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Design and Sustainability Assessment of Lightweight Concept for an Automotive Car Module

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Abstract

Recently sustainability has become a priority for industry production. This issue is even more valid for the automotive sector, where Original Equipment Manufacturers have to address the environmental protection in addition to the traditional design issues. Against this background, many research and industry advancements are concentrated in the development of lightweight car components through the application of new materials and manufacturing technologies. The paper deals with an innovative lightweight design solution for the bumper system module of a C-segment gasoline car. The study has been developed within the Affordable LIght-weight Automobiles AlliaNCE (ALLIANCE) project, funded by the Horizon 2020 framework programme of the European Commission. A rear crash management system module, that is currently in series production and mainly consists of conventional steel and aluminum materials, is re-engineered making use of ultra high strength 7000 series alloys. The design alternatives are described and assessed regarding the achieved weight saving. The study is complemented by a sustainability assessment of the different modules performed through the Life Cycle Assessment methodology. The analysis takes into account production, use and End-of-Life stages and the results are expressed in terms of Global Warming Potential according to the CML 2001 Life Cycle Impact Assessment method.

Introduction

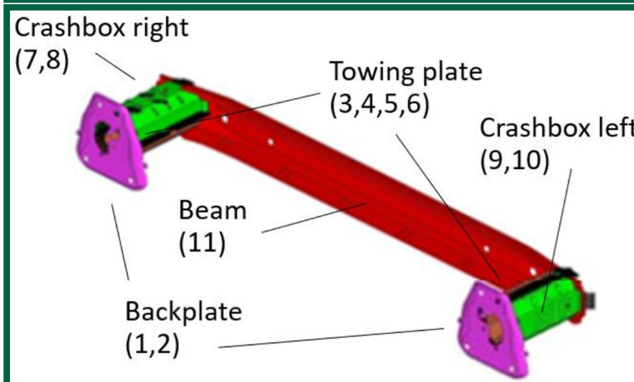
Due to the increasingly stringent European regulations on air pollution, great attention has been paid to CO_2 car emissions in the last decade. As a consequence, Original Equipment Manufacturers (OEMs) and materials suppliers are strongly committed to develop cleaner materials and production processes as well as environmentally friendly propulsion technologies [1,2]. In this context, lightweighting is one of the key design strategies for the automotive sector which has proved to guarantee both technical, economic and environmental benefits [3,4]. The main lightweighting approaches are based on the use of light materials, stronger materials and design optimization [5]. The first strategy consists in the use of a broad series of innovative materials (such advanced high strength steel, 6000/7000 series aluminium alloy, composites and hybrid materials) in order to reduce vehicle mass as well as improve fuel economy [6]. Light materials enable lowering the use stage impact through a reduction of energy consumed during operation but, on the other hand, they usually involve negative effects on production (particularly raw materials acquisition and processing) and End-of-Life (EoL) stages, thus preventing (or at least limiting) the expected benefit on Life-Cycle (LC) perspective [7]. Additionally, lightweighting involves high production costs due to the considerable value of the basic materials, long cycle times, significant investments for new machinery, and modification of well-established production chain processes [8]. The adoption of stronger metal materials, instead, allows achieving substantial environmental impact saving during operation without increasing significantly the quota of production. However, also this solution involves high costs due to tooling and machinery expenses [9,10]. Concerning the design perspective, the main solutions are the optimization of cross-section structures and the reduction of component thicknesses while maintaining the same construction material. This strategy results in lower energy and resource consumption during use, but it requires long design and development process time.

In view of the above, literature provides a deep knowledge of advantages and disadvantages offered by the different eco-design strategies in the automotive field [11]. In this regard, several Life Cycle Assessment (LCA) studies exist dealing with the sustainability assessment of automotive lightweight design. Below three of them are taken into account as representative of the current state-of-the-art. [12] provides a practical example of integrating LCA within the traditional design procedure in the application of glass-reinforced PolyEthylene Terephthalate (PET) to a gasoline vehicle throttle body. The LCA is applied at two different levels of the design process, material selection and concept design. The design assessment demonstrates that the composite component guarantees the same functional and performance level of the reference one (made of aluminium) while enabling a simplification of both manufacturing and assembly processes. Concerning the environmental point of view, the shift to the lightweight alternative provides a remarkable impact reduction for most of the considered impact categories. [13] presents a combined LCA/LCC comparative study for a reference and lightweight design solution applied to a door structure module. The case study stresses that the substitution of steel with aluminium provides substantial impact saving on a LC perspective. Concerning the economical assessment, the production costs of aluminium are considerably higher with respect to steel, but the Fuel Consumption (FC) saving in use stage makes that the novel solution is preferable after a mileage of approximately 83000 km. [14] evaluates three different design solutions for car chassis components: the steel reference module is compared with a series of innovative alternatives concerning materials, design choices and use of new technologies. The results of the study confirm substantially the outcomes of previous cited researches: lightweighting determines a reduction of environmental impacts in the use phase, thus compensating the increase in costs and environmental burdens of the production.

The present research reports the development of new lightweight rear Crash Management System (CMS) module made completely of ultra-high-strength aluminium extrusions in replacement of conventional steel/aluminium baseline components. The research and development activity has been performed within the ALLIANCE European project [15], which is aimed at developing novel advanced materials and production technologies to achieve an average weight reduction of 25 % over 100k units. The lightweight design solution is compared to the reference one in terms of lightweight potential, design and sustainability issues. The environmental assessment is performed through the LCA methodology.

TABLE 1 Image, part list and manufacturing of EU CMS reference module

Reference EU CMS



Component	Material	Mass [kg]	Thickness [mm]	Manufacturing Process
1. Back plate right	HCT600X	0.445	2.06	Cold stamping
2. Back plate left	HCT600X	0.342	2.0	Cold stamping
3. Outer towing plate	HC420LA	0.064	2.0	Cold stamping
4. Inner towing plate	HC420LA	0.068	2.0	Cold stamping
5. Reinforcement outer towing plate	HC260LA	0.038	2.6	Cold stamping
6. Reinforcement inner towing plate	HC260LA	0.048	2.6	Cold stamping
7. Crash box upper right	HCT600X	0.353	1.4	Cold stamping
8. Crash box lower right	HCT600X	0.284	1.4	Cold stamping
9. Crash box outer left	HCT600X	0.438	2.0	Cold stamping
10. Crash box inner left	HCT600X	0.295	1.2	Cold stamping
11. Beam	HCT980X	1.614	1.2	Cold stamping
	Total	**3.989**		

Design

This paragraph provides a description of the two design alternatives for the CMS module in terms of the main design and technological features. The reference vehicle model on which the CMS module is installed is a C-segment vehicle (gasoline model). Due to different crash requirements provided by sales geographical areas (America and Europe), the design of the bumper system is differentiated in EU and US versions.

Reference Modules

The EU reference module has a mass of about 4 kg and it is completely made of steel. On the other hand, the US reference demonstrator is a hybrid steel-aluminium-design with a mass of nearly 7 kg. Tables 1 and 2 report image and part list respectively of EU and US demonstrators, including material composition, thickness and manufacturing process of different components.

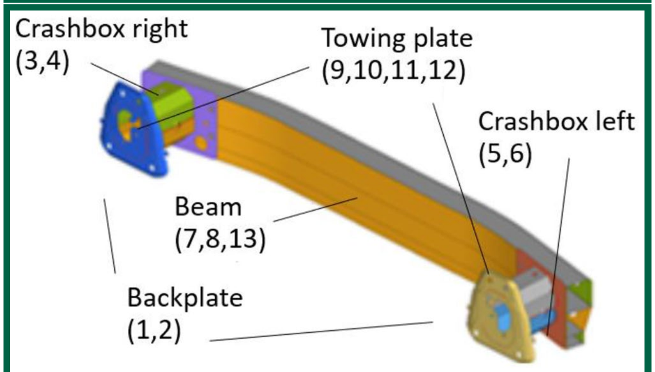
Lightweight Modules

For both EU and US versions an optimized open beam profile made of an ultra-high-strength aluminium alloy is developed. As the new design should not require a modification of existing parts (i.e. the bumper cover and the wire harness), the design space is defined based on surrounding parts.

The newly developed lightweight CMS module for the EU version consists of a tailored extruded beam profile made of the precipitation hardenable high-strength aluminium alloy 7003, with a thickness ranging locally from 1.8 mm to 2.0 mm. The two crashboxes and the two backplates are also extruded parts made of aluminium alloy 7003. The thickness of crashboxes and backplates is respectively 2.1 and 4.0 mm. For the

TABLE 2 Image, part list and manufacturing of US CMS reference module

Reference US CMS



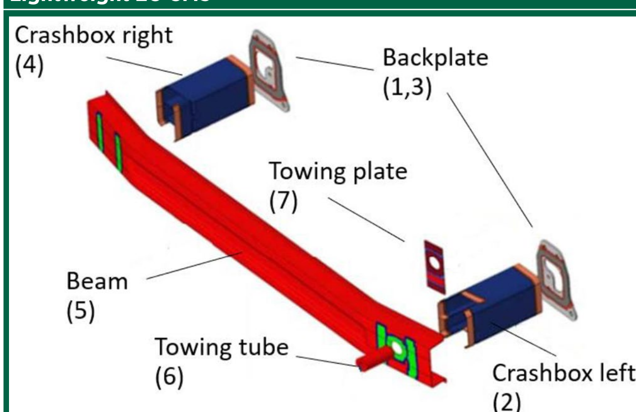
Component	Material	Mass [kg]	Thickness [mm]	Manufacturing Process
1. Back plate right	HCT600X	0.447	2.6	Cold stamping
2. Back plate left	HCT600X	0.344	2.0	Cold stamping
3. Crash box upper right	HCT600X	0.194	1.2	Cold stamping
4. Crash box lower right	HCT600X	0.293	2.0	Cold stamping
5. Crash box upper left	HCT600X	0.192	1.2	Cold stamping
6. Crash box lower left	HCT600X	0.291	2.0	Cold stamping
7. Beam plate US right	HC420LA	0.382	2.3	Cold stamping
8. Beam plate US left	HC420LA	0.536	3.2	Cold stamping
9. Outer towing plate	HC420LA	0.064	2.0	Cold stamping
10. Inner towing plate	HC420LA	0.068	2.0	Cold stamping
11. Reinforcement outer towing plate	HC260LA	0.038	2.6	Cold stamping
12. Reinforcement inner towing plate	HC260LA	0.048	2.6	Cold stamping
13. Beam	EN AW7003 HS	4.020	2.5 to 3.5	Extrusion + Bending
	Total	**6.917**		

beam profile the chosen alloy is trimmed to a slightly higher strength as for the other two components. As the ductility requirements for the crash boxes are very high, a very ductile special version of the alloy AW7003 in overaged condition (T7) has been utilized for both modules. Although the adjusted strength can also be achieved with 6000 alloys, this alloy has clear advantages with regard to deformability, resistance to crack initiation and the stability of the properties in large series production. As for the European market there are no high speed rear crash requirements the utilized material is a high strength version of the AW7003 in a slightly overaged temper. This material combines a strength level that can only hardly be reached with 6000 series alloys with good ductility behavior reaching a high production efficiency. The open beam design combined with a special extrusion design and a special forming concept adapted to the material characteristics offers the best compromise between weight savings, costs and robustness in case of a crash event. The towing hook nut and the towing hook plate are made of the aluminium alloy 6082 which is a precipitation hardenable high-strength alloy of the 6000 series. The total mass of the newly developed rear CMS accounts for about 2.4 kg. In the end, material change, application of heat treatment and use of tailored extruded blanks makes that the lightweight design solution provides a weight reduction of nearly 40 % with respect to the reference while keeping the same performance goals. Image of lightweight EU CMS module as well as material, dimensional and technological specifications are reported in Table 3.

The development focus for the US version is to find a good compromise between withstanding a high bending moment and providing a good ductility for the high-speed rear crash, which is a special US requirement. The new design combines the idea of using an open and deep formed profile with the use of an ultra-high strength alloy. Although the profile varies locally between 3.0 mm and 4.0 mm in thickness, the high

TABLE 3 Image, part list and manufacturing of EU CMS lightweight module

Lightweight EU CMS

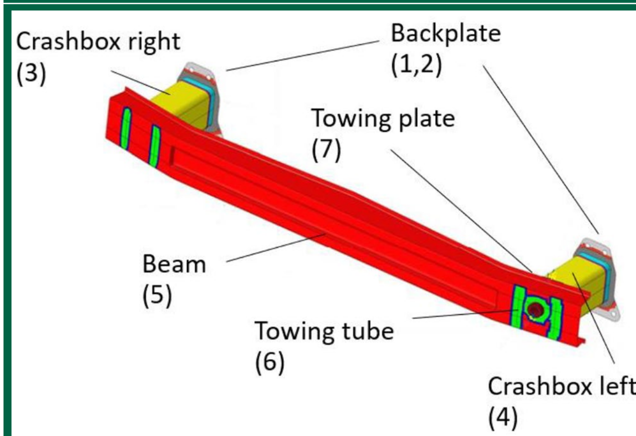


Component	Material	Mass [kg]	Thickness [mm]	Manufacturing Process
1. Back plate left	EN AW7003 LS	0.148	4.00	Extrusion + Punching
2. Crash box left	EN AW7003 LS	0.404	2.10	Extrusion + Milling
3. Back plate right	EN AW7003 LS	0.148	4.00	Extrusion + Punching
4. Crash box right	EN AW7003 LS	0.383	2.10	Extrusion + Milling
5. Beam	EN AW7003 HS	1.202	1.8 to 2.0	Extrusion + Forming & Punching
6. Towing tube	EN AW6082	0.103	7.90	Extrusion + Milling
7. Towing plate	EN AW6082	0.028	2.40	Extrusion + Punching
	Total	**2.416**		

depth can be reached by a combined stretch bending and forming process utilizing a w-temper material. The resulting beam provides high bending stiffness due the ultra-high yield strength, the formed depth and flange combined with a deformability in high speed crash event as with the beam opening the load is beneficially distributed over a large area. The extrusion alloy AW 7046 offers very high values of strength combined with good weldability due to the low copper content. Additionally, the shown arc welded module a bolted version has been designed. With this version heat affected zones could be avoided and an assembly sequence according the OEM's requirements can be enabled. Nevertheless the welded version offers the highest light-weighting potential. Material, dimensions and technological specifications of rear flange plates, crash-boxes, towing hook nut and towing hook plate components are almost identical to the ones of the EU version. Therefore, similar considerations regarding design and manufacturing features of these parts can be made. Altogether, the total mass of the newly developed US rear CMS accounts for 3.79 kg, which means a weight reduction of about 45 % with respect to the reference module (same performance levels). Table 4 reports image, material composition, dimensional and manufacturing features of lightweight US rear CMS.

TABLE 4 Image, part list and manufacturing of US CMS lightweight module

Lightweight US CMS



Component	Material	Mass [kg]	Thickness [mm]	Manufacturing Process
1. Backplate	EN AW 7003	0.148	4.00	Extrusion + Punching
2. Backplate	EN AW 7003	0.148	4.00	Extrusion + Milling
3. Crashbox right	EN AW 7003	0.392	2.10	Extrusion + Punching
4. Crashbox left	EN AW 7003	0.404	2.10	Extrusion + Milling
5. Beam	EN AW 7046	2.560	3.0 to 4.0	Extrusion + Forming & Punching
6. Towing tube	EN AW 6082	0.103	7.93	Extrusion + Milling
7. Towing plate	EN AW 6082	0.031	2.40	Extrusion + Punching
	Total	**3.786**		

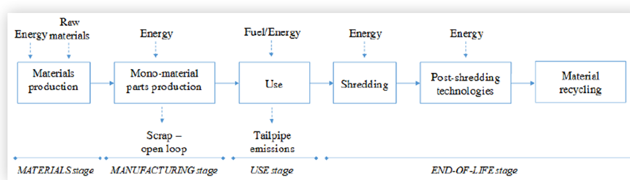
Sustainability Assessment

LCA is a technique to assess environmental impacts associated with all LC stages of a product [16], process or service from raw material extraction and processing (through the product's manufacture, distribution and use) up to the recycling and final disposal of the EoL materials. The procedures for conducting an LCA study are included in the 14040 series environmental management standards of the International Organisation for Standardisation (ISO) [17]. According to literature, LCA studies provide different level of analysis, which may concern vehicle or component, and different level of data collection and modelling of the use phase. The main alternative approaches for data collection and interpretation of results focus on the bill of materials, and vehicle assemblies/modules.

Functional Unit and System Boundaries

The target of the work is developing a "from-cradle-to-grave" LCA in order to determine the environmental impacts of the product in terms of Global Warming Potential (GWP). The final aim is comparing the environmental profile of the reference and lightweight design solution for both EU and US CMS versions. The comparison should rely on the capability of the reference and lightweight design alternatives to provide the same mechanical and functional performances. The Functional Unit (FU) is defined as the module installed on the reference car assuming a LC mileage of 230000 km [18]. The use stage is evaluated basing on the Worldwide harmonized Light-duty Test Cycle (WLTC) [19]. The entire LC of the

FIGURE 1 Overview of LC stages of CMS module



CMS module is assessed subdivided into three main stages: production, use and EoL (see Figure 1). The impacts are assessed through the GWP impact category, expressed in kg CO_2 eq. The chosen LCIA method for the impact assessment is the CML 2001 [20].

Life Cycle Inventory

The LCI modelling is performed through the break-down approach taking into account the outcomes of ENLIGHT [21] and e-LCAr [22] projects. The LCI is carried out by means of the Gabi software [23]. The inventory is modelled as materials/energy consumption, waste production and emissions to the environment by using processes and elementary flows from the GaBi LCI dataset. Below the LCI modelling and data collection are described for each LC stage of the module.

Production: Materials and Manufacturing Sub-Stages Production impact is provided by two main contributions:

- Materials sub-stage, which incorporates environmental loads from raw material extraction up to the production of semi-finished products
- Manufacturing sub-stage, which includes activities for converting semi-finished products into the final module parts.

For both Materials and Manufacturing sub-stages, the breakdown approach provides that each mono-material part of the module is assessed separately. As a consequence, the total production impact of the overall module is obtained as the sum of contributions of the single mono-material parts. The inventory is modelled as materials/energy consumption, waste production and emissions to the environment. Considering the materials sub-stage, the entire production chain of semi-finished products is taken into account. The inventory is mainly constituted by secondary data from the GaBi process dataset basing on primary data regarding material composition of the module, mass of mono-material parts and production processes (see Tables 1, 2, 3 and 4). These data are collected by means of specific questionnaires filled out by project partners involved in the design activity. On the other hand, the manufacturing sub-stage assesses energy consumption and scrap rate of manufacturing processes of finished CMS parts. The assessment includes also the recycling of scrap materials from production activities. Materials are assumed to be recovered through an open loop recycling taking into account the environmental credits due to raw materials substitution. On the other hand, joining and assembly processes as well as transportations during production are out the system boundaries because a pre-assessment investigation reveals that their impact is negligible with respect to total LC GWP. On the other hand, the LCI modelling of the manufacturing sub-stage is mainly based on primary data collection coming from direct measurements on suppliers processes site. Where innovative materials and manufacturing technologies developed within the project are applied, LCI data provided by materials/technologies providers are used.

Use Stage The use stage considers all impacts associated with the operation of the module, which are provided by both fuel transformation processes upstream to FC (Well-To-Tank, WTT) and CO_2 exhaust air emissions during driving (Tank-To-Wheel, TTW). The inventory is modelled as materials/energy consumption and waste production (WTT sub-stage) and emissions to the environment (TTW sub-stage). The required LCI data are the amount of FC and CO_2 emissions associated with the operation of CMS. The allocation of both vehicle FC and emissions to the specific module is performed through the FRV-based approach [24]. The inventory referring to both WTT and TTW sub-stages is performed basing on secondary data from both literature and LCI GaBi dataset. The FRV-approach calculations as well as the main assumptions and modelling boundary conditions are reported in Table 5.

TABLE 5 LCI use stage modelling and inventory data

Use stage		
LCI modelling	$FC_{100km} = \frac{CO_{2\,km}}{2370} * 100$	
	$FC_{veh} = \frac{FC_{100km}}{100} * mileage_{use} * \rho_{fuel}$	
	$FC_{module} = \frac{FRV * m_{module} * mileage_{use}}{10000} * \rho_{fuel}$	
	$CO_{2\,module} = CO_{2\,km} * mileage_{use} * \frac{FC_{module}}{FC_{veh}}$	
	FC_{100km} = vehicle Fuel Consumption per 100 km [l/100km]	
	$CO_{2\,km}$ = vehicle CO_2 emissions per-kilometer [g/km]	
	FC_{module} = amount of Fuel Consumption associated with the module [kg]	
	m_{module} = module mass [kg]	
	$mileage_{use}$ = use stage mileage [km]	
	ρ_{fuel} = fuel density (0.741 [kg/l])	
	FRV = Fuel Reduction Value (FRV) [l/100km*100kg]	
	$CO_{2\,module}$ = amount of CO_2 emissions associated with the component [g]	
	FC_{veh} = vehicle Fuel Consumption (kg)	
	2370 = mass of CO2 per liter of petrol [g/l]	
LCI data	Propulsion technology	ICE gasoline
	Vehicle class	C-segment
	$mileage_{use}$ [km]	230000
	FRV (WLTC) [l/100km*100kg]	0.170*
	CO_{2_km} [g/km]	144*
	* Average value representative of generic C-segment gasoline vehicle	

EoL Stage Similar to production, the EoL stage is modelled at vehicle level. The considered EoL scenarios are consistent with [25, 26] and they are representative of the current European technology level. It is assumed that the CMS is not dismantled from the EoL vehicle and it is forwarded to the shredding process. After that, the EoL scenarios are defined, including sorting and recycling processes (open loop recycling). The modelling takes into account also the avoided impacts achieved through the substitution of virgin raw materials with secondary materials. In this regard, the main assumption is related to the environmental credits stemmed from the recycling processes. The considered substitution factors for the replacement of virgin raw materials are from the Gabi LCI database. Table 6 reports electricity consumption and separation efficiency for the considered EoL processes as well as substitution factors functional to model open loop recycling.

Table 7 provides a qualitative overview of LCI data collection for all LC stages of the CMS module.

TABLE 6 Electricity consumption of EoL processes and substitution factors of open loop recycling

EoL stage					
		Steel parts (shredding, materials sorting & material recycling)		Aluminium parts (shredding, materials sorting & material recycling)	
		LCI data	Quality	LCI data	Quality
Reference module	Electricity for shredding [MJ/kg]	0.18	Secondary	0.18	Secondary
	Electricity for EoL materials sorting [MJ/kg]	0.12		0.12	
	Share of recycled material (both manufacturing scraps and EoL materials) [%]	98		51	
	Substitution factor for recycling of manufacturing scraps [%]	51		94	
	Substitution factor for recycling of EoL materials [%]	33		42	

TABLE 7 Overview of LCI data collection

LCI data collection		
LC stages & processes		**Type**
Materials	LCI data regarding raw materials extraction and production processes	Secondary
	LCI data regarding production processes of semi-finished products	Primary / Secondary
Manufacturing	LCI data regarding production processes of finished parts	Primary / Secondary
	Scrap rate of production processes of finished parts	Primary / Secondary
Use	LCI data regarding the production of fuel associated with module operation	Primary / Secondary
	CO_2 emissions associated with module operation	Primary / Secondary
EoL	LCI data regarding shredding, separation and recycling processes	Secondary

LCIA Results and Discussion

Tables A1 and A2 in the Appendix report the LCIA impacts in terms of GWP for both reference and lightweight design alternatives. Numbers are presented for both total LC and single LC stages.

Contribution Analysis of Impact by LC Stage Figures 2 and 3 report the GWP contribution analysis by LC stage of the entire CMS module respectively for the

FIGURE 2 Contribution analysis by LC stage for the reference design solutions

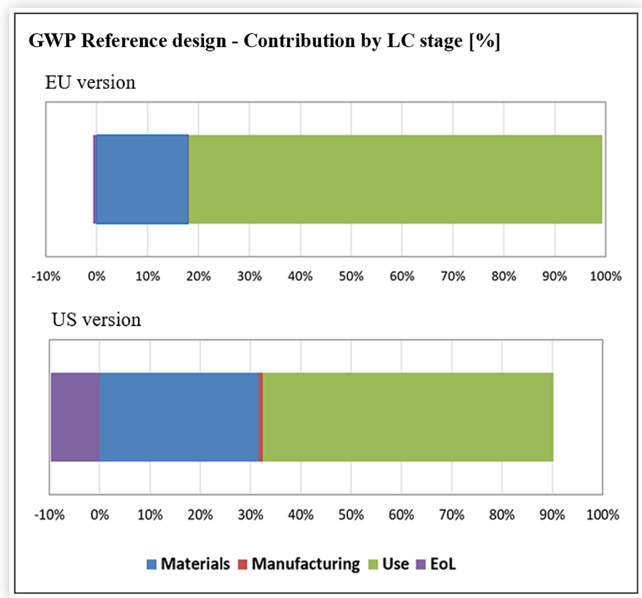
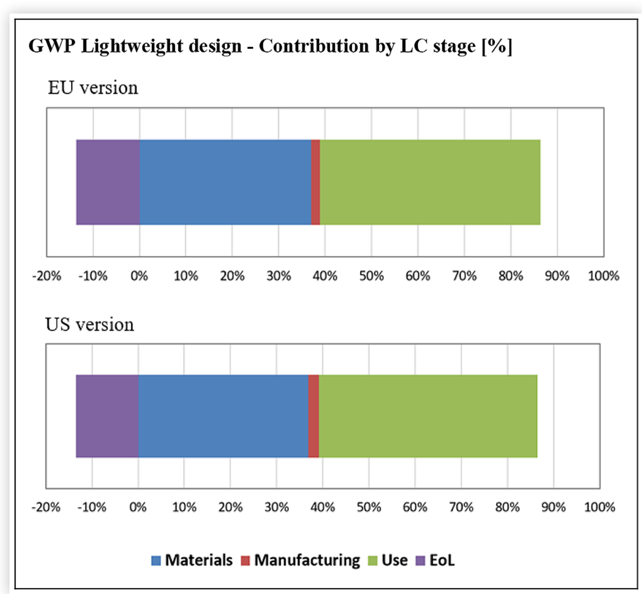


FIGURE 3 Contribution analysis by LC stage for the lightweight design solutions



reference and lightweight alternatives. Concerning the reference design, the contribution analysis of the EU CMS version reveals that the use stage has a leading role, representing about 81 % of total LC GWP. The quota of materials is also relevant (about 18 %) while the manufacturing and EoL stages do not reach a threshold of 1 %. Concerning the EoL, the impact is negative due to the environmental credits achieved through recycling processes. The operation covers the majority of impacts also for the reference design of the US CMS version (58 % of absolute total LC GWP), although the percentage is substantially lower with respect to the EU variant. On the other hand, the contribution of materials and EoL stages is also relevant (respectively about 31 and 10 % of total LC GWP) while the quota associated with manufacturing is about 1 %.

Concerning the lightweight design (both EU and US versions), the quota of total LC GWP associated with use stage is notably lower than the reference solutions (about 48 % and 47 % respectively for EU and US modules). As a consequence, the contribution of Materials and EoL stages grow significantly (respectively 37 % and 14 % for both EU and US versions), while manufacturing reaches a quota of about 1-2 %.

Comparative Assessment Reference-Lightweight Design

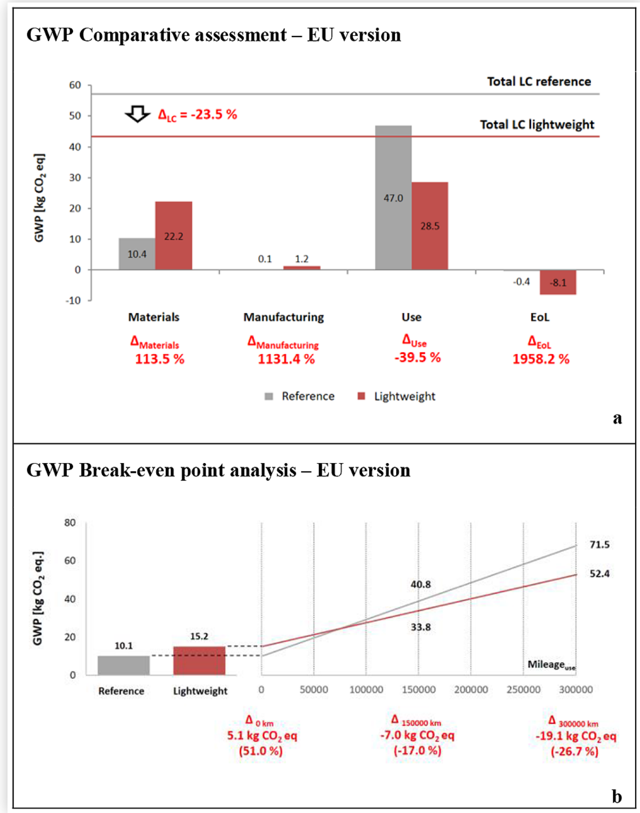
This paragraph reports the comparative assessment between the reference and lightweight design alternatives for the CMS module (both EU and US versions). Figures 4 and 5 investigate the GWP variation by reporting

- comparison reference-lightweight at both total LC and single stage levels
- break-even point analysis in function of operation mileage

respectively for EU and US CMS versions.

The comparative assessment for the EU configuration (Figure 4.a) shows that the impact of the lightweight module is definitely lower with respect to the reference one, leading to an impact decrease of about 23-24 % on LC perspective. The environmental convenience of the novel alternative occurs in use and EoL phases while for materials and manufacturing the GWP increases. Concerning operation, the 18.5 kg CO_{2eq} GWP decrease leads to a percent impact reduction of about 39 % for this stage. This is due to the fact that lightweighting involves a lowering of FC, which in turn has a double beneficial effect: on one hand the need for the production of a lower amount of fuel, and on the other hand the abatement of CO_2 emissions, which are linearly proportional to the amount of gasoline used. EoL impact decreases of about 8 kg CO_2 eq, which leads to a very high reduction for this phase (about 1958 %). Despite in the novel solution the amount of material forwarded to recycling activities is lower, the environmental credits of innovative module are notably higher. The main explanation for this lies in the material composition of the module and it is determined by two main reasons. The first one is that energy consumption of aluminium recovery processes is lower with respect to steel. The second one is that aluminium has an higher substitution factor due to the greater economic value of the EoL metal scrap in terms of equivalent of primary materials with respect to steel. On the other hand,

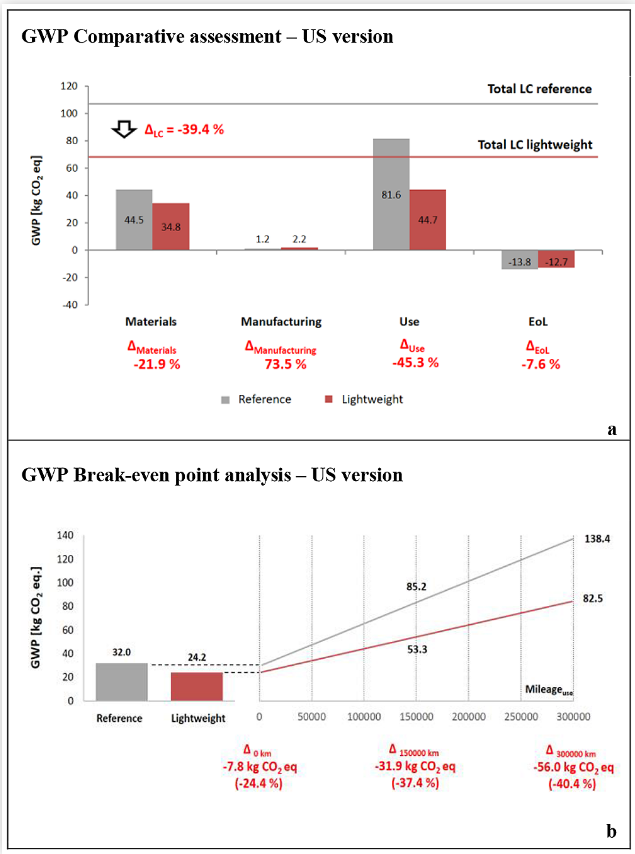
FIGURE 4 Comparative assessment reference-lightweight solutions (EU version)



the 11.8 kg CO_2 eq increase in materials phase leads to an impact growth of about 114 % for this stage. Such an increase is associated with the fact that the reference CMS is totally made of pressed steel, while the lightweight one is totally made of EN AW7003 and EN AW6082 extruded aluminium. Indeed, aluminium presents higher impacts in raw materials acquisition, which are not counterbalanced by the reduction of materials quantity (about 39 % mass saving). Finally, the 1.1 kg CO_2eq increase in manufacturing stage leads to a very high impact growth for this stage (about 1130 %). The break-even analysis (Figure 4.b) reveals that the reduction in use stage impact achieved through lightweight design counterbalances the higher burdens in production and manufacturing stages at a LC mileage of about 64000 km. At 0 km the novel solution involves a GWP growth of 5.1 kg CO_{2eq} (percent increase of 51.0 %), while at 150000 and 300000 km it provides a GWP saving respectively of 7.0 and 19.1 kg CO_{2eq} (17.0 % and 26.7 % in percentage terms).

The comparative assessment for the US configuration (Figure 5.a), shows that the environmental burden of the innovative module is definitely lower with respect to the reference one, leading to a decrease on LC perspective of about 39 %. The environmental convenience of the novel alternative occurs in materials and use phases while for manufacturing and EoL the GWP increases. The first point is that the 45.3 % use stage GWP saving provides the highest reduction in absolute terms (about 37 kg CO_{2eq}). This is due to the fact that operation is responsible for the major part of the overall impact of the

FIGURE 5 Comparative assessment reference-lightweight solutions (US version)



module. The second largest GWP decrease in absolute terms is achieved in the materials acquisition (9.7 kg CO_2eq - about 22 % impact decrease). The GWP reduction in materials stage is mainly ascribable to the fact that

- the amount of materials used for the lightweight variant (3.79 kg) is about 45 % lower with respect to the reference one (6.92 kg) and it is totally aluminium (96 % EN AW7003 and 4 % EN AW6082) while the reference module is composed of the share of 58 % EN AW7003 aluminium and 42 % pressed steel
- the amount of aluminium used for the baseline module is higher (4.02 kg and 3.79 kg respectively for reference and lightweight CMS)
- the impact of aluminium in raw materials acquisition stage is higher with respect to steel

The EoL involves a 1.1 kg CO_2 eq GWP increase. The EoL credits provided by the novel module are smaller because the amount of aluminium forwarded to recycling activities is lower than the reference design. The manufacturing stage impact shows a relevant increase (about 73.5 %) but the low GWP caused by energy consumption of manufacturing activities makes that it is very small in absolute terms (1.0 kg CO_2 eq). The break-even point analysis (Figure 5.b) stresses that there is no environmental equivalence during operation, since the impact of reference design in mileage-independent phases is higher than the one of the innovative module. As a consequence, the impact of novel design is lower for any value of distance and the advantage of lightweight CMS becomes larger at LC mileage growing. Indeed, from a value of 7.8 kg CO_2eq at 0 km, the GWP reduction grows up to 31.9 kg CO_2 eq at 150000 km and 56.0 kg CO_2 eq at 300000 km. On the other hand the percent impact reduction increases at LC mileage growing (24.4, 37.4, 40.4 % respectively at 0, 150000 and 300000 km).

Conclusions

The study investigates two design alternatives for a rear CMS module of C-segment gasoline car: a reference solution based on steel (EU version) and hybrid steel-aluminium (US version) is compared to a lightweight alternative made of ultra-high-strength aluminium 6000/7000 series alloy. The comparative assessment is performed basing on the achieved weight saving as well as the sustainability profile of the different design options.

The EU CMS lightweight design based on AW 7003 extrusions for both beam and crashboxes allows achieving approximately 39 % mass reduction with respect to the steel reference version. 7000 series alloy is used as main construction material as it represents a good compromise between strength, production efficiency and design freedom. In the US CMS lightweight design the beam is made of AW7046 which provides very high values for strength and ductility combined with a good weldability due to the low copper content, while AW 7003 is chosen for the crashbox offering a good lightweight potential (about 45 %). For both EU and US versions an open beam profile combined with special extrusion design and forming concept adapted to the material characteristics offers the best compromise between lightweighting and robustness in case of crash event.

Concerning the environmental assessment, lightweight option provides a very relevant advantage for both EU and US versions, leading to a total LC GWP reduction respectively of about 24 and 39 %. The operation phase provides the higher contribution to impact decrease thanks to the lowering of fuel consumption, which means lower GWP for the production of fuel as well as abatement of exhaust CO_2 emissions during use. Considering the other LC stages, the effect of lightweighting differentiates between EU and US versions. For the EU CMS, the impact strongly reduces in the EoL stage (higher GWP credits provided by the recycling of aluminium scrap with respect to steel reference components) while it increases in the materials phase (lower GWP in raw materials extraction/production for reference pressed steel semi-finished products with respect to 6000 and 7000 extruded parts). On the other hand, the lower amount of materials used for the lightweight US CMS provides a GWP advantage in raw materials acquisition with respect to the reference steel module. Finally, the break-even point analysis reveals that for both EU and US configurations the environmental benefit of lightweight design grows at LC mileage increasing, thus leading to an overall GWP saving of about 27 % and 40 % at 300000 km respectively for EU and US versions.

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Definitions, Acronyms, Abbreviations

CMS - Crash Management Systems
EoL - End-of-Life
FC - Fuel Consumption
FU - Functional Unit
GWP - Global Warming Potential
ISO - International Organisation for Standardisation
LC - Life Cycle
LCA - Life Cycle Assessment
LCC - Life Cycle Costing
LCI - Life Cycle Costing
OEMs - Original Equipment Manufacturers
TTW - Tank-To-Wheel
WLTC - Worldwide harmonized Light-duty Test Cycle
WTT - Well-To-Tank

APPENDIX

TABLE A1 Global Warming Potential for total LC and single LC stages of the reference design (both EU and US versions)

	Global Warming Potential (GWP) - Reference design [kg CO_2 eq]					
		Production				
	Part name	Materials	Manufacturing	Use (WLTC)	EoL	Total LC (WLTC)
EU version	Back plate left	1.160E+00	1.080E-02	5.246E+00	-4.400E-02	6.373E+00
	Back plate right	8.900E-01	8.270E-03	4.036E+00	-3.380E-02	4.900E+00
	Outer towing plate	1.670E-01	1.550E-03	7.576E-01	-6.330E-03	9.198E-01
	Inner towing plate	1.740E-01	1.620E-03	7.977E-01	-6.630E-03	9.667E-01
	Reinforcement outer towing plate	9.890E-02	9.190E-04	4.449E-01	-3.760E-03	5.409E-01
	Reinforcement inner towing plate	1.250E-01	1.160E-03	5.617E-01	-4.750E-03	6.831E-01
	Crash box upper right	9.190E-01	8.540E-03	4.162E+00	-3.490E-02	5.055E+00
	Crash box lower right	7.390E-01	6.870E-03	3.349E+00	-2.810E-02	4.067E+00
	Crash box upper left	1.140E+00	1.060E-02	5.174E+00	-4.340E-02	6.282E+00
	Crash box lower left	7.680E-01	7.140E-03	3.481E+00	-2.920E-02	4.227E+00
	Beam	4.200E+00	3.900E-02	1.904E+01	-1.600E-01	2.312E+01
	Total	**1.038E+01**	**9.647E-02**	**4.705E+01**	**-3.949E-01**	**5.713E+01**
US version	Back Plate Left	8.950E-01	8.320E-03	4.058E+00	-3.400E-02	4.927E+00
	Back Plate Right	1.160E+00	1.080E-02	5.275E+00	-4.420E-02	6.401E+00
	Outer Towing Plate	1.670E-01	1.550E-03	7.576E-01	-6.330E-03	9.198E-01
	Inner Towing Plate	1.740E-01	1.620E-03	7.977E-01	-6.630E-03	9.667E-01
	Reinforcement Outer Towing Plate	9.890E-02	9.190E-04	4.449E-01	-3.760E-03	5.409E-01
	Reinforcement Inner Towing Plate	1.250E-01	1.160E-03	5.617E-01	-4.750E-03	6.831E-01
	Crash Box Upper Right	5.050E-01	4.690E-03	2.288E+00	-1.920E-02	2.779E+00
	Crash Box Lower Right	7.630E-01	7.090E-03	3.460E+00	-2.900E-02	4.201E+00
	Crash Box Upper Left	5.000E-01	4.640E-03	2.268E+00	-1.900E-02	2.754E+00
	Crash Box Lower Left	7.570E-01	7.040E-03	3.431E+00	-2.880E-02	4.167E+00
	Beam Plate Right	9.940E-01	9.240E-03	4.506E+00	-3.780E-02	5.472E+00
	Beam Plate Left	1.400E+00	1.300E-02	6.319E+00	-5.310E-02	7.679E+00
	Beam	3.700E+01	1.170E+00	4.744E+01	-1.350E+01	7.211E+01
	Total	**4.454E+01**	**1.240E+00**	**8.160E+01**	**-1.379E+01**	**1.136E+02**

TABLE A2 Global Warming Potential for total LC and single LC stages of the lightweight design (both EU and US versions)

	Global Warming Potential (GWP) - Lightweight design [kg CO_2 eq]					
		Production				
	Part name	Materials	Manufacturing	Use (WLTC)	EoL	Total LC (WLTC)
EU version	Back Plate Left	1.360E+00	4.170E-02	1.746E+00	-4.980E-01	2.650E+00
	Back Plate Right	1.360E+00	4.170E-02	1.746E+00	-4.980E-01	2.650E+00
	Crash Box Left	3.720E+00	1.130E-01	4.767E+00	-1.360E+00	7.240E+00
	Crash Box Right	3.520E+00	1.040E-01	4.519E+00	-1.290E+00	6.853E+00
	Beam	1.100E+01	8.500E-01	1.416E+01	-4.040E+00	2.197E+01
	Towing Tube	9.440E-01	2.920E-02	1.215E+00	-3.470E-01	1.842E+00
	Towing Plate	2.570E-01	8.340E-03	1.746E+00	-4.980E-01	2.650E+00
	Total	**2.216E+01**	**1.188E+00**	**2.849E+01**	**-8.127E+00**	**4.371E+01**
US version	Back Plate Left	1.360E+00	4.170E-02	1.746E+00	-4.980E-01	2.650E+00
	Back Plate Right	1.360E+00	4.170E-02	1.746E+00	-4.980E-01	2.650E+00
	Crash Box Left	3.720E+00	1.130E-01	4.767E+00	-1.360E+00	7.240E+00
	Crash Box Right	3.610E+00	1.080E-01	4.626E+00	-1.320E+00	7.024E+00
	Beam	2.350E+01	1.810E+00	3.021E+01	-8.610E+00	4.691E+01
	Towing Tube	9.440E-01	2.920E-02	1.215E+00	-3.470E-01	1.842E+00
	Towing Plate	2.840E-01	8.340E-03	3.658E-01	-1.040E-01	5.541E-01
	Total	**3.478E+01**	**2.152E+00**	**4.467E+01**	**-1.274E+01**	**6.887E+01**

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