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INFLUENCE OF REMANUFACTURING ON LIFE CYCLE STEPS: AIR COMPRESSOR STUDY CASE IN BRAZIL

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ABSTRACT

Remanufacturing is a key scenario in end-of-life (EOL) management. From Life Cycle Assessment's (LCA) point of view, means more elementary processes after the product's use phase. However, this choice affects the early steps of its life cycle, usually by decreasing demand on acquisition of raw-materials, lower need of manufacturing processes, and an addition of life time. This paper aimed to discuss the influences of the Remanufacturing Scenario on early steps of its life cycle. The methodology used was the LCA based on LCA standards. We used as study case an air compressor and compared the Remanufacturing Scenario with a Reference Scenario where the final disposal was set the equipment to a landfill. The Life Cycle Impact Assessment was performed with the software SimaPro@7.3 and CML2000 method for Abiotic Depletion and Global Warming, and Total Accumulative Energy Demand (single issue). The case study showed that the Remanufacturing as EOL Scenario is able to decrease until 47% of the impacts compared to the Reference Scenario. However, this improvement can not always represents a better environmental performance when considered a numerical balance of the impacts inside each phase.

INTRODUCTION

Remanufacturing is a key scenario in end-of-life (EOL) management of products, besides its economic benefits is a feasible option to achieve many of the goals of sustainable development. For some authors as Kerr and Ryan (2001), Guide Jr et al. (2000) and Amezcua et al. (1995) this final disposal's strategy is able to minimize the environmental impact of industry by reusing materials and consequently decreasing natural resources consumption, reducing energy use and the need to landfilling industrial products.

There are many definitions for remanufacturing, but most are variations of the same basic idea of product rebuilding. It can be understood as a process of 'restoring a product to like-new condition by reusing, reconditioning, and replacing parts'. Nowadays there are more companies that are implementing remanufacturing strategies in order to retain the accumulated value of products and components or comply with the recent laws of integrated responsibility of EOL products, as in European Union Directive 2002/96/EC on Waste



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Electric and Electronic Equipment (WEEE) and the National Policy on Solid Waste in Brazil (2010). These laws describe waste reduction in the front as first measure to ensure the sustainability, positioning the remanufacturing as preferable final destination.

From Life Cycle Assessment's (LCA) point of view, this EOL scenario means more elementary processes after the product's use phase including more inputs and outputs and new components consumption by replacement. That consequently generates more environmental impacts. Usually it is necessary some basic processes as disassembly, testing, remanufacturing (or repair) and reassembly. The logistic is also more complex, because involves the reverse flux of the EOL product to the manufacturer and then a return to the market for second use. However, this choice for waste management affects the early steps of its life cycle, usually by decreasing demand on acquisition of raw-materials (by the reuse of parts), lower need of manufacturing processes, and an addition of life time of the product that usually reflects on a positive environment impact balance.

This paper aimed to discuss the influences of the Remanufacturing Scenario on early steps of its life cycle related to the generation of environmental impacts, analysing positive and negative aspects on the major four phases in a life cycle.

MATERIALS AND/OR METHODS

The methodology used was the Life Cycle Assessment (LCA) based on the standards ABNT ISO 14040 (2009a) and 14044 (2009b) using as study case an air compressor. In order to better understand these influences we compared the Remanufacturing Scenario with a Reference Scenario composed of a life cycle without returning of the equipment to the consumer, where the final disposal was set to a landfill.

The functional unit was established by the total amount of compressed air produced during the primary operation phase, 1;180;000.00 m³ at 7.5 BAR of pressure operating for 10 years. This means a reference flux of 0.66 compressors to Remanufacturing Scenario since this final disposal scenario adds 5 years of life to the equipment and 1.00 compressor to Reference Scenario. The Use phase is therefore equalised by the reference flux and wasn't accounted on environmental impact assessment.

The Product's system was a reciprocating air compressor with electrical operation manufactured by a major metal-mechanic industry located on southern of Brazil. Once the main goal of this paper was to understand the influences of the remanufacturing on life cycle, the boundaries were positioned involving all four major life cycle's steps, from acquisition of raw materials to final disposal, with system expansion to avoid allocation when there were co-products of processes (i.e. metal scraps). As we opted for system expansion, we had positive environmental impacts associated with the avoided products.

Both, Reference and Remanufacturing Scenario starts with the acquisition of raw materials from natural resources and primary manufacturing of the components that are sent to the manufacturing line where there are manufacturing processes to built and to assemble this parts to the final product. Then the equipment is sent to the consumers where operates during ten years. Until this point, the inputs and outputs are identical but have different values because of the reference flux. After the use phase, the Reference Scenario disposes the obsolete compressor in the landfill involving reverse logistic to the landfill. Meanwhile the



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Remanufacturing Scenario has the reverse logistic to the company for entering in remanufacturing processes, that were proposed in order to guarantee a second life to the equipment, increasing in five years the original use lifetime. During remanufacturing processes, waste is generated, headed by the non-reusable components of the compressor. The destination was set to the industry foundry, recycling centers and landfilling. After its disassembly, it was assumed that the recyclable parts would be sent to the company's foundry and recyclers sites, to landfilling for non-recyclable fractions and electrical motor's devolution for its own manufacturer.

For build the inventory, primary data were collected from the company to all life cycle of the compressor, with secondary complementation by Ecoinvent Database®. The early steps of its life cycle were raised from production control, while the use phase from Testing Sector. Negative impacts related to components consumption on remanufacturing processes were considered on 'Acquisition of Raw-Materials', as well as positive impacts associated to avoided products from recycled materials. Other impacts were accounted to 'Final Disposal' phase.

The Life Cycle Impact Assessment was performed with the software SimaPro® 7.3 using the CML 2000 method with adaptations, including Total Accumulative Energy Demand (single issue). Besides this adapted impact category, we analysed Abiotic Depletion and Global Warming.

RESULTS AND DISCUSSION

The case study showed that the Remanufacturing as EOL Scenario is able to decrease until 46% of the impacts for Abiotic Depletion, 47% for Global Warming and 39% in Total Energy Demand, compared to the Reference Scenario (see 'Total' column in Table 1).

However, this improvement can not always represents a better environmental performance when considered a numerical balance of the impacts inside each phase. It is the case of the final disposal phase where although remanufacturing generates less environmental impacts considering all life cycle, this Scenario ended up increasing them to this step by 76% to Abiotic Depletion, 70% for Global Warming and 72% in Energy Demand as shown in Table 1. This behavior occurred due the increase of complexity of processes, logistics, input consumptions and output generations that overpasses the environmental gain generated by the extension of the use life time, accounted by the dilution of impacts by the reference flux. On the other way, for the Manufacturing phase the reduction is exactly 33% for the three impact categories once the EOL Scenario as Remanufacturing reduces the need of manufacturing processes in the same temporal horixonte.

Analysing the Acquisition of raw-materials' phase, the Remanufacturing Scenario reached 69% of reduction for Abiotic Depletion, 75% for Global Warming and 57% of reduction on Energy Demand compared to Reference Scenario. Negative impacts are increased by the raw materials consumed by replaced components while the original consumption of raw materials reduces 33% by the reference flux. This sum would be more impactant than the Acquisition of raw material's phase from Reference Scenario if it hadn't been considered the avoided products from recycling metals. As we considered this conception, positive impacts were associated to this recycled fractions and then to this life cycle phase.

Abiotic Depletion (kg SO ₂ eq.)				Total
LCA Phases	Acquisition of Raw Materials	Manufacturing	Final Disposal	-
Reference Scenario	3,02	0,68	0,16	3,86
Remanufacturing Scenario	0,94	0,46	0,68	2,08
Global Warming GWP100 (kg CO ₂ eq.)				Total
LCA Phases	Acquisition of Raw Materials	Manufacturing	Final Disposal	-
Reference Scenario	309,89	81,34	26,29	417,52
Remanufacturing Scenario	78,21	54,23	87,23	219,67
Total Cumulative Energy Demand (MJ eq.)				Total
LCA Phases	Acquisition of Raw Materials	Manufacturing	Final Disposal	-
Reference Scenario	7103,67	1920,21	388,18	9412,06
Remanufacturing Scenario	3077,30	1280,14	1393,77	5751,21

Table 1. Environmental impacts of the air compressor divided by LCA phases for Remanufacturing and Reference Scenarios.

CONCLUSIONS

With the results obtained with this study we can better understand the dynamic of the environmental impacts generation when applied remanufacturing as an EOL scenario. According to this scope definition and the product system used as an example, only the Final Disposal step demonstrated an increase of impacts, other all steps shown only environmental improvements, being able to reach around 46% and 47% of reduction in Abiotic Depletion and Global Warming respectively and 39% of Energy Demand when encompassed all life cycle, reinforcing the remanufacturing as better EOL scenario to sustainable development. It is also clear that changes on last life cycle step can cause different reactions to the early phases, showing the vital importance of the inclusion of the early steps at the assessment. For instance, assessing only the final disposal phase, remanufacturing would be the worst environmental scenario according to the scope in this LCA and consequently could induce to a misleading choice.

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