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Methodology for the sustainability assessment of marine technologies

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ABSTRACT

This contribution presents an integrated quantitative approach for the holistic assessment of the sustainability of technologies. The methodology envisages environmental, economic and social sustainability assessments separately, then collates them to obtain a single measure of sustainability. Standard life cycle assessment and economic evaluation methods are used to provide quantitative measures for environmental and economic parameters. A new method is used to evaluate the social sustainability, enabling the quantitative integration of all three indices. Individual indices are developed and combined to provide a single performance index of sustainability. This particular tool allows technology stakeholders to incorporate sustainability principles to their design and operation activities. It provides also a benchmark platform for comparing various technologies from a sustainability standpoint.

1. Introduction

Since the Brundtland Report was published originally in 1987, defining sustainable development as a common approach that seeks the protection, throughout generations, of human and environmental well-being (WCED, 1987), more than 300 definitions have emerged (Johnston et al., 2007). Lozano (2008) has presented an extensive discussion relating to the diversity of the approaches considered, during past decades, to represent sustainability. The work culminates by proposing the need to consider an holistic three-dimensional understanding of sustainability. This approach combines, essentially, the integrational (i.e. integration of environmental, economic and social aspects, together with the interactions between them) and the intergenerational (interactions between the short-, long, and longer-term) perspectives in a Two-Tiered Sustainability Equilibria.

Furthermore, whilst the 20th Century has been characterised by the debate on the meaning of sustainable development and sustainability, the trend presently seems to be directed towards redefining the concept of sustainability with a pragmatic approach (Kates et al., 2005; Ayre and Callway, 2005), such as with (a) common strategies (Goodland, 2002), (b) principles (Johnston et al., 2007; Adams, 2006; ICPG, 2003; Vanclay, 2003; Burdge, 2004), (c) assessing the sustainability of products through assessment methodologies (Pope et al., 2005; Gibson, 2005; Pearce, 2008; Tugnoli et al., 2008), or (d) designing sustainable products following sustainable principles within the product design stage (Bhamra et al., 1999; Bhamra and Lofthouse, 2007), also known as Design for Sustainability.

Presently, there is an increasing interest in sustainable products and it is becoming clear that a major shift towards sustainable production and consumption is essential in a competitive market. According to some authors, sustainable products are more marketable and may show economic advantages (Sherwin, 2004; Armstrong, 1997). Nevertheless, there has been very little evidence of a widespread opportunity for this holistic thinking in the commercial design industry (Bhamra and Lofthouse, 2007). Some of the reasons for this limited success in implementation are that the terms "sustainable" and "sustainable development" are still only vaguely defined (Johnston et al., 2007; Klöpffer, 2003).

Abbreviation: BAMES, Social sustainability assessment tool (see Cabezas-Basurko, 2010); DALY, Disability-Adjusted Life Years. Number of years lost due to ill-health, disability or early death as a result of environmental pollution; El-Chem, electro-chemical treatment; HAS, holistic ASsessment tool (see Cabezas-Basurko, 2010); IMO, International Maritime Organization; LCA, life cycle assessment; LCC, Life Cycle Costing; MJ, Surplus of energy in Mega Joules. Energy requirement for future extraction of these resources (minerals and fossil fuels); PAFm2yr, Potentially affected Fraction of species, multiplied by the area and time; PDFm2yr, Potentially Disappeared Fraction multiplied by the area and time; Pt, Eco-points of Eco-Indicator99 impact assessment method. One Pt represents one-thousandth of the yearly environmental load of one average European inhabitant; UV, ultra-violet treatment; WHO, World Health Organization.

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Likewise, there is a lack of an international agreement to utilise sustainable metrics (Hutchins and Sutherland, 2008; Lozano, 2008).

Regarding the maritime industry, discussion and research on sustainability has had little impact until recently. It was not until the beginning of the 21st Century that the representatives of the International Maritime Organization (IMO) publicly, amongst others, established the direction and goals to be achieved for a sustainable future for the maritime industry (MCA, 2005a; Mitropoulos, 2005; EC, 2001). Large shipping companies and stakeholders have responded also by including environmental protection and sustainability in their corporate agendas. Nevertheless, the absence of any clear guidelines, experiences, together with the conflicting criteria for sustainable marine technologies, results in confusion for marine designers and operators.

By introducing a quantitative and holistic approach, this contribution is an attempt to address some of these challenges, using a simply structured and flexible procedure. The development of a single methodology is attempted; this is integrated into a computing tool to assess, model and integrate all the dimensions of sustainability (environmental, economic, and social) for marine technologies. This research aims to guide marine technology designers and operators towards embracing sustainability principles in their activities (i.e. in the early stage of the product design, within the selection of alternative production processes or within the operation stage of the technology), to achieve a more sustainable future for the marine industry.

2. Sustainability assessment

Traditionally, life cycle methods have been considered for evaluating sustainability in engineering; these being mainly the Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and the Social Life Cycle Assessment (Klöpffer, 2003; UNEP, 2009; Dreyer et al., 2006). Nonetheless, there are additional methods available such as the Global Reporting Initiative or Corporate Social Responsibility (Hutchins and Sutherland, 2008; GRI, 2006); there are used to engage and drive a company, project or policy's effort towards presenting a more sustainable future (Lozano and Huisingh, 2011). According to Charter and Tischner (2001) the design for sustainability involves a change in behaviour and purpose: (i) guaranteeing a reduction in environmental impacts by reducing the consumption of materials and energy; (ii) selecting lower impact materials, or energy options; (iii) incorporating socioeconomic dimensions of sustainability into the design, thereby producing a positive impact on the health and productivity of workers. The assessment of sustainability of a product design, or a new alternative design is, therefore, the core element to optimise the design from the sustainability point of view.

The limitation of the available methodologies, to assess the sustainability of marine technologies, has initiated the development of a specific sustainability assessment methodology within a maritime context, centred mainly upon onboard technologies.

The proposed methodology is divided into eight steps: Step 1 – *Scope*; Step 2 – *Identification of vectors*; Step 3 – *Data collection*; Step 4 – *Assessment*; Step 5 – *Modelling*; Step 6 – *Indices*; Step 7 – *Weighting*; and Step 8 – *Decision-making*. The first five steps are applied independently to every sustainability dimension and to each targeted system, or technology. Three independent sustainability indices will be obtained in Step 6 as an outcome of the previous five steps, each representing a sustainability dimension performance. These indices may be weighted then in Step 7, following present policies which create a global sustainability numerical indexing. In Step 8, these outcomes are compared to the requirements and goals set by the user in Step 1; hence, decisions will be made in this step to select the most sustainable alternative for the sought-after goals. The methodology is represented graphically in Fig. 1 and is described below, in more detail:

2.1. Step 1. Define the scope of the study (scope)

Assessing the sustainability level of a technology is a complex procedure. There are many considerations, each of which plays a part in the process and assessment of the sustainability for the whole life cycle of that technology. This approach requires that every single parameter, system or procedure which comprises a technology, should be evaluated. On occasions, the main objective for assessing the sustainability of a technology is to compare two different technologies which are part of a larger system (such as a ship). For instance: to decide whether or not to install a diesel-fuelled engine, as opposed to a heavy-fuel oil powered engine; to use intermodal transportation, as opposed to using waterborne transportation throughout; or to bring ballast water ashore for treatment, instead of installing ballast water treatment equipment onboard.

Therefore, the first step is to define the objectives to be achieved by the study and the technology to be considered. This step should include the information regarding the system description and the characteristics of the technology, as well as the system boundaries, limitations, and assumptions that are to be considered within the study.

2.2. Step 2. Identification of impact vectors

The second step is to analyse each technology/system from the life cycle perspective to accordingly: identify the vectors (variables and parameters), that may create an impact on the environment; change the safety level onboard; and impose additional costs during the entire life cycle period.

2.3. Step 3. Data collection (inventory)

The third step is to compile data referring to the vectors identified in the previous step. The most common tool for social data collection is a questionnaire. Collecting sufficient and quality data is crucial, if realistic research is sought. Furthermore, the data must be as wide-ranging and as complete as possible, in order to foresee potential unexpected circumstances.

2.4. Step 4. Assessment of inventory (assessment)

Once data are collected, the user can proceed to evaluate the data using a combination of different impact assessment methods, together with a set of indices and indicators. This approach permits an understanding of the magnitude of the impact. There are several impact assessment methods available presently; however, the majority of these fail to address the sustainability of marine-related technologies (Cabezas-Basurko, 2010; Fet and Sørgård, 1998).

The most widely-accepted and utilised method, to assess environmental sustainability of a product or process, is the LCA. It is used also as part of an environmental management tool to improve the environmental footprint of enterprises such as the environmental management systems (Fet, 1998); likewise, in projects of other scales such as the Environmental Impact Assessment, which assess all environmental and social aspects of a project's action before authorisation is given to its development (Glasson et al., 2005).

Regarding economic sustainability, the normal procedure used in industry to analyse costs of a product is to adopt financial methods, such as cost-benefit analysis, Life Cycle Costing (LCC) or