship and most of its elements (hull, top cover, seats, etc.) are made of local palosanto wood. The ship was locally constructed.

The barge has an off-board 80 hp gasoline engine, it is about 13 m long and 4 m wide, and has the capacity to carry 42 seated passengers. Its fuel consumption is approximately between 9 to 14 US gallons per day, giving an annual consumption of about 5,000 US gallons.

On the other hand, scenario B comprises the construction and operation of the solar powered catamaran. The catamaran and most of its elements (hulls, seats, etc.) are made of reinforced glass fiber; it is currently under construction in a shipyard close to the city of Guayaquil (Ecuador). A deck roofed with photovoltaic modules will be installed between the hulls. As far as the dimensions are of concern, the catamaran is about 15.4 m long and 6.4 m wide.

The solar ship is provided with a stand-alone 4.2 kWp photovoltaic system with panels integrated on the roof. Due to weight, capacity and durability are important issues in transport, the battery bank consist on 6 Li-Ion batteries operating at 48 V and a total capacity 540 Ah. The electricity produced by the panels is managed by a 48 V MPPT charge controller and a Li-On Battery Management System (BMS). In addition, the ship has a 5 kVA inverter-charger to supply power from the local grid because the PV system is designed to produce a fraction of the electricity demand. All the system will be monitored to obtain the energy performance parameters to assess accurately the environmental impacts of this alternative for maritime transport. Fig. 2 shows a schematic diagram of the electric system of the solar powered catamaran.

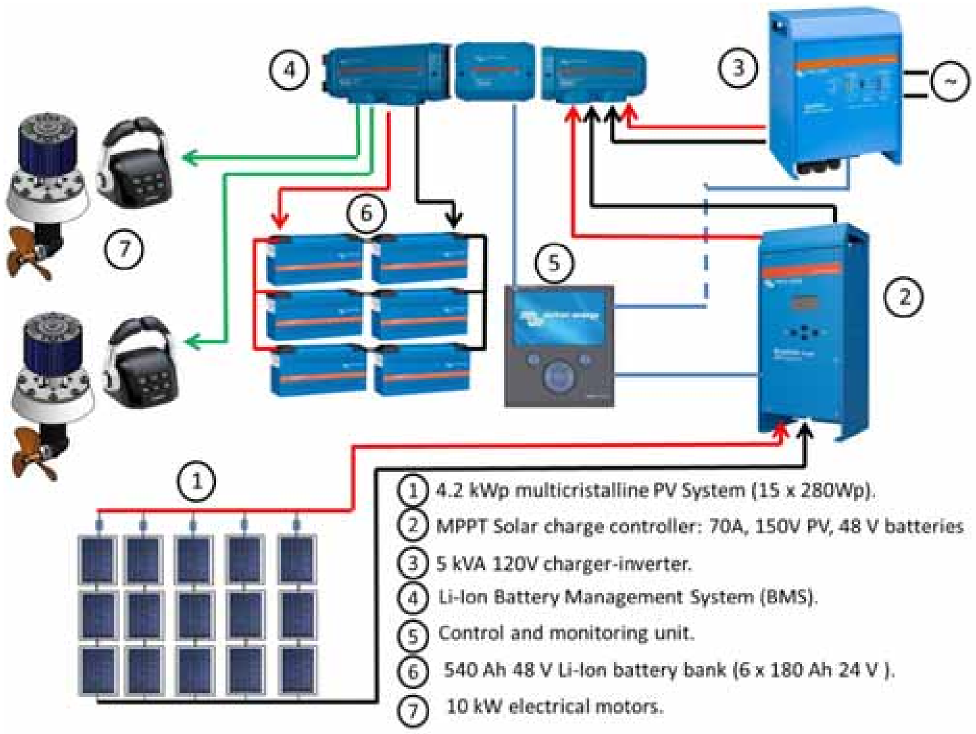

Fig.2: Electrical diagram of the solar catamaran indicating the main components.

<u>Functional unit</u>

The functional unit provides a reference to which the inputs and outputs are related. For the purpose of this assessment, the functional unit chosen was the operation of both conventional and solar ships during one year period. For the allocation -apportioning of the input or output flows of a unit process to the system under study- of construction phase flows, 15 years of use phase was the period considered.

<u>Data quality</u>

In order to tackle the analysis of the results in greater depth, the systems (scenarios A and B) have been divided in the subsystems of construction and use. All the data related to the energy and material consumptions of the subsystems of construction were obtained from the company which manages the construction of the solar catamaran, with the exception of the electrical system.

The electrical system of the ship is divided into the electric propulsion subsystem and the PV generation subsystem. The propulsion subsystem consists basically of two electrical drives and their controls. The elements of the PV subsystem can be classified into three groups: generation (photovoltaic panels), storage (batteries) and the Balance of System (BOS), which are the support structure, inverters, control, etc. It was relatively easy to find information to perform Life Cycle Assessment for PV panels (Choi and Ftenakis, 2014, Bekkelund 2014) and Li-Ion batteries (Victron Energy, 2013; EPA, 2013). However, information regarding BOS and electric motors is rather scarce. For the BOS we estimated the materials of the solar charger, charger-inverter and cabling escalating the data available at Bekkelund (2013). For the electrical motors of the propulsion subsystem, the information of a Life Cycle Assessment of a 10 kW 3-phase motor was taken into account (Boughanmi et al., 2012). It is remarkable that for this preliminary assessment, mass and energy balances for the electrical components were inventoried using data from Ecoinvent database.

3.2. Life Cycle Inventory

Life Cycle Inventory (LCI) analysis involves the collection and computation of data to quantify relevant inputs and outputs of a product system, including the use of resources and releases to air, water and land associated with the system (ISO 14040:2006). The inventory data were collected for each process unit included within the system boundaries (construction and use phase). Data sources were previously indicated in the data quality sub-section.

A comprehensive Life Cycle Inventory (LCI) for the construction of each ship was compiled. In order to provide an overview of the different models, a general description of the energy employed to build the conventional and the solar powered boats is summarized in Table 2 and Table 3.

Tab. 2: Energy consumption related to the construction of conventional ship.

Quantity	Power tools / Equipment	Hours/day	Number of days	Power (HP)	Total (HP)
3	Grinding machine	3	35	0.25	78.75
4	Hand drill	2	48	0.18	69.12
1	Crane	4	3	638.75	7,665.00
1	Jigsaw	5	12	0.25	15.00
1	Spray gun + air compressor	5	8	1.00	40.00
2	Electric chain hoist	2	6	0.25	6.00
2	Hand saw	4	25	2.00	400.00
1	Edge banding machine	4	21	1.50	126.00
1	Table saw	4	45	2.00	360.00
TOTAL					8,759.87

Tab. 3: Energy consumption related to the construction of the solar powered ship.

Quantity	Power tools / Equipment	Hours/day	Number of days	Power (HP)	Total (HP)
2	Grinding machine	3	25	0.25	37.50
3	Hand drill	2	30	0.18	32.40
1	Crane	4	3	365	4,380.00
1	Jigsaw	6	15	0.25	22.50
1	Spray gun + air compressor	5	8	1.00	40.00
2	Electric chain hoist	2	6	0.25	6.00

TOTAL	4,518.40

Figure 3 shows the solar resource, electricity demand and PV production of the ship with a solar fraction around 80%. The high specific production of 1,650 kWh/kWp indicates the important solar irradiation in Galapagos Islands and the potential role of PV systems to supply part of the electricity in the maritime transport. However, the main drawback of this system is the high initial cost, especially for the Li-Ion batteries.

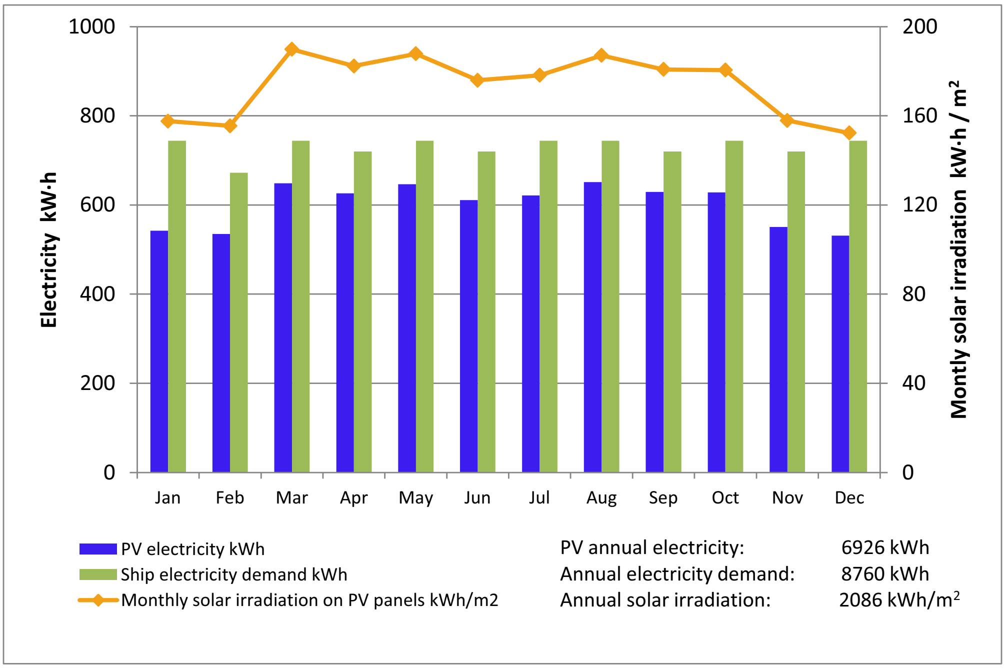

Fig. 3: Solar resource, PV electricity and electricity demand of the ship calculated with PVSyst.

3.3. Impact Assessment

Figure 4 shows the environmental fingerprint of both options Solar ship and Conventional ship. The diagram represents a comparative analysis of the environmental advantages and disadvantages of the two alternatives. For each category, the characterization values were obtained and they are relatively compared, assigning a value "1" to the least favorable alternative in the category under analysis. With the exception of the category of Photochemical Oxidation (PO), the results obtained show a significant improvement in the environmental performance when Solar ship is considered (from 58.42 to 99.99% for the categories analyzed).

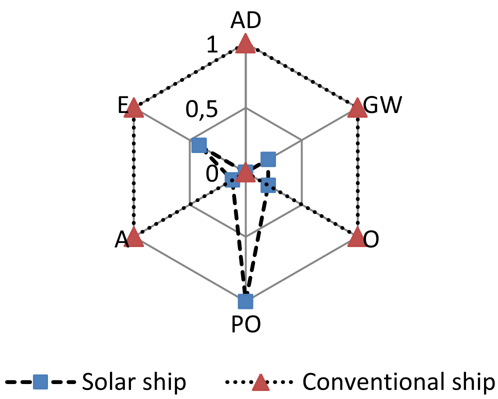

Fig. 4: Environmental fingerprint of Solar ship vs. Conventional ship. AD: Abiotic Depletion; GW: Global Warming; O: Ozone Layer Depletion; PO: Photochemical Oxidation; A: Acidification; E: Eutrophication.

The analysis of the contribution of the different subsystems to the impact categories is required to detect the "hot spots". The results for the characterization of scenario 1 show that almost environmental impact is associated to the operation of the ship (use phase), for all the categories analyzed. For the case of the solar powered catamaran, the construction phase play a significant role, mainly associated to the fabrication of the electrical system components. These preliminary results strengthen the hypothesis that the use of these solar resource in maritime transport is more sustainable than its use as fuel.

4. Future Outlook

This project aims to explore and test the hypothesis that solar powered transport promotes an environmentally friendly model. Pressures on transport industry to develop strategies and means to achieve sustainability are expected to grow. The aforementioned catamaran was selected as a pilot project for the adoption of a new line of research with the aim of promoting renewable energy and avoid serious threats to the environment in one of the most biodiverse areas on the planet.

Promoting environmental research and technology innovation was the main goal of the present work, based on a case study of the development of a solar-powered catamaran used for transporting passengers to the Galapagos Islands. The findings of the study shed light on whether or not the adoption of solar powered transport model is favorable from an environmental point of view. However, further research must focus on a sensitivity analysis considering climatic variations as well as specific data for the manufacture of electric components.

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6. Acknowledgement

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