Life Cycle Assessment of an Autonomous Underwater Vehicle. ENDURUNS Project Case

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Abstract. The use of the autonomous vehicles for marine and submarine works has evolved considerably in the last decade. The appearance of new imaging, navigation and communications technologies allow large operability possibilities. The Autonomous Underwater Vehicles are used currently for several offshore missions and applications. There exists some innovative purposes in the line of the sustainable development and green energy mobility. ENDURUNS project is an European research initiative in the framework of "Horizon 2030" with the aim of seabed survey. The novelty of this project is the use and implementation of renewable energy (Hydrogen Fuel Cell) for the underwater vehicle developed, achieving the zero emissions objective. This paper analysed the product environmental management using the Life Cycle Assessment methodology, ISO 14040. This analysis reports different values of Damage and Environmental Impact. The Eco-Indicator 99 method is employed with the SimaPro software. The results obtained from the analysis are used to evaluate the Life Cycle environmental impact.

Keywords: ENDURUNS project · Autonomous underwater vehicle · Renewable energies · Sustainable development · Life cycle · Environment impact

1 Introduction

In the last few years, these vehicles have been improved by the automatization and robotization upgrades achieving the challenge to be unmanned vehicles, called Autonomous Underwater Vehicles. These innovations preserve away the submersion risks for the driver, or operator, during the missions. There are interesting reviews in this field with historical and technical notes in references [1, 2]. ENDURUNS project develops this objective with the financial support from the European Commission into the "Horizon 2020" programme [3]. Thus, the project is framed in a global movement around the oceans survey and maritime mobility interest.

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To measure the impact of this project in terms of sustainability and environment impact, it is required the Life Cycle (LC) description and Life Cycle Assessment (LCA) evaluation. Thereby, it takes in account the normativism and policies that this study requires. The ISO 14000 series describes the most relevant aspect of the LC issues.

The rest of the paper is presented as follows: In Sect. 1, it is described the state of art and methodology background for this study. In Sect. 2, it is detailed the Life Cycle Assessment (LCA) developed for the ENDURUNS AUV. In Sect. 3, it is presented the most representative results evaluating them. Finally, in Sect. 4, it is resumed the main conclusions of this work.

2 Methodology Fundaments

The LC study can be developed at different levels of complexity depending on the stages included itself. The complete LC are defined from the initial of the product until the dismantling and recycled, completing the ecological loop called as cradle to cradle, as it is described in [4]. Figure 1 shows the graphical LC representation of the ENDURUNS case of study for the AUV, composed by six stages. However, there exist different levels to simplify the study, e.g., the cradle to gate approach, which is focused only in the manufacturing process as it is resumed in [5].

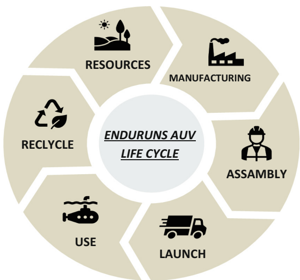

Fig. 1. ENDURUNS AUV life cycle stages

The contribution of a product to the contamination is determined by the emissions and environmental damage produced during its LC [6, 7]. In Europe, it is used the European Conformity (CE) and Environmental Product Declaration (EPD) certificates. EPD is a certificate that provides relevant, verified, quantitative, and comparable information about the environmental impact of a product [8, 9]. The LCA framework is structured in four interconnected phases [10]: Goal and Scope Definition (Phase 1); Inventory analysis (Phase 2); Impact Assessment (Phase 3), and; Interpretation (Phase 4) [11].

3 Life Cycle Assessment for ENDURUNS AUV

The framework of the LCA describes four well-defined phases to accomplish a successful study. However, this is a theoretical assumption. Certain stages of the UAV LC like assembly, launch or product use represents individual altogether contributions, while the AUV are decomposed in its different components. Thus, the simulation case defines the cradle to grave study.

3.1 Objective, Scope and Definition

This phase defines the aim, scope, and context of the study. The LCA developed for the ENDURUNS AUV implies a deep analysis of the LC processes and subprocesses until the product retirement [12, 13]. The scope of this study corresponds to the Cradle to Grave LC stages, in this case: the manufacturing processes of each AUV component, the assembly process, the launch and the set-up operation, the use implications during the AUV life and, finally, the end of life, or dismantling process [14, 15]. To develop this study, it has been considering the information obtained from the project updates. The most intensive and complex subprocess evaluated is the components of the UAV [16]. The prototype it shown in Fig. 2.

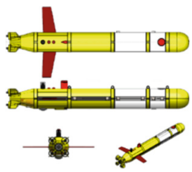

Fig. 2. ENDURUNS AUV prototype

It is possible to observe the modular character of the UAV: propulsion, mapping, energy, and buoyancy parts. This configuration contributes to the UAV versatility, allowing future modifications in function new mission requirements [17, 18]. This fact supposes a positive point in the sustainability field. Finally, the results obtained from the model are useful for the environmental analysis of the project, helping to evaluate the emissions and wastes generated, contributing with the sustainable optimization that it is purposed in ref. [19].

3.2 Inventory Analysis

This phase tries to resume and quantify the inputs and outputs involved in the LC processes and stages. These flows correspond with the raw materials, energy use and waste generation along the product LC, as it is described in ref. [20]. This part of the study needs a great volume of data. The use of the SimaPro software brings the workspace to develop this process and storage all the information. The system boundary of the product is represented by the square dotted line, leaving aside the materials extractions. Each process of the product LC defined previously must be added to the software model. It is possible to divide the inventory into the different processes, including the individual flows on them.

Table 1. Eco-Indicator 99 results for ENDURUNS USV

Damage Cat.		Human health (DALY)						Ecosystem quality (PDF*m^2year)			Resources (MJ)	
Impacts		Carcinogens	Resp. organics	Resp. inorganics	Climate change	Radiation	Ozone layer	Ecotoxicity	Acidification	Land use	Minerals	Fossil fuels
Product life cycle processes	Manufacturing	4,23E−3	2,13E−6	3,05E−3	4,13E−4	4,88E−6	1,99E−7	1,02E4	52,9	1,35E3	564	1,72E3
	V. assembly	1,82E−4	5,37E−8	1,13E−4	3,64E−5	6,88E−7	1,15E−8	495	3,05	59,2	13,3	146
	Set Up	4,57E−6	1,95E−8	7,84E−5	2,55E−5	7,16E−7	3,05E−8	11,6	1,97	1,21	0,29	82,1
	Launch	2,08E−5	7,64E−7	1,45E−3	1,05E−4	9E−7	8,89E−8	304	60,3	8,42	3,87	821
	Use	3,45E−4	4,48E−6	1,17E−3	6,16E−4	5,15E−6	9,25E−7	693	31,1	160	33,9	1,42E4
	Maintenance	1,75E−5	5,73E−7	1,08E−3	7,65E−5	5,99E−7	6,31E−8	231	45,1	6,96	2,99	609
	Dismantling	−4,4E−4	2,56E−7	6,51E−4	3,51E−5	2,43E−7	2,9E−8	806	20	1,93	−97	287
	Recycling	2,61E−4	−5,8E−8	−5,2E−5	1,56E−5	1,68E−7	1,6E−8	2,62E3	−0,6	3,28	5,24	39,3
	Partial sum	4,62E−3	8,21E−6	7,53E−3	1,32E−3	1,33E−5	1,36E−6	1,54E4	214	1,59E3	526	1,79E4
	Total	0,0135						3340			1840	

3.3 Impact Assessment

Following the guidelines of the UNE-EN-ISO 14040:2006, there exist several methodologies developed to measure the environmental impact, among the most popular: Recipe, IMPAC 2002+, Eco-Indicator 99, EDP or ILCD [21, 22]. In this paper, it has been applied the Eco-Indicator 99 method to evaluate the ENDURUNS AUV case. Table 1 shows the numerical results obtained.

This methodology was developed by Mark Goedkoop, with the PRè-Consultans team collaboration, to avoid the weighting step issues arising from the ISO 14040 [23]. SimaPro software brings also a clear graphical representation of the LCA results.

3.4 Interpretation

This phase of the LCA intended to provide a resume of the results and outcomes from the method. The interpretation of these values allows the analysis of the product contamination grade. In this case, it is obtained a preliminary and estimated evaluation of the ENDURUNS project AUV.

4 Conclusions

Research initiatives as ENDURUNS project, in the framework of "Horizon 2020" by the European commission, requires a detailed Life Cycle Assessment due to its eco-design character. The autonomous underwater vehicle developed in the ENDURUNS project features with a hydrogen fuel cell as energy source. Thus, the conclusions derived from the study can be employed as environmental impact auditory. The main conclusions are resumed in the following points:

- The Damage Categories numerical results allows to detect the higest values of each enviromental impact and life cycle process.
- The contribution of each process of the life cycle is measurable.

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