Assessing the environmental and economic performance of alternative car chassis

Cite as: AIP Conference Proceedings **2139**, 060001 (2019); https://doi.org/10.1063/1.5121666
Published Online: 26 August 2019

Carla L. Simões, Carlos J. Ribeiro, Pedro Bernardo, et al.

Assessing the Environmental and Economic Performance of Alternative Car Chassis

Carla L. Simões[b], Carlos J. Ribeiro[b], Pedro Bernardo[c], António J. Pontes[a,b], C.A. Bernardo[a,b,*]

[a]*Institute for Polymers and Composites - IPC/I3N, Minho University, Azurém, 4800-058 Guimarães, Portugal*
[b]*Innovation in Polymer Engineering - PIEP, Minho University, Azurém, 4800-058 Guimarães, Portugal*
[c]*Car Multimedia Portugal, S.A., Rua Max Grundig, 35, Lomar, 4705-820 Braga, Portugal*

* Corresponding author: cbernardo@dep.uminho.pt

Abstract. The main objective of this study is to evaluate the life cycle environmental and economic performance of a car multimedia chassis containing metallic parts, and compare it with new, totally plastic, chassis designs. The Life Cycle Assessment and Life Cycle Costing methodologies were applied. All systems boundaries consider material and parts production, and the use and End of Life (EoL) phases of the chassis. The results showed that the former system has a higher environmental impact, the material production being the main contributor followed by the use phase, and Fossil depletion the most burdensome impact category. All total plastic scenarios enable approximately 40% weight reduction, mitigating both the Global Warming Potential and the Cumulative Energy Demand environmental impacts until the end of the use phase. However, this result is inverted including the EoL phase, as recycling the metal is more favourable than incinerating the polymer and recovering energy. All TPC scenarios present a higher cost. Although their assembly and use phases costs are lower than the corresponding BSL ones, this does not mitigate the higher material and production costs. Again, at EoL, recycling the metal is more cost favourable. The present work evidences that to make sustainable decisions environmental and economic considerations should be concurrently contemplated in product development.

Keywords: Life Cycle Assessment; economic analysis; plastic car chassis; sustainability; automotive parts; design for environment
PACS: 81; 88

INTRODUCTION

Together with safety and performance, environmental impact reduction and cost containment throughout the complete life cycle (LC) of a vehicle are the major issues for today's automotive industry. Consequently, decisions on product development must involve technological requirements as well as economic and environmental considerations [1]–[4]. Such considerations should be assisted by adequate LC thinking-based tools, such as Life Cycle Assessment (LCA) [5], [6] and Life Cycle Costing (LCC) [7], [8].

In this context, the main objective of this study, continuing a research programme focussed on the same subject, is to evaluate the LC environmental and economic performance of a car multimedia chassis containing metallic parts (thereafter called "BSL"), and compare it with new, totally plastic, chassis designs (thereafter called "TPC").

The present work focuses on how Life Cycle Thinking, LCA, and economic assessment methodologies can be used to evaluate environmental and economic impacts of alternative production systems.

METHODOLOGY

The LCA study was done according to the ISO 14040 series procedures [5], [6] and the LCC study according to the Ciroth et al. [7] and Swarr et al. guidelines [8]. The estimation of the polymer composite components production cost was done via a Process Based Cost Model (PBCM) [9], [10].

LCA and LCC results

The target product of this study is a car multimedia chassis whose function is to protect the electrical/electronic components that compose the car multimedia solution. Its main objective is to evaluate the LC environmental and

Proceedings of PPS-33
AIP Conf. Proc. 2139, 060001-1–060001-5; https://doi.org/10.1063/1.5121666
Published by AIP Publishing. 978-0-7354-1882-0/$30.00

economic performance of the selected car chassis that will constitute the baseline platform product, and compare it with a new car multimedia chassis design (total plastic chassis). The functional unit is a car multimedia chassis unit, which meets the mechanical, thermal and electrical requirements, as defined by the client, and has a service life of 200,000 km (maximum distance driven in the expected use life of a vehicle [11], [12]). All solutions under study have the essential function of mechanically protecting the multimedia contents, while guaranteeing adequate thermal and electromagnetic shielding. All systems boundaries consider material and parts production, and the use and end of life (EoL) phases of the chassis.

The selected LC impact assessment (LCIA) method was the ReCipe Endpoint (H/A) [13]. The Energy consumption, according to the Cumulative Energy Demand (CED) method [14], and the Global Warming Potential (GWP) impact categories [14] were analysed. The goal and scope steps of the LCC study were consistent with those of the LCA. Therefore, the functional unit, system boundary and other fundamental assumptions were the same.

The new car multimedia fully polymer chassis design (TPC) is still in development by the project team (Bosch, UM, PIEP) and, thus, not yet in real production. Therefore, its LC characterization is not a final version, but rather a first approach that will be updated in the future. Hence, the definition of the LC characterization of the TPC parts and product require the formulation of some assumptions. In this study the first version, subsequently called TPC01, will be studied. Additionally, four scenarios were developed with four possible alternative materials.

All the systems have been modelled by means of the commercial ecoinvent database [15] and, whenever possible, using field data from the companies involved in the study, which were ultimately summarized in the LC inventory that was performed in SimaPro 8.04 [16]. Some data did not exist in the ecoinvent database and, hence, their inventory was collected from other sources. The carbon fibres inventory data were collected from Schmidt and Watson [17], and the glass fibres and waste treatment by incineration with energy recovery inventory data from the European LC Database (ELCD) [18]. The car multimedia chassis EoL scenarios were modelled under the following assumptions: (i) incineration, considering environmental credits due to energy recovery; and (ii) recycling, considering that production of primary metal was avoided.

An environmental LCC was selected in the present work, which considers all direct costs of the different actors intervening in the product LC. The system was modelled using market prices. In the LCC inventory the data collected were adjusted, where appropriate, to Euros 2016.

Figure 1 a) compares the BSL and the 4 TPC01 possible material scenarios, on a functional unit basis. The BSL system has a higher impact in almost all environmental impact categories, except Climate change human health, Climate change ecosystems and Terrestrial ecotoxicity. The TPC01A system depicts the worse performance in these impact categories, in the case of the latter, together with TPC01C system. Considering the 4 TPC01 possible material scenarios, the TPC01D system shows the best environmental performances in all impact categories. These results are a consequence of the different environmental impacts of the various composites reinforcements. The carbon fibre has the highest environmental impact of all the reinforcement materials, followed by the stainless steel and the glass fibres. Graphite is the reinforcement that shows the smallest environmental impact.

The LCIA normalization results of the 5 systems are shown in Figure 1b), on a functional unit basis. The Fossil depletion, Climate change human health and Climate change ecosystems impact categories are the most significant environmental burdens of all systems. Fossil depletion is more significant for the BSL system, The two other ecosystems are more significant for the TPC01A and TPC01C systems, respectively.

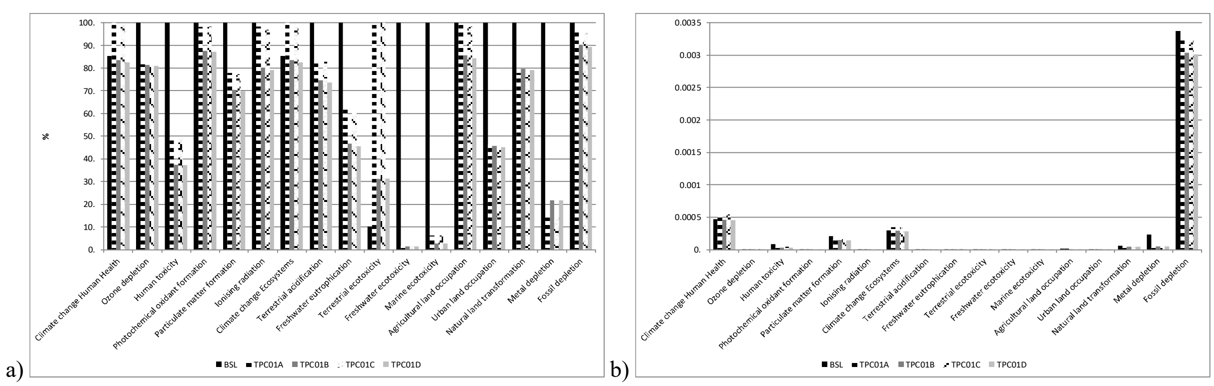

FIGURE 1. LCIA a) characterization and b) normalization results of the BSL versus TPC01 possible material scenarios, on a functional unit basis.

The single score results obtained (expressed in Eco-Indicator points (Pt)), on a functional unit basis, were 1.19 Pt, 1.13 Pt, 1.02 Pt, 1.12 Pt and 1.01 Pt, for the BSL, TPC01A, TPC01B, TPC01C and TPC01D, respectively. They are relatively close, in any case they show that, all caveats considered, the TPC01B/TPC01D systems are environmentally preferable (in circa of 15%).

Figure 2 a) shows the systems GWP characterization results, expressed as the differences between the BSL and the four TPC01 possible material scenarios, throughout their LC. These differences are presented (in the ordinate axis) as a function of the several LC phases (in the abscissa axis), each phase being represented by a line segment. All TPC01 possible material scenarios mitigate the GWP environmental impacts until the use phase, since the results have a negative value until that phase. The new concept designs (TPC01) allow achieving approximately 40% weight reduction, therefore enabling these results. These results are inverted, however, when the EoL phase is included. At EoL, recycling the metal (steel and aluminium) is more favourable regarding GWP than incinerating with energy recovery the composite, since an increase of this environmental impact category is observed (to overall positive values).

Figure 2 b) shows the systems CED characterization results, expressed as the differences between the BSL and the four TPC01 possible material scenarios, throughout their LC. Again all TPC01 possible material scenarios mitigate CED until the use phase, since the results have a negative value until that phase. However, these results are, once more, inverted when the EoL phase is included. The new concept designs (TPC01) allow achieving approximately 40% weight reduction, therefore enabling these results. It should be noted that the CED of the material production in the new designs TPC01A/TPC01C was higher than in the BSL. This was due to the fact that polymer matrix composites are produced through a more energy intensive (by unit weight) process than steel/aluminium, and the weight reduction doesn't mitigate this energy increase. At the EoL phase it was again observed that recycling the metal (steel and aluminium) is more favourable regarding CED than incinerating the composite and recovering energy, since a significant increase of this environmental impact category is observed.

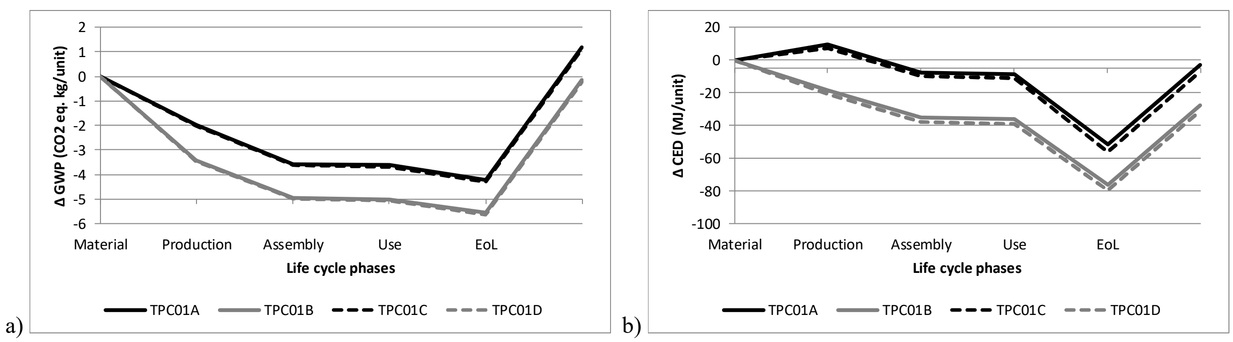

FIGURE 2. Characterization a) GWP (CO2 eq. kg/unit) and b) CED (MJ/unit) results for the difference between the BSL and the TPC01 possible material scenarios (two series are hidden by the data of the others).

Figure 3 shows the systems cost results, expressed as the differences between the BSL and the TPC01 possible material scenarios, throughout their LC. Globally, the TPC01 scenarios do not mitigate the cost impact, since their cumulative differences along the LC have a final positive value. Although the assembly and use phases costs are lower than in the BSL, this does not mitigate the higher material and production costs.

In conclusion, the new concept designs allow achieving approximately 40% weight reduction, but not cost reduction, since the polymeric composite materials have a very high price. At EoL it is again observed that recycling the metal (steel and aluminium) is more favourable regarding cost than incinerating the polymer composite and recovering energy.

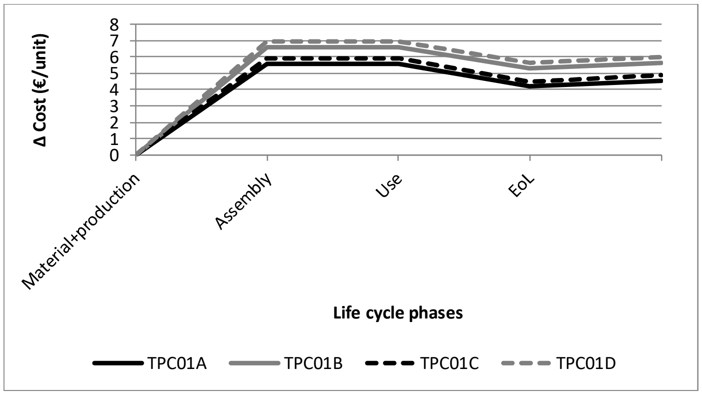

FIGURE 3. Cost results (€/unit) for the difference between the BSL and the TPC01 possible material scenarios.

CONCLUSIONS

In the present work it was concluded that the metallic chasis has the highest environmental impact of all the systems considered, the material production being the main contributor, followed by the use phase. The TPC01B/TPC01D system shows the best environmental performance (in circa of 15%), being, in this case, the use phase the main contributor, followed by the material production. The Fossil depletion, Climate change human health and Climate change ecosystems impact categories are the most significant environmental burdens in all systems.

All TPC01 possible material scenarios, which enable approximately 40% weight reduction, mitigate the GWP and CED environmental impacts until the use phase. However, these results are inverted when the EoL phase is included in the assessment. It should be noted that the CED of the material production in the new designs was higher than in the case of BSL. This is due to the fact that polymer matrix composites are produced through a more energy intensive (by unit weight) process than steel/aluminium, and the weight reduction doesn't mitigate this energy increase. At EoL, it was observed that recycling the metal (steel and aluminium) is more favourable regarding GWP and CED than incinerating the polymer composite and recovering energy.

All TPC01 possible material scenarios present a higher assembly cost. None of these scenarios mitigate the cost impacts, since the results have a positive value. It was observed that the TPC01 assembly and use phases costs are lower than the corresponding ones of the BSL. However this does not mitigate the higher material and production costs. The new concept designs allow achieving approximately 40% weight reduction, which does not lead to a cost reduction, since the polymeric composite materials have a very high price. Again, at EoL it was observed that recycling the metal (steel and aluminium) is more favourable regarding cost than incinerating the polymer composite and recovering energy.

ACKNOWLEDGMENTS

The present work was partially financed by the Portuguese Incentive System for Research and Technological Development, as co-promotion Project nº 36265/2013 (Project HMIExcel – 2013-2015). The authors thank the support of the Bosch Car Multimedia Portugal, S.A. company throughout the inventory phase of the study. Two of the authors (CAB, AJP) acknowledge the funding received from FCT, the Portuguese Foundation for Science and Technology, through project UID/CTM/ 50025/2013 and from the COMPETE 2020 Programme under project POCI-01-0145-FEDER-00768.

REFERENCES

1. N. S. Ermolaeva, M. B. G. Castro, and P. V. Kandachar, “Materials selection for an automotive structure by integrating structural optimization with environmental impact assessment,” *Mater. Des.* **25**(8), 689–698 (2004).
2. P. Peças, I. Ribeiro, A. Silva, and E. Henriques, “Comprehensive approach for informed life cycle-based materials selection,” *Mater. Des.* **43**, 220–232 (2013).

3. I. Ribeiro, P. Peças, A. Silva, and E. Henriques, "Life cycle engineering methodology applied to material selection, a fender case study," *J. Clean. Prod.* **16**(17), 1887–1899 (2008).

4. C. A. Ungureanu, S. Das, and I. S. Jawahir, "Subodh K. Das and Weimin Yi,n, eds., Life-cycle cost analysis: aluminium versus steel in passenger cars," in *Aluminium alloys for transportation, packaging, aerospace, and other applications*, edited by b Subodh K. Das, Weimin Yin, The minerals, Metals & Materials Society, Pittsburgh, PA, 2007.

5. International Organization for Standardization (ISO), "ISO 14040: 2006 - Environmental management – Life cycle assessment – Principles and framework," in *ISO 14000 International Standards Compendium*, Genève, Switzerland, 2006.

6. International Organization for Standardization (ISO), "ISO 14044: 2006 - Environmental management – Life cycle assessment – Requirements and guidelines," in *ISO 14000 International Standards Compendium*, Genève, Switzerland, 2006.

7. A. Ciroth, G. Huppes, W. Klöpffer, I. Rüdenauer, B. Steen, and T. Swarr, *Environmental life cycle costing*, 1st ed. Pensacola, FL: CRC Press, Publishing House Taylor and Francis, SETAC Press, 2008.

8. T. Swarr *et al.*, *Environmental life cycle costing: a code of practice*, 1st ed. New York, NY: Society of Environmental Toxicology and Chemistry, 2011.

[9. R. Kirchain, "Cost modeling of materials and manufacturing processes," in *Encyclopedia of Materials: Science and Technology*, edited by *K.* H. Jurgen Buschow, Robert Cahn, Merton Flemings, Bernhard Ilschner, edward Kramer, Subhash Mahajan and Patrick Veyssiere*,* vol. 2, Elsevier B.V., 2001, pp. 1718–1727.

10. C. L. Simões, R. Figueirêdo de Sá, C. J. Ribeiro, P. Bernardo, A. J. Pontes, and C. A. Bernardo, "Environmental and economic performance of a car component: assessing new materials, processes and designs," *J. Clean. Prod.* **118**, 105–117 (2016).

11. C. Koffler, "Life cycle assessment of automotive lightweighting through polymers under US boundary conditions," *Int. J. Life Cycle Assess.* **19**(3), 538–545 (2014).

12. R. A. Witik, J. Payet, V. Michaud, C. Ludwig, and J.-A. E. Månson, "Assessing the life cycle costs and environmental performance of lightweight materials in automobile applications," *Compos. Part Appl. Sci. Manuf.*, **42**(11) 1694–1709 (2011).

13. M. Goedkoop, R. Heijungs, M. Huijbregts, A. D. Schryver, J. Struijs, and R. van Zelm, *ReCipe 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level - Report I Characterisation*, First edition. Amersfoort, The Netherlands: Ministry of Housing, Spatial Planning and the Environment, 2009.

14. M. Goedkoop, M. Oele, and S. Effting, *SimaPro Database Manual: Methods library*. The Netherlands: PRé consultants B. V., 2004.

15. The Swiss Centre for Life Cycle Inventories, *Ecoinvent database version 3.1*. Zürich, Switzerland, 2013.

16. *SimaPro 8.04*. The Netherlands: PRé consultants B. V., 2014.

17. J. H. Schmidt and J. Watson, "Eco Island Ferry: Comparative LCA of island ferry with carbon fibre composite based and steel based structures," 2.0 LCA consultants, 2014.

[18. European Commission - DG Joint Research Centre - Institute for Environment and Sustainability, *ELCD v2.0 database*. Brussels, Belgium, 2010.