Comparison of Primary Energy Consumption Between Additive Manufacturing Processes and CNC Machining Applied to Components in the Oil and Gas Sector

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This work elucidates the environmental impact on the production of components in the oil and gas sector by analyzing two different production routes. To this end, a life cycle assessment of the CNC machining process and additive manufacturing (AM) was carried out using Multi Jet Fusion (MJF) technology. Life cycle inventories were prepared for both processes, using the Open LCA software and information from the Ecoinvent database to develop the life cycle, with Cumulative Energy Demand (CED) being considered as the impact method. From the analysis, it was found that the machining process presented an energy demand of 7177 MJ. In contrast, the MJF presented 3214 MJ, less than half of the primary energy required to produce one unit of the studied component, thus indicating that manufacturing by MJF presents greater environmental sustainability than the conventional machining process.
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Introduction

The rise of Industry 4.0 and the technological development in the production sector awakened productivity linked to sustainability. This factor changed the way of analyzing the performance of the production system. Before, factors such as cost, time, quality, and flexibility were considered. However, robust global trends such as climate change have changed how performance is analyzed by including sustainability in all phases of the decision-making process.

Over the years, research into technologies that enable production with significant gains, reduced material used, improved customization, and reduced product availability time on the market has increased [1]. Thus, additive manufacturing (AM) emerged in this scenario, subsequently being considered an ally in reducing environmental impacts by generating less waste of raw materials and fewer emissions than other more traditional processes.

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For the most part, components in specific sectors, mainly oil and gas, are manufactured using conventional processes, such as machining, forging, or casting, and are often manufactured outside the country, which generates more significant costs and impacts due to imports. The choice for conventional processes is due to the reliability and maturity of the processes since most of these components are high risk. The oil and gas industry's adoption of AM makes a significant contribution to the supply chain, as manufacturing using this process can be done with little human supervision, more quickly, and using geometries considered complex [2]. Furthermore, it is possible to contribute to reducing environmental impacts during the component production process.

However, analysis of how much the replacement of conventional processes with AM applied to the oil and gas sector contributes to reducing or generating environmental impacts still needs to be explored. As a result, this work aims to investigate the environmental sustainability of AM when applied to the oil and gas sector in the production of a camera housing used in underwater robots, with specific objectives: identifying process parameters and data, carrying out assessment life cycle considering the conventional process and AM and analyzing the results found for the investigated impact method.

Materials and Methods

The work method was based on the life cycle assessment of a camera housing used on underwater robotic platforms for the oil and gas sector.

The component was produced in conventional manufacturing using the CNC machining process and in AM using Multi Jet Fusion (MJF) technology. When manufactured by machining, Al alloy 6061 was used, weighing 6.15 kg in the end and requiring 62 screws for assembly, while when produced by MJF polyamide 12 (PA 12) was used, weighing 1.82 kg in the end and requiring just 4 screws for assembly. All processing data specific to machining and AM were identified for the life cycle assessment. The cradle-to-gate range was used, considering the impacts generated from the raw material's production to the component's final production, excluding usage impacts. The life cycle inventories were modified considering the use of 28 kg of Al alloy, 0.08 kg of oil, and energy consumption of 183.2 kWh for machining a camera housing unit, while for MA by MJF. It was achieved using 4.1 kg of virgin PA 12, 16.3 kg of recycled PA 12, 0.13 kg of fusing agent, 0.09 kg of detailing agent, and an energy consumption of 73.1 kWh. The Open LCA software was used with data extracted from the Ecoinvent database, and the Cumulative Energy Demand impact method (CED) was used for the life cycle impact assessment (LCIA) to construct inventories and calculate life cycle impacts, so it is possible to obtain information on the primary energy demand linked to production.

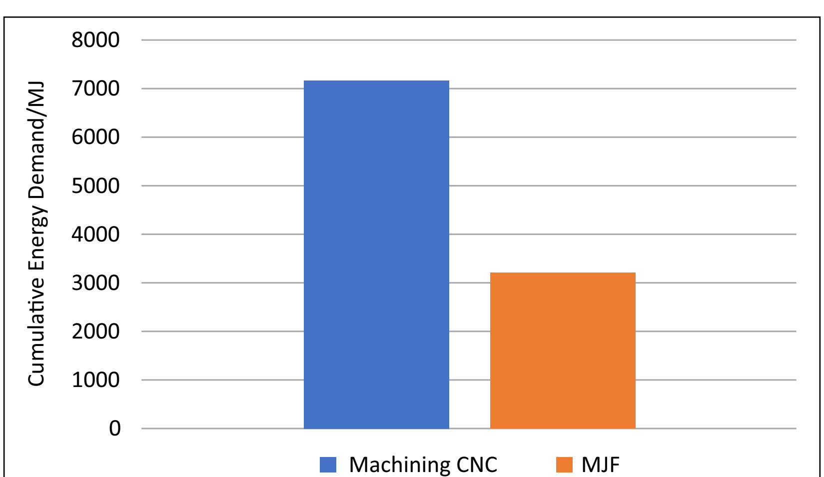
Results and Discussion

The results obtained for the CED impact method show a lower need for energy demand on the part of the AM using the MJF technology, with 7177 MJ being the energy demand of the CNC machining process and 3214 MJ the energy demand of the MJF (Figure 1). Some Studies indicate that material and energy consumption represent the most significant consumption among the processes in the component production system, which are the biggest generators of environmental impact [3].

The CED method is an indicator used as a parameter of energy efficiency and monitoring for the environmental impacts of processes. It compares the demand for primary energy when applying an LCA study [4]. Based on the result of the graph, it is clear that the technology of MJF has a lower CED impact than machining due to its more energy-efficient production process and lower material waste.

When checking the energy demand of machining, it is possible to identify aluminum production as the most significant contributor to environmental impacts, which can be justified by the fact that even though the Brazilian energy matrix is based mainly on hydroelectric plants, the aluminum alloy used is of origin primary, not presenting a reduction

Figure 1. CED category result for CNC and MJF machining.



in impacts due to the recycled portion. Figure 2 shows the percentages inherent to the production of the functional unit through machining in (a) and through MJF in (b).

On the other hand, the energy demand of the PA 12 production process, the most significant contributor to the impacts of CED by MJF, is not even more significant because its proportion of use involves 80% of reused powder, dissipating the environmental impact generated by the production of the material -cousin. The energy demand for the production of PA 12 may have a high contribution due to the powder production process having the possibility of involving precipitation or direct polymerization [5]. However, even with this factor, the energy demand of MJF for the production of the camera housing has a lower value than half of that used in CNC machining.

Final Considerations

The use of AM technologies by some sectors can generate several application advantages and, in some cases, reduce environmental impacts compared to specific processes used for years. Thinking about the greater adoption of AM by the oil and gas sector and alignment with impact reduction initiatives and frameworks with companies that care about the sustainability of their processes and activities, this study analyzed the demand for primary energy for a manufactured component by machining and by MA using MJF technology. AM, using MJF technology, generated lower impacts than CNC machining when analyzing the CED method, indicating that MJF technology is a more environmentally sustainable option than machining regarding accumulated energy demand.

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Figure 2. Percentage of participation in manufacturing processes for the CED category:(a) Participations in machining and (b) Participations in MJF.