Environ. Process.
https://doi.org/10.1007/s40710-017-0270-7

ORIGINAL ARTICLE

Environmental Impact Assessment of Internal Combustion and Electric Engines for Maritime Transport

Geovanna Villacreses[1] · Sofía S. Salinas[1] · Wilson D. Ortiz[1] · Stefany Villacís[1] · Javier Martínez-Gómez[1,2] · Ricardo A. Narváez C.[1]

Received: 31 May 2017 / Accepted: 27 September 2017

Abstract This paper aims to analyze the impacts of replacing the propulsion technology of small-scale maritime transportation, which currently uses internal combustion engines and may be required to be replaced by electrical propulsion. This analysis has been performed through a qualitative and quantitative assessment of socio-environmental impacts of the replacement proposal. The methodology followed for estimating the impacts of using both types of engines was to adopt a graded scale and a cause-effect matrix. This methodology allowed relating the activities of both types of propulsion with social and environmental factors. The evaluation of the socio-environmental impacts showed that electrical engines generate 2.8 times less impact if compared with combustion engines due to pollution reduction mainly. Consequently, it was possible to highlight the environmental benefit that the implementation of electric engine generates in small-scale maritime transport.

Keywords Environmental impact assessment · Leopold matrix · Conesa methodology · Small-scale maritime transport

1 Introduction

Emissions from land and maritime transport cause environmental impacts on the atmosphere and contribute to climate change (Uherek et al. 2010; Faour and Fayad 2014). In addition, carbon emissions related with shipping activities are increasing and will continue to do so in the next years (Viana et al. 2014). For this reason, it is important the environmental impact assessment performance with the purpose of analyzing the significance over the environment

✉ Geovanna Villacreses
geovanna.villacreses@iner.gob.ec

[1] Instituto Nacional de Eficiencia Energética y Energías Renovables – INER, Quito, Ecuador

[2] Universidad Internacional SEK Ecuador, Quito, EC170134 Quito, Ecuador

when performing such type of actions (Pinto et al. 2014; Sengers and Raven 2015). This significance should be analyzed by considering the society as a whole, i.e., the affected region and particular local characteristics should be included as part of the analysis of short and long-term effects (Canter and Kamath 1995). Environmental impact assessment (EIA) becomes an important tool for predicting impacts before any human intervention over the environment. The most relevant information to be obtained after such assessment aims to identify the magnitude of impacts, the main adverse effects, and potential mitigation measures for avoiding or reducing such issues (Glasson et al. 2012; Greig and Duinker 2011). The application scope of this tool usually includes the physical-chemical, biological, cultural and socioeconomic environment components within several projects of biodiversity, energy sector, and industry in general (Canter and Kamath 1995). EIA can be used as a sustainable development tool for identifying the barriers, the realistic political, social, economic and technical opportunities for its optimization (Petts 1999). Moreover, EIAs are used prior to the execution of various types of projects related to manufacturing or natural resources exploitation (Antal and Van den Bergh 2013), or industrial policy planning (Wathern 2013).

The EIA methodology has been adopted by around 100 countries, and by several non-governmental organizations and funding agencies (Cashmore 2004). Developing countries have realized the potential of performing EIA in order to become familiar with environmental planning. Within this context, Colombia was the first Latin American country to report the implementation of an EIA in its state planning in 1974 (Wathern 2013). The definition of the elements of an EIA varies depending on the country, and on the scope of the study. However, it is currently evolving due to the relevance of the socio-economic dimension, public participation, and especially, activities performed after the implementation stage such as control and monitoring (Glasson et al. 2012).

The use of EIA has increased progressively in the last 15–20 years, due to the necessity of solving the environmental issues that result from climate change, biodiversity loss, damage of marine areas, among others. Meanwhile, there have been found some stages that need to be enhanced when taking the EIA into practice, such as: scope, consideration of alternatives, screen, monitor and quality control. Besides, when performing an EIA, the necessary input data should be taken into account to develop their actions in order to implement a national policy to reduce greenhouse emissions (Morgan 2012).

In addition, some weaknesses have also been identified. For instance, lack of understanding about policies, laws and licensing concerning environmental issues, untrusted processes of waste disposal, and undesirable results after decision-making processes and regulatory constraints are among the most common failures identified in the methodology. In order to improve the EIA application, it is necessary to achieve an effective participation of public and private stakeholders involved in the process. Their participation should be mainly focused on establishing new policies for sustainable natural resources management. In this regard, it is proposed that EIA application migrates from the rationalist mode of current overly, to a more participatory manner which considers participation of all the stakeholders (Morgan 2012).

The earliest method~~s~~ applied to performing an EIA included the design and application of two-dimensions interaction matrices based on the presentation of the activities of the project along one axis, and the assessment of environmental factors in the remaining axis. It is relevant to mention that several modifications have been applied to this methodology such as the application of stepped matrices. Within this context, the matrix of Leopold et al. (1971) was developed. This tool considers beneficial or harmful environmental impacts, and displays each action and its potential for generating an impact over each environmental factor. The matrix constitutes a list of the activities for the project on the horizontal axis and the environmental factors list on the left axis (Clark et al. 2012). Hence, it shows the interaction between these two items considering its magnitude and importance. Each interaction evidences the characteristics of the impacts and the undesirable factors that need to be mitigated (Canter and Kamath 1995). Its use has been reported in evaluating thermal power generation projects in Mexico, since it is a well-known methodology and represents lower costs if compared with other EIA methodologies (Mexiquense et al. 2006). On the other hand, several studies have concluded that the Leopold matrix methodology lacks of measurable parameters, such as energy pathways, food webs, nutrient cycles and diversity patterns (Clark et al. 2012).

The environmental impact assessment (EIA) has been developed as tool of the environmental management for 40 years. During this period, environmental change and its implications have been an important topic of study. In this sense, EIA has been advanced continuously by the experience of practice (Morgan 2012). Nowadays, the implication of the natural environment in the society is the most important of the key factors to reach a decision. Hence, it is required to update the study process according to the progress made in the field. In consequence, this paper consists of two parts. The first one based on the origins of EIA and the second part of the paper reflects the recent trends in EIA, and the opportunities that are available to shape the future of the technique.

Both methodologies are combined with the aim of assessing the impacts, quantitatively and qualitatively, and then evaluating them using the Leopold matrix. For the qualitative evaluation, authors selected the methodology proposed by Conesa (2009); moreover, the quantitative valuation is performed with the *ad hoc* methodology (experts panel). With the obtained results, the identified impacts are evaluated for both marine propulsion technologies. The purpose of this research is to determine the incidence on the environment of migrating from a combustion engine to an electric motor in the ships used for small-scale passenger transportation. For this purpose, the identification and quantification of environmental and social impacts based on the Conesa (2009) methodology has been carried out. In addition, the environmental impact assessment has been performed using the cause-effect matrix developed by Leopold et al. (1971).

2 Materials and Methods

The methods of this research involve the study area description, the identification of the operation activities for boats, the identification of the environmental factors, and the combination of Leopold matrix and Conesa environmental impact assessment methods.

2.1 Environmental Impact Assessment

According to Conesa (2009), the Environmental Impact Assessment (EIA) is a legal-administrative method, which aims to identify, predict and interpret the environmental impacts that projects would produce in the case of being executed. In addition, results can be used in prevention, correction and impact evaluation to accept, modify or reject them.

The EIA should consider all environmental factors that are likely to affect the environment. Such scope requires defining the environment as a set of physical, biological and socio-economic factors and their interactions. Furthermore, an EIA should incorporate the environmental variable in problems solving owing to prevent significant environmental problems. In such terms, EIA becomes a preventive planning tool suitable for reducing economical costs through prevention. It also implies encouraging the population participation in decision-making process by including justified and feasible criteria expressed by their members. Such factor can provide a long-term approach and an integrated vision of human actions on the environment.

2.2 Qualitative Impact Assessment

In order to measure the environmental impact in qualitative terms, the variable “Importance” is used. It allows to measure the quality change of the environmental parameter, as a result of the actions before and after being impacted (Morgan 2012).

The methodology proposed by Conesa (2009) allows the qualitative measurement of the environmental impacts through the calculation and analysis of “Importance”. The methodology is based on the "Methodological Guide for Environmental Impact Assessment" by Conesa (2009). The Importance was calculated using Eq. (1) proposed by Conesa (2009), and the range of values of Importance was rescaled between 1 and 10:

$$\boldsymbol{Importance}\ (\boldsymbol{I}) = \pm(3\boldsymbol{IN} + 2\boldsymbol{EX} + \boldsymbol{MO} + \boldsymbol{PE} + \boldsymbol{RV} + \boldsymbol{SY} + \boldsymbol{AC} + \boldsymbol{EF} + \boldsymbol{FR} + \boldsymbol{MC}) \quad (1)$$

where: IN is the intensity; EX is the extension; MO is the moment; PE is the persistence; RV is the reversibility; SY is the synergy; AC is the accumulation; EF is the effect; FR is the periodicity; MC is the recoverability. The explanation of the environmental impacts assessment is presented in Table 1 (Conesa 2009).

When analyzing the applicability of this method for both scenarios, the *Employment* parameter did not consider the *Recoverability*. Moreover, for the *Travel Experience* parameter, *Reversibility* and *Recoverability* attributes were not taken into account because of the lack of measurable criteria related with them.

2.3 Quantitative Impact Assessment

In this research, the variable “Magnitude” is used to evaluate the environmental impact quantitative dimension. The definition of the magnitude using the methodology of the panel of experts was chosen. The panel of experts included specialists from the Instituto Nacional de Eficiencia Energética y Energías Renovables (INER) in various topics such as environmental issues, mechanical items, and electrical applications.

The expert panel is an *ad hoc* method that consists of the systematization of queries sent to a group of experts which are also familiar with the project. Experts are supposed to identify the appropriate information and elaborate qualitative and quantitative models for enabling the prediction or identification of impacts (Leopold et al. 1971; Espinoza 2002). The value scale presented in Table 2, indicates values between 1 and 10 to maintain the same importance scale.

2.4 Leopold Matrix

Leopold Matrix was designed for infrastructure projects and is especially useful due to its scope and content related with preliminary evaluations that are expected to identify major environmental impacts (Leopold et al. 1971). Its limitations are based on the fact that it only allows to identify impacts and their origin without marking them (Leopold et al. 1971;

Table 1 Typology of environmental impacts (Conesa 2009)

Criteria	Types
Overall impact type	- Positive or beneficial: those that improve the environment. - Negative or harmful: those that cause degradation or harm the natural area.
Intensity (IN)	It refers to the incidence of the action over the environmental factor. - Low impact: expresses a minimal modification - Medium impact: expresses medium-degree of alteration. - High impact: expresses a significant disturbance. - Very high impact: it implies almost a total destruction. - Total impact: it expresses total destruction.
Extension (EX)	It reflects the extent of the specific component of the environment that is affected by the implementation of the project. - Punctual impact: when the shocking action produces a much-localized effect. - Partial impact: the one whose effect supposes a noticeable incidence in the environment. - Wide or large impact: the one whose effect is detected in an extended part of the area under study. - Total impact: the one whose effect is generalized along the environment. - Critical location impact: effect is critical for the environment.
Term-based occurrence (MO)	It refers to the term comprised between the moment that the impact is committed, and the first registry of the effect over the environmental factor. - Long-term: time of manifestation in more than 10 years. - Medium-term: time of manifestation between 1 and 10 years. - Short-term: time of manifestation in less than one year. - Immediate: the time between the beginning of the action and its manifestation is practically null. - Critical Moment impact: the shocking action that takes place is critical, regardless of the moment it appears.
Persistence (PE)	It refers to the term that the effect lasts over the environment. - Fleeting impact: minimal last. - Momentary impact: shorter than 1 year. - Temporary impact: between 1 and 10 years, regardless of any action taking place. - Persistent impact: between 11 and 15 years. - Permanent impact: continuous effect for a period that exceeds 15 years.
Reversibility (RV)	This criterion denotes the suitability of reconstruction the affecting factor has by itself, once the project stops acting over the environment. - Reversible: when the environment can assimilate the alteration without human intervention • Short-term: less than 1 year. • Medium-term: between 1 and 10 years. • Long-term: between 11 and 15 years. - Irreversible: self-reconstruction is unlikely or extremely difficult without human intervention. Assimilation term can take longer than 15 years.
Synergy (SY)	It is understood as the interaction of two or more causes that boosts their effects by acting together, if compared with the effect that each one could have individually. - Without synergism or simple: their interaction does not produce synergistically effects. - Moderate synergism: their interaction produces medium or low synergy. - Significant synergism: their interaction is quite synergistic.
Accumulation (AC)	This criterion indicates the progressive augmentation of the effect's manifestation, if the action persists repeatedly. - Non-cumulative or simple: when the action produces individualized effects, it does not induce the generation of new effects. - Cumulative: when the prolonged action in time, progressively increases the magnitude of the effect.
Cause-Effect Relation (EF)	This criterion refers to how an effect manifests as consequence of a given action in a timely and geographical basis.

Table 1 (continued)

Criteria	Types
	- Direct: those effects that cause the actions and they occur at the same time and place of them. - Indirect: changes that may occur later or in different places.
Periodicity (PR)	It refers to how prompt is the manifestation of a given effect. - Irregular (sporadic): when the manifestation is repeated without a regular periodicity. - Periodical: when they manifest in regular cycles. - Continuous: when the manifestation is constant.
Recoverability (RC)	This criterion refers to the suitability of recovering its original state after a given impact, through human intervention. - Recoverable: effects can be neutralized within a given time by corrective and restorative measures. • Immediate: minimum or zero neutralization time. • Short-term: neutralized in less than 1 year. • Medium-term: neutralized between 1 and 10 years. • Long-term: neutralized between 11 and 15 years. - Likely to be mitigated: the alteration can be mitigated by establishing corrections. - Compensable: the alteration can be mitigated by compensating the negative effects. - Non-recoverable: when the alteration of the environment is unlikely to be entirely repaired by human intervention. Neutralization time may take longer than 15 years.

Espinoza 2002). Moreover, the matrix includes a list of 100 actions that can cause environmental impacts and 88 environmental characteristics. This combination generates an array with 8800 cells. In each box, there is a distinction between magnitude and importance of impact, on a scale from 1 to 10 (Leopold et al. 1971; Espinoza 2002).

This matrix is generally used in a reduced mode, which considers only the actions applicable to the project and the most relevant impacts. Furthermore, each cell will contain a fraction where the numerator is the Magnitude and the denominator is the Importance. The sum by columns will show the impacts of the project actions on each environmental factor, and therefore, its fragility; while the sum by rows will result in a relative assessment of the effect that each action would produce in the environment and its aggressiveness.

When multiplying the Importance by the Magnitude, the obtained value is equal to the Impact generated by the action on the environmental parameter. This value can range from 1 to 100 and can either be positive or negative. In addition, the panel of experts has proposed a scale of intermediate values with their corresponding hierarchy of impact, as shown in Table 3.

Table 2 Magnitude value scale

Range	Impact
1–2	Irrelevant
3–4	Low
5–6	Medium
7–8	High
9–10	Very high

Table 3 Hierarchy of environmental impact

Negative Impact	Range
Severe	$-100 \le \text{Impact} \le -75$
High	$-75 < \text{Impact} \le -50$
Medium	$-50 < \text{Impact} \le -25$
Low	$-25 < \text{Impact} \le -1$
Positive Impact	Range
Low	$1 \le \text{Impact} < 25$
Medium	$25 \le \text{Impact} < 50$
High	$50 \le \text{Impact} \le 100$

2.5 Case Study

Part of the Galapagos Marine Reserve, affected by small-scale passenger transportation, is evaluated. The area is considered a protected area with a rich biodiversity of natural species (Fernández-Vítora 2009). This area is being altered due to human activities, especially because of tourism performed without the required environmental standards. In this context, the Ecuadorian government promotes the initiative Zero Fossil Fuels in Galapagos with a goal of reducing the fossil fuels consumption (Muñoz et al. 2015; Villacís et al. 2015; Martínez-Gómez et al. 2016; Villacreses et al. 2017).

Currently, there are some maritime activities of passenger transport in this area (coaster ships) and some beached boats for artisanal fishery. These boats use fossil fuels as their power source, so their operation and maintenance has led to the presence of oils and hydrocarbons in the sea, as well as emissions of polluting gases and particulate matter (Danulat and Edgar 2002). This pollution can be clearly perceived by tourists and locals, generating discomfort to them.

For this study, a direct influence area (DIA) was established in the zone between the dock of Puerto Ayora and the different destinations visited by boats during their operation. Similarly, an indirect influence area (IIA) was established in the marine space covering a radius of 1 nautical mile from the dock. In this indirect area, the socio-economic environment was considered, being the entire population taken into account, since it is the main stakeholder of the transportation service, as shown in Fig. 1. The physical and biotic environment was considered as part of the assessment.

This study has considered the modification of a conventional boat, i.e., the replacement of the internal combustion engine (ICE) by an electric engine (EE) was assessed. This task includes the necessary adjustments for the operation of the electrical system such as batteries, battery charger, junction box, electronic control, top cover and solar panels. A conventional transportation ship is shown in Fig. 2.

A conventional transportation ship consists on a mono-hull boat with the following considered specifications: i) hull structure made of fiberglass, reinforced polyester, resin and impact protection provided by a camphor wood structure. The interior surfaces are protected by using marine plywood and core balsa; ii) hull coated with antifouling paint tin-free for keeping the aesthetics of the boat; iii) upper deck (roof) constructed using sandwich sheets of polyester resin reinforced by fiberglass and balsa core.

The specifications of the ICE Yamaha FT50CET are: i) engine displacement of 935 cm^3; ii) compression ratio of 9.3, iii) Output power of 50 kW at 5500 rpm; iv) Maximum fuel consumption of 16 L/h at 5500 rpm. The specifications of the EE are: i) three-phase AC

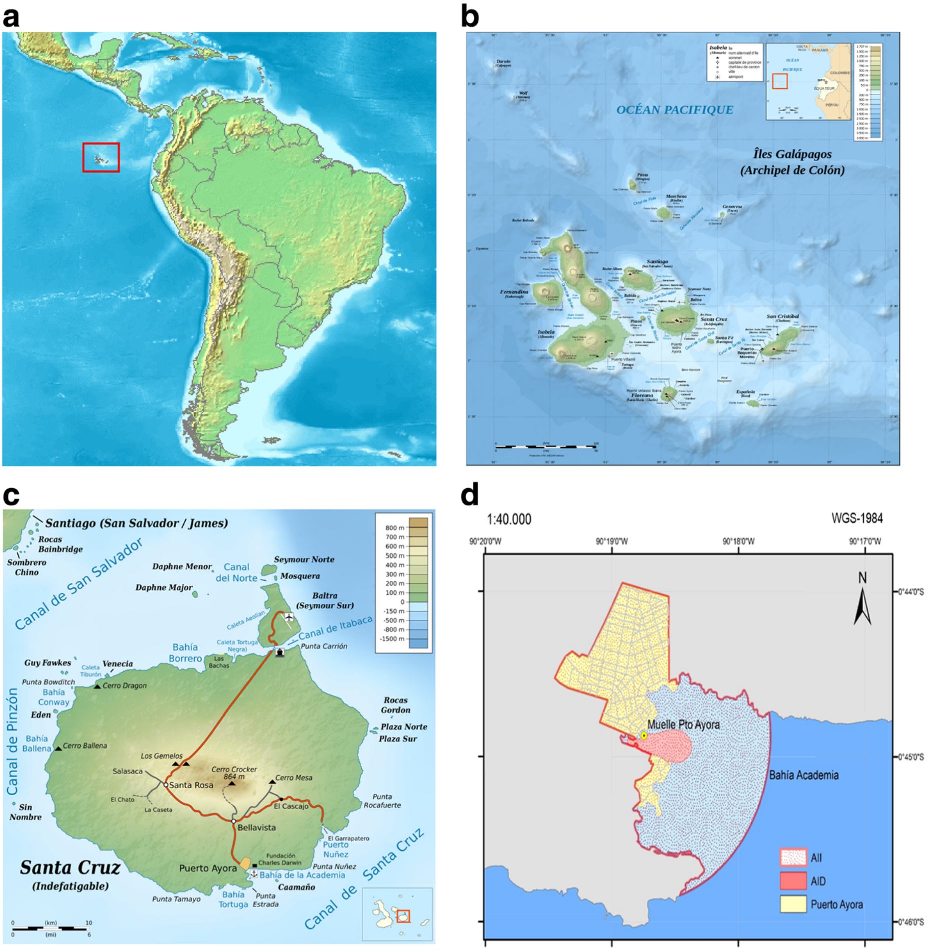

Fig. 1 **a**) Location of Galapagos islands in South America, **b**) Galapagos islands map (image of Eric Gaba), **c**) Santa Cruz island map, and **d**) Direct and indirect areas of study

permanent magnet engine of 8 kW sized to operate the boat; ii) lithium ion batteries of 12 V to provide electrical power; iii) solar panels as a source of energy.

Fig. 2 Conventional water taxi

In addition, the charging point of the boat would have been located at the dock of Puerto Ayora. This charging point should be located in an accessible site for the boats that require charging. The charging station would consist of: i) the formation of a rectangular concrete base to settle the structure; ii) an electrical supply tower made of marine grade stainless steel covered with electrostatic painting; iii) electrical devices, such as control panels, switches, electric wires, sockets, etc. for the charging point proper operation.

2.5.1 Activities Identified in the Case Study

The operation activities of the boats with ICE and EE technologies and their descriptions are presented in Table 4. These activities have taken into consideration the stages of construction and maintenance of the charging station, operation of the boats, maintenance of different engines, maintenance of the ships and final closing or disposal.

2.5.2 Environmental Factors of Case Study

The environmental factors are components of the biotic, abiotic and socioeconomic elements likely to be impacted, positively or negatively, by one or more actions. The list of environmental factors and their specific parameters for the case studies are presented in Table 5.

3 Results and Discussion

The developed methodology was used in order to obtain a value of total environmental impact in environmental impact units (EIU). This section presents the results of the multiplied Leopold matrices for the analyzed mobility scenarios. According to the scale of values proposed by the panel of experts for performing the environmental impact hierarchy, the results obtained from the use of Leopold matrix are shown in Tables 6 and 7, for the ICE and EE scenarios, correspondingly.

In the ICE scenario, 79 (90.8%) of the 87 impacts were determined to fall into the category of low negative, 2 (2.3%) in the category of medium negative, and 6 (6.9%) were determined as low positive impacts. For the EE model, 60 impacts were determined in total, 51 (85.0%) in the category of low negative, 2 (3.3%) in the medium negative and 7 (11.7%) in the low positive impacts. For both scenarios no impacts were obtained at the negative level of the hierarchy, neither critical nor high and neither medium nor high positive impacts. The results obtained by multiplying the Leopold matrices figures show the impacts of all the analyzed environmental factors. In contrast, EIA from water transport usually needs chemical tracers of shipping emissions, particle size distribution, ambient PMx concentrations, impact of harbor loading and unloading operations on ambient PMx concentrations and impact of shipping emissions on gaseous pollutant concentrations (Uherek et al. 2010; Viana et al. 2014).

The total environmental impact value equals to 1023.3 EIU for ICE, and 364.3 EIU for EE, with both values being negative. This finding demonstrates that both projects generate a harmful impact on the fragile ecosystem of the Galapagos Islands. However, the effect that produces the alternative of implementing an EE is 2.8 times lower than the current model (ICE), hence its potential implementation would bring a relative benefit. Both scenarios generate a positive impact on the economic aspect, 29.2 EIU for ICE and 22.2 EIU for EE, as they generate sources of employment (and income) for the population, in various activities

Table 4 Activities and description of the operating activities of boats with ICE and EE technologies

Stage	Symbol	Activities	Description
Construction and maintenance of the charging station	EE-A1	Conformation of concrete base	Construction of a small concrete base for setting up a charging station.
	EE-A2	Installation of a power supply tower	Placing of a metal structure and its corresponding connections for the power supply tower.
	EE-A3	Maintenance of the charging station	Inspection of the electrical circuits and wiring connections. Rewiring when required.
Operation of the water taxi boats	ICE-A1	Bunkering logistics	Fuel transfer from the Ecuadorian continental territory to the island and its internal distribution.
	ICE-A2 EE-A4	Vessels displacement	Movement of the ships along the path of service.
	ICE-A3 EE-A5	Refueling	Fueling of the boat from the service station until filling the tank (ICE).
		Energy charging	Power supply to charge batteries (EE).
Maintenance of engine	ICE-A4	Oil and filter change	Used engine oil removal and filter replacement.
	ICE-A5	Fuel filter change	Replacing the fuel filter at the end of its lifetime.
	ICE-A6	Air filter change	Replacing the air filter at the end of its lifetime.
	ICE-A7 EE-A6	Bearing lubrication	Lubrication of internal engine bearing and propeller.
	EE-A7	Terminals cleaning	Removal of fouling at the terminals of the battery through a softening solution made of sodium bicarbonate.
	ICE-A8 EE-A8	Engine repair	Corrective maintenance of the engine when it has been damaged.
Maintenance of boat	ICE-A9 EE-A9	Hull	Underwater cleaning of the hull with soap and water, using an abrasive sponge to loosen deposits.
		Deck cleaning	Cleaning of solar panels with water and detergent and using brushes or sponges suitable for glass (EE).
	ICE-A10 EE--A10	Hull painting	Painting of the hull using antifouling paint, prior to this: the hull should be washed with soap and water; the wax should be removed using solvents, sand the surface and perform hull repairs if necessary.
	ICE-A11	Canvas cover changing	Renovation of the canvas covers for wastage.
	ICE-A12 EE--A11	Fixing of hull damage produced by collisions	Correction of cracks, bumps, holes and other damage present in the hull, by rectifying the fiberglass.
Closing or disposal	EE-A12	Changing batteries	Replacement of lead batteries at the end of their lifetime (every 2 years) / Replacement of lithium batteries, engine and solar panels at the end of their lifetime (every 7 years)
	EE-A13	Engine changing	Replacing the engine at the end of its lifetime (average lifetime 15 year).
	ICE-A14	Engine removal	Removal and disposal of the internal combustion engine (average lifetime 25 years).
	ICE-A15 EE--A14	Renewal or change of the hull	Removal of the hull in order to reintroduce the fiber in the resin or arrange it in a continental landfill (average lifetime 15 years).
	EE-A15	Repair of solar panels	Replacement of solar panels at the end of their lifetime (average lifetime 25 years or less time if they present collisions).

Table 5 Environmental factors specified for the scenarios

Environment	Environmental component	Environmental parameter
Biotic	Flora and Fauna	Diversity and abundance
Abiotic	Water	Oils and fuels
		Surfactants
		pH
		Vibrations
		Solid waste
	Air	CO_2
		HC not combusted
		NO_x
		Particulate matter
		Noise
	Soil	Liquid waste
		Solid waste
	Aesthetic	Landscape
Socio-economic	Economy	Employment
	Social	Health and security occupational
		Health and safety for tourists
		Travel experience

involvement. This variation is minimal, so it is considered that the potential contributions of both scenarios on this aspect are similar, as Table 8 shows.

When analyzing the impact on the environmental factors for the situation of mobility with the conventional propulsion system, the water factor contributes to a high proportion with 276.3 EIU (Table 8). This fact can be explained by mentioning that this environment is exposed to different alterations during the operation and maintenance stages, such as: oil spills, oil and grease, cleaning spills and pollution produced by solid waste thrown from the boat. Likewise, for the situation of electrical motor, the soil factor contributes to a high proportion with 117.7 EIU. The alteration of soil quality is mainly caused by the wrong disposal techniques of different types of waste, such as: construction debris, electrical equipment, cleaning cloth with pollutants, abrasive paper, leftover paint and technological waste.

In addition, it should be considered that all the activities that make up each of the studied stages for both scenarios produce a negative transformation in the environment. In the environmental impact assessment analysis of the stages of the ICE scenario, it was determined that the boat operation generates the greatest impact with 439 EIU. In the environmental impact assessment analysis of each stage of the EE, it was determined that the construction and maintenance of the charging station stages will cause the largest socio-environmental impact with a value of 163 EIU, since it would induce alterations of the soil and water quality as a potential result of a wrong disposal of the generated solid waste. Air quality would also be affected because of the noise and particulate matter emitted during its construction (see Fig. 3).

In addition, a significant reduction of the impact that the ship displacement produces on the environment can be seen, since it would be reduced from 271.4 EIU in the ICE scenario to 36.7 EIU in the EE scenario (7.4 times lower). This finding is related to the elimination of water and air pollution. There also exists an improvement in the travel experience for both stakeholders and service agents. Similarly, a decline in the socio-environmental impact is shown at the engine maintenance stage, decreasing its value by 5.3 times from 281.2 EIU for the ICE scenario to 52.6 EIU for the EE scenario. This variation is caused by the reduction in hazardous waste generation (oils and greases, contaminated rags, fuel spills, among others).

Table 6 Multiplied Leopold matrix for internal combustion engine

Environmental factors	Shocking activities														
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
1. BIOTIC															
1.1. Fauna															
Diversity and abundance	−12.2	−16.4	−28.0	−17.0	−19.0		−13.0		−16.8				−13.0	−4.8	
2. ABIOTIC															
2.1. Water															
Oils and fuels	−11.4	−14.4	−20.3	−13.0	−13.0		−14.0	−12.0						−5.0	
Surfactants		−13.8	−17.5	−11.0	−11.0			−11.0						−4.4	
pH		−12.0	−13.3	−9.5	−9.5			−9.0						−3.8	
Vibrations		−21.0													
Solid waste		−7.8							−18.6						
2.2. Air															
CO_2	−6.0	−21.7													
HC not combusted	−6.0	−21.7													
NO_x	−6.0	−19.6													
Particulate matter	−6.0	−19.6				−6.8		−5.4		−5.6		−8.0			
Noise	−4.4	−24.0								−3.8		−10.0			
2.3. Soil															
Liquid waste	−10.0							−19.8		−14.5		−14.0	−18.0	−5.6	
Solid waste	−4.8			−15.0	−15.0	−15.0	−11.5	−19.2	−8.7	−15.0	−7.8	−13.0	−15.0	−5.8	−22.4
2.4. Aesthetic															
Landscape	−3.4	−23.4													−19.6
3. SOCIO-ECONOMIC															
3.1. Economy															
Employment	2.6	3.2						6.9		5.7	5.4	5.4			
3.2. Social															
Health and security occupational	−4.9	−25.6	−16.0					−18.4	−21.7	−23.1	−4.6	−9.2	−7.8		
Health and safety for tourists		−20.0													
Travel experience		−13.6													
TOTAL IMPACT FOR ACTION (EIU)	−72.5	−271.4	−95.1	−65.5	−67.5	−21.8	−38.5	−87.9	−65.8	−56.3	−7.0	−48.8	−53.8	−29.4	−42.0

Table 7 Multiplied Leopold matrix for electric engine

Environmental factors	Shocking activities														
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
1. BIOTIC															
1.1. Fauna															
Diversity and abundance	−8.8			−5.6		−5.2	−4.8		−2.8			−6.9	−3.2		
2. ABIOTIC															
2.1. Water															
Oils and fuels						−4.6									
Surfactants															
pH							−3.8								
Vibrations				−19.8											
Solid waste	−27.2	−7.5		−8.4					−3.1						
2.2. Air															
CO_2															
HC not combusted															
NO_x															
Particulate matter	−17.0									−2.8	−2.0				
Noise	−12.0			−2.4						−1.9	−2.5				
2.3. Soil															
Liquid waste										−2.9	−2.8	−5.8			
Solid waste	−15.6	−15.0	−10.0			−9.0	−8.4	−9.0	−8.7	−3.0	−2.6	−3.3	−3.0	−9.6	−9.0
2.4. Aesthetic															
Landscape	−2.7	−10.8		−3.6										−8.4	−10.0
3. SOCIO-ECONOMIC															
3.1. Economy															
Employment	5.1	5.1		2.3				6.0		1.9	1.8				
3.2. Social															
Health and security occupational	−4.4	−15.0	−27.2	−11.2	−10.4			−13.8	−3.1	−3.3	−2.3	−2.3			
Health and safety for tourists				−8.8											
Travel experience				20.8											
TOTAL IMPACT FOR ACTION (EIU)	−82.6	−43.2	−37.2	−36.7	−10.4	−18.8	−17.0	−16.8	−17.7	−12.0	−10.4	−18.3	−6.2	−18.0	−19.0

Table 8 Impacts over environmental factors

Environmental factors		ICE		EE	
		Impact on factor	Impact on nvironment	Impact on factor	Impact on environment
BIOTIC	Flora and Fauna	- 140.2	- 140.2	- 37.3	−37.3
ABIOTIC	Water	- 276.3	- 747.4	- 74.4	−268.2
	Air	- 174.6		- 40.6	
	Soil	- 250.1		- 117.7	
	Aesthetic	- 46.4		- 35.5	
SOCIO-ECONOMIC	Economic	29.2	- 135.7	22.2	.58.8
	Social	- 164.9		- 81.0	
TOTAL IMPACT		- 1023.3	- 1023.3	−364.3	- 364.3

The results obtained in this research exposed qualitative and quantitative factors, which allow having a comprehension of the potential environmental issues. These results allow affirming that it is evident that the change of technology is beneficial for the care of the environment and the preservation of the Galapagos Islands.

4 Conclusions and Recommendations

An assessment of the environmental effects of a potential conversion from internal combustion engines to electric motors was developed. This research found that the most convenient methodology for fulfilling the requirements was the cause-effect matrix developed by Leopold et al. (1971), as it allowed to insert environmental factors and apply them for obtaining the impacts assessment of a potential implementation of electric motors in marine transport activities.

Similarly, in order to reduce subjectivity in the chosen methodology, it was established that the method developed by Conesa (2009) is highly relevant for determining the importance of each environmental issue, since it considers several attributes for characterization and establishes a scale of marks for each one of them. Regarding the necessity of quantifying the magnitude, the method of the panel of experts was found appropriate; it was composed of specialists in the field and the study area. They sought unifying criteria from several points of view and ended in a consensus figure.

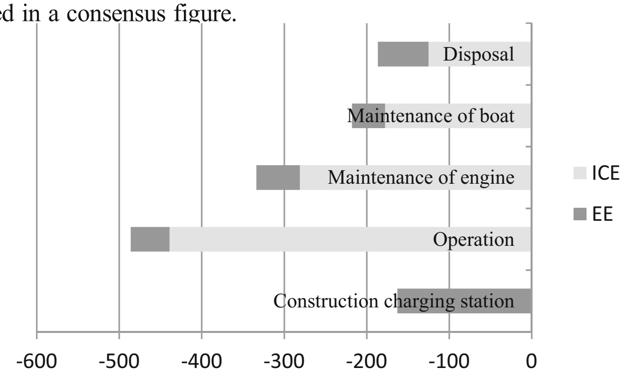

Fig. 3 Environmental impact for ICE and EE activity

After the evaluation of the socio-environmental impacts for comparing both propulsion technologies, it was determined that EE would generate 2.8 times less impact to the local environment. This could be achieved due to the significance of air and water pollution reduction. EE would generate null emission of gaseous and particulate matter of combustion; moreover, the alteration of water and soil would be reduced due to neglecting fuels and oils of the operation. EE would cause less negative impacts on the marine biota and habitat, as well as an improved travel experience for both tourists and boaters whose health risks would be minimized.

The environmental management plan proposed in this study for the insertion of the new propulsion model establishes a group of measures that would collaborate directly and indirectly to the conservation and maintenance of the ecosystem quality. Moreover, they could be replicated and adapted to the existing similar boats and future projects. The introduction of the electric motor as the propulsion technology for the small-scale ships represents innovation and development in several ways, such as charging stations implementation and innovation in fleets. These advances would be used as reinforcement measurements of maritime transport with highest standards of environmental quality.

From these results, the Environmental Management Plan can be set. This research approached the activities development applicable to the maritime transport scenario with electrical motors. The Environmental Management Plan contemplates a set of impacts prevention and mitigation tasks, a waste management, training, contingency measurements definition, an occupational safety plan and a waste disposal procedure.

References

Antal M, Van den Bergh JC (2013) Macroeconomics, financial crisis and the environment: Strategies for a sustainability transition. Environ Innov Soc Trans 6:47–66. https://doi.org/10.1016/j.eist.2013.01.002

Canter LW, Kamath J (1995) Questionnaire checklist for cumulative impacts. Environ Impact Assess Rev 15(4): 311–339

Cashmore M (2004) The role of science in environmental impact assessment: Process and procedure versus purpose in the development of theory. Environ Impact Assess Rev 24(4):403–426. https://doi.org/10.1016/j.eiar.2003.12.002

Danulat E, Edgar GJ (Eds.) (2002) Reserva Marina de Galápagos: línea base de labiodiversidad. Fundación Charles Darwin and Servicio Parque Nacional Galápagos, Santa Cruz, Ecuador. Available online at: http://www.darwinfoundation.org/files/library/pdf/RMG-Linea-Base-Bio.pdf. (in Spanish)

Clark BD, Gilad A, Bisset R, Tomlinson P (2012) Perspectives on Environmental Impact Assessment: Proceedings of the Annual WHO Training Courses on Environmental Impact Assessment, Centre for Environmental Management and Planning Springer Science & Business Media

Conesa V (2009) Guía Metodológica para la Evaluación del Impacto Ambiental (cuarta ed.). Ediciones Mundi-Prensa, Madrid (in Spanish)

Espinoza GA (2002) Gestión y fundamentos de evaluación de impacto ambiental. BID/CED

Faour G, Fayad A (2014) Water environment in the coastal basins of Syria - assessing the impacts of the war. Environ Process 1(4):533–552. https://doi.org/10.1007/s40710-014-0043-5

Fernández-Vítora VC (2009) Guía metodológica para la evaluación del impacto ambiental. Mundi-Prensa Libros, Madrid (in spanish)

Glasson J, Therivel R, Chadwick A (2012) Introduction to Environmental Impact Assessment, Fourth Edi. Routledge, New York

Greig LA, Duinker PN (2011) A proposal for further strengthening science in environmental impact assessment in Canada. Impact Assess Proj Apprai 29(2):159–165

Leopold LB, Clarke FE, Hanshaw BB, Balsley JR (1971) A Procedure for Evaluating Environmental Impact. Geological Survey Circular 645, U.S. Geological Survey, United States Department of the Interior, Washington D.C.

Martínez-Gómez J, Ibarra D, Villacis S, Cuji P, Cruz PR (2016) Analysis of LPG, electric and induction cookers during cooking typical Ecuadorian dishes into the national efficient cooking program. Food Policy 59:88–102. https://doi.org/10.1016/j.foodpol.2015.12.010

Mexiquense EC, González ME, Luís A, Peralta Gallegos JC, Troyo Diéguez E, Ortega Rubio A (2006) Evaluación de impacto ambiental del sector eléctrico en el norte de México. Evolución histórica e implicaciones para la sostenibilidad 6:219–263 (in spanish)

Morgan RK (2012) Environmental impact assessment: the state of the art. Impact Assess Proj Apprais 30(1):5–14

Muñoz M, Herrera I, Lechón Y, Iglesias Martínez E (2015) Life Cycle Sustainability Assessment of electricity from Straight Jatropha Oil Ecuadorian case. 7th International Conference on Life Cycle Management. Bordeaux 2015, August 30–September 02. 1

Petts J (1999) Handbook of Environmental Impact Assessment Volume 2: Environmental Impact Assessment in practice: Impacts and limitations. Black Science

Pinto R, da Conceição Cunha M, Roseta-Palma C, Marques JC (2014) Mainstreaming sustainable decision-making for ecosystems: integrating ecological and socio-economic targets within a decision support system. Environ Process 1(1):7–19. https://doi.org/10.1007/s40710-014-0006-x

Sengers F, Raven R (2015) Toward a spatial perspective on niche development: The case of Bus Rapid Transit. Environmental Innovation and Societal Transitions 17:166–182

Uherek E, Halenka T, Borken-kleefeld J, Balkanski Y, BerntsenT BC, Gauss M, Hoor P, Juda-Rezler K, Lelieveld J, Rypdal K, Schmid S, Melas D (2010) Transport impacts on atmosphere and climate: Land transport. Atmos Environ 44(37):4772–4816

Viana M, Hammingh P, Colette A (2014) Impact of maritime transport emissions on coastal air quality in Europe. Atmos Environ 90:96–105

Villacís S, Martínez J, Riofrío AJ, Carrión DF, Orozco MA, Vaca D (2015) Energy efficiency analysis of different materials for cookware commonly used in induction cookers. Energy Procedia 75:925–930. https://doi.org/10.1016/j.egypro.2015.07.252

Villacreses G, Gaona G, Martínez-Gómez J, Jijón DJ (2017) Wind farms suitability location using geographical information system (GIS), based on multi-criteria decision making (MCDM) methods: The case of continental Ecuador. Renew Energy 109:275–228. https://doi.org/10.1016/j.renene.2017.03.041

Wathern P (2013) Environmental Impact Assessment: Theory and Practice. Routledge. Taylor & Francis, London and New York, pp 1–332