LCA APPLIED TO ECO DESIGN: A COMPARISON BETWEEN RESULTS FROM A RIGOROUS CRADLE-TO-GRAVE ASSESSMENT AND SOLIDWORKS SUSTAINABILITY TOOL

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Abstract: Life Cycle Assessment (LCA) applied to Ecodesign is essential for guiding sustainable design decisions and allows the identification and opportunities of environmental improvement from the early stages of product development. This study aimed to compare the results of carbon footprint between a rigorous LCA and the use of SolidWorks Sustainability tool in the context of Ecodesign for a camera housing produced by Additive Manufacturing using the Multi Jet Fusion technology and the polyamide 12 (PA 12) material. According to the results, the values for SolidWorks Sustainability were 42% higher compared to the rigorous LCA study, with the main contribution from impacts related to electricity production. The main limitations of using this tool were identified and discussed.

Keywords: Sustainable design; Additive manufacturing; LCA

ANÁLISE DE CICLO DE VIDA APLICADO À ECODESIGN: Uma comparação de resultados entre uma análise rigorosa e da ferramenta SolidWorks Sustainability

Resumo: A Avaliação do Ciclo de Vida (ACV) aplicada ao Ecodesign é essencial para orientar as decisões de projeto sustentável e permite a identificação e oportunidades de melhoria ambiental desde os estágios iniciais de desenvolvimento do produto. Este estudo teve como objetivo comparar os resultados da pegada de carbono entre uma ACV rigorosa e o uso da ferramenta SolidWorks Sustainability no contexto do Ecodesign para um abrigo de câmera produzida por Manufatura Aditiva utilizando a tecnologia Multi Jet Fusion e o material poliamida 12 (PA 12). De acordo com os resultados, os valores do SolidWorks Sustainability foram 42% maiores em comparação com o estudo ACV, com a principal contribuição dos impactos relacionados à produção de eletricidade. As principais limitações do uso dessa ferramenta foram identificadas e discutidas.

Palavras-chave: Design sustentável; Manufatura aditiva; ACV

1 INTRODUCTION

Ecodesign can be defined as the design and development of products focused on reducing their environmental impact throughout their entire lifecycle [1]. Pressure for the adoption of ecodesign has been growing following the global trend for decarbonization and sustainable development, which has posed a challenge to all sectors of society, including manufacturing [2].

Life Cycle Assessment (LCA) [3,4] is the methodology usually used to quantify environmental impacts of products. The analyses require substantial resources, especially for data collection, and provide essential information to guide product development, such as hotspots and opportunities within the product system to reduce impacts. However, this type of analysis is usually done after product design, when all its parameters have already been defined.

Ecodesign tools were developed to address this issue, such as the SolidWorks Sustainability, which is a tool integrated into the CAD software that provides dynamic feedback on life cycle environmental impact factors of a product during design [5]. The analysis includes all product lifecycle steps: ore extraction from the earth, material processing, part manufacturing, assembly, product usage, end of life, and transportation services [6], however, it does not provide any documentation on data used for calculation. To check whether if results follow an LCA approach, they need to be compared with a comprehensive LCA for the same product.

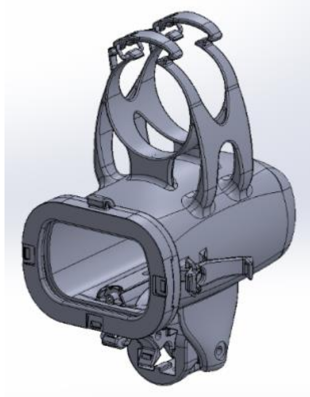
Based on this context, this study aimed to compared results of environmental impacts from a rigorous LCA study and SolidWorks Sustainability, with the purpose to identify any discrepancies and discuss the use of this particular simplified LCA tool.

2 METHODOLOGY

2.1 Project

To conduct a comparative analysis of the environmental impacts throughout the life cycle of a product, we selected a camera housing as our study case (Figure 1). This component serves as a prototype for robotic tools designed for subsea operations and was produced using an additive manufacturing (AM) technology known as HP Multi Jet Fusion (MJF), with polyamide 12 (PA-12) as the primary material. It was design to hold a MultiSense S7 camera with a support structure for a BlueView M900 sonar device, for subsea pressure conditions up to 6 bar.

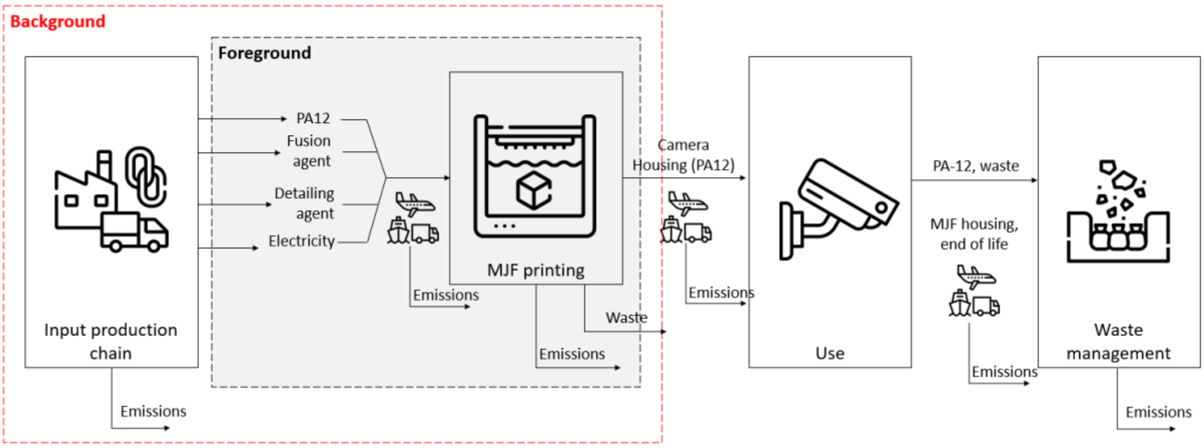
Figure 1. Camera housing 3D model and its main properties

	Properties
	• Material: Polyamide 12 powder • Manufacturing method: HP MultiJet Fusion • Total weight: 1,84 kg • Estimated lifespan: 1 year

2.2 Rigorous Life Cycle Assessment

The LCA of the camera housing followed the methodology outlined in ISO 14040 and ISO 14044. This approach encompasses several stages, including (i) objective and scope definition, (ii) inventory analysis, (iii) life cycle impact assessment, and (iv) interpretation of results. The LCA adopted an attributional modeling approach, considering a cradle-to-gate boundary, which excludes the use and final disposal phases of the analysis. The software OpenLCA version 2.0 was used to calculate results for impact assessment and uncertainty analysis. The product system considered can be seen in Figure 2. The declared unit used for the assessment was one (01) camera housing.

Figure 2. Product system



The AM process was done by a HP MJF 5210 printer with a maximum chamber capacity of 41 L (380 mm x 284 mm x 380 mm), which uses PA-12 powder, fusion and detailing agents as main inputs, as well as electricity (medium voltage). Packing density (volume of printed parts divided by total building volume) for a full build chamber was assumed to be 10 % according to values provided by the manufacturer [7]. Plastic waste generated during the process was assumed to be managed through landfilling. Additionally, the printed parts undergo a cleaning process through sandblasting, which requires electricity and generates plastic waste (around 10 % of the total part weight). A comprehensive overview of the inputs and outputs associated with the MJF process can be found in Table 1. Given the lack of Life Cycle Impact Assessment (LCIA) data for PA-12 powder production, data for polyamide 6 was used instead, which is a common premise applied in LCA studies with a focus on additive manufacturing [8,9].

For this study, a cutoff rule of <1% of the total mass and energy inputs/outputs was applied, and a physical criterion was used to allocate impacts between the camera housing and the other printed parts. Data for foreground processes were collected directly from the Bureau of AM of CIMATEC Park. The Ecoinvent database version 3.8 [10] was used for the background processes.

Table 1. Inventory to produce one camera housing by MJF

Item	Value	Unit	SD^2_g	Intermediate and elementary flows in Ecoinvent v3.8
Input				
Nylon 6	3,35	Kg	1,306	market for nylon 6 | nylon 6 | APOS, U
HP detailing agent	0,04	Kg	1,306	-
HP fusion agent	0,05	Kg	1,306	-
Electricity	60,91	kWh	1,306	market group for electricity, medium voltage | electricity, medium voltage | APOS, U
Transport, truck	14,73	t.km	2,029	market for transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5 | APOS, U
Transport, container ship	43,82	t.km	2,029	market for transport, freight, sea, container ship | transport, freight, sea, container ship | APOS, U
Output				
Reference product				
Camera housing	1,84	Kg	-	-
Waste				
Waste, plastic	1,51	Kg	1,306	treatment of waste plastic, mixture, sanitary landfill | waste plastic, mixture | APOS, U

2.3 SOLIDWORKS Sustainability tool

The Sustainability tool (Figure 3) provides environmental impact results for a specific part designed in the SOLIDWORKS software based on parameters that need to be previously defined in its task pane. The input data includes all product phases from a life cycle perspective, and are classified in: Material, Manufacture, Transportation (from manufacture to use phase), Use, and End of Life (EoL). Results are calculated using the CML impact assessment method, based on the GaBi LCIA database. However, it was not possible to identify either the database version or the datasets considered in the analysis. Table 2 presents the data used in the analysis for the study case.

Figure 3. Sustainability tool interface

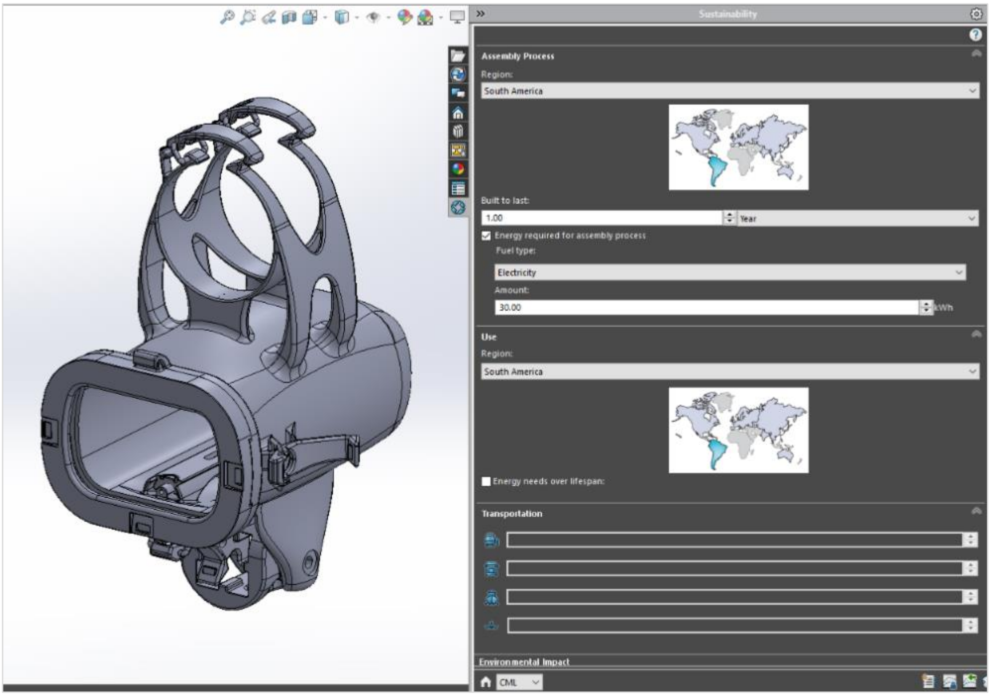


Table 2. Input data to SOLIDWORKS Sustainability

Material	
Name	PA Type 6
Weight	1.84 kg
Manufacture	
Region	South America
Process	Custom
Electricity consumption	0.03 kWh/g
Scrap rate	-
Built to last	1 year
Paint options	No paint
Transportation	
Truck	32 km
Use	
Region	South America
Lifespan	1 year
End of life	
Recycled	0%
Incinerated	0%
Landfill	100%

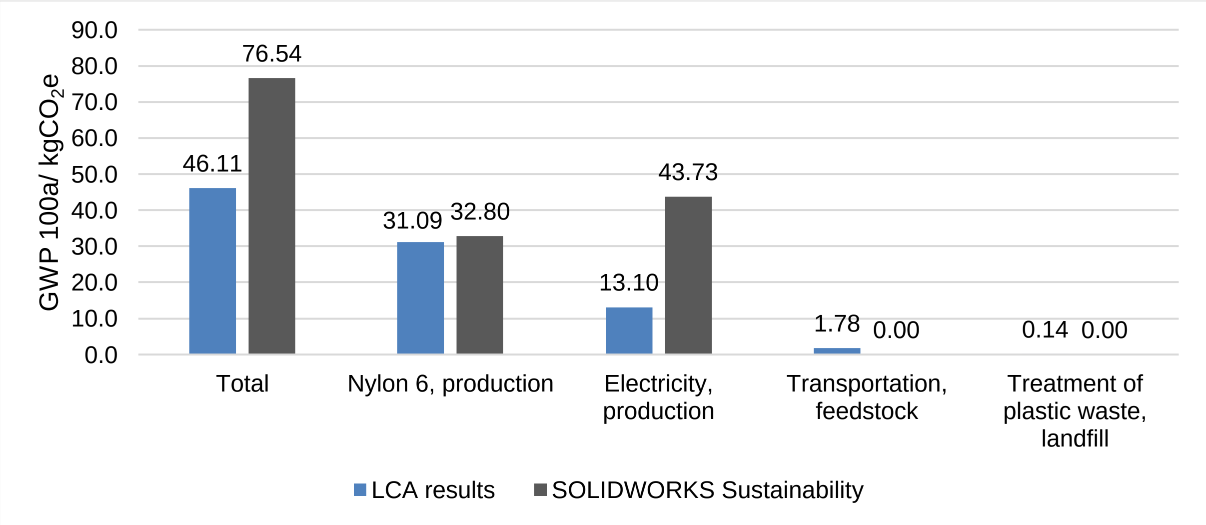
2.4 Impact category

The impact category of Global Warming Potential 100a (GWP 100a) was selected for the comparison of the assessment options considered in this study. It considers total Greenhouse Gases emissions per functional unit, and its potential effects for global warming for a 100-year period based on the characterization model proposed by the Intergovernmental Panel on Climate Change (IPCC), expressed as mass of CO_2 equivalent [11].

3 RESULTS AND DISCUSSION

The GWP results to produce one Camera Housing are shown in Figure 3, comparing a rigorous LCA with the SolidWorks Sustainability. It was possible to observe that in both assessments, nylon 6 and electricity production processes represented > 95 % of total environmental impacts for the camera housing. However, SolidWorks results are 42 % higher when compared to the rigorous LCA study, with 90 % of this relative difference being attributed to the electricity production process.

Figure 4. Comparison of results for GWP 100a impact category, divided by processes



A plausible explanation for the expressive difference in value for the carbon footprint of electricity production lies in the utilization of a regional dataset that represent the Brazilian system in the case of rigorous LCA. Brazilian energy matrix relies up to 60 % on hydropower systems [12], which are considered to have a lower carbon footprint when compared to coal or natural gas power production systems, for example [13]. Since the choice of location in the SolidWorks Sustainability was limited to macro regions, South America in this case, and it was not possible to define which datasets from the GaBi database would be used, this difference could not be mitigated.

The Sustainability tool proved to be useful as a preliminary assessment, especially by introducing life cycle thinking and environmental criteria during the design conception process in a simple and fast way, with the possibility of comparing different materials and design options. However, some limitations of its results need to be addressed:

- **Dataset information**

There is no information available of the database version used to calculate results as well as datasets for location-specific scenarios.

- **Estimation of material inputs**

Mass of input materials for the production system are calculated using the material's density and the volume of the 3D model on SolidWorks, which means that only the mass of the part is considered. This can lead to potential inaccuracies when modelling the product system. For instance, in this study case, the 3D printing of the camera housing (weighing 1.84 kg) needed approximately 3.34 kg of virgin PA12 powder when employing MJF technology. This additional calculation had to be performed separately due to the software's inability to account for it.

- **Inventory data**

Although some parameters used as inputs in the Sustainability tool can be found in the literature, detailed life cycle inventory data would still be needed to assure the reliability of results, which might not be available in this early stage of design. This contradiction has been already identified as a central limitation for many Ecodesign tools [1,2]; however, one could also argue that assumptions and data related to product use and end-of-life phase remain uncertain even when using a rigorous LCA approach [14]. The important question is how to deal with these uncertainties and to include them into account when calculating impacts, which leads to the next limitation.

- **Data uncertainty assessment**

LCA studies typically employ a quali-quantitative approach to handle data uncertainties, utilizing a Pedigree Matrix in combination with Monte Carlo simulation [15,16]. However, the Sustainability tool lacked the provision of any kind of uncertainty assessment for the calculated results. This aspect holds significant importance, especially considering its use for comparative analyses of designs under varying scenarios.

4 CONCLUSION

This study compared impact results of a rigorous LCA with SolidWorks Sustainability for a PA12 camera housing manufactured using HP Multi Jet Fusion. For this study case, energy production was the main source of the relative difference between results, which might have been caused by differences in datasets used. Main limitations of using SolidWorks Sustainability were identified as lack of information about the database used, the need to estimate material inputs based on inventory analysis, and not on the design volume,

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