Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 136 (2025) 44–48

www.elsevier.com/locate/procedia

35th CIRP Design 2025

Life cycle analysis of innovative automotive lightweight applications of low-density steels: preliminary overview

Martino Oliboni[a], Elena Battiston[a], Pere Barriobero Vila[b], Ester Basagaña[c], Jose Maria Cabrera[b], Irene Calliari[a], Juan Emilio Rey Castañeda[b], Roberto Elvira[d], Towhid Faraji[e], Luca Pezzato[a], Mirko Pigato[a], Ulrich Prahl[e], Mathias Zapf[e], Anna Vilalta[c], Anna Mazzi[a]*

[a] *University of Padova, Department of Industrial Engineering, Via Marzolo, 9, 35131 Padova, Italy*
[b] *Technical University of Catalonia (UPC), Department of Materials Science and Engineering, Av. Eduard Maristany 16, 08019, Barcelona, Spain*
[c] *COMFORSA, Camí de la Creu, nº1, 17530 Campdevànol, Spain*
[d] *SIDENOR I+D, S.A., Barrio Ugarte, s/n, 48970 Basauri, Spain*
[e] *Institute of Metal Forming, TU Bergakademie Freiberg, Bernhard-von-Cotta Straße 4, 09599 Freiberg, Germany*

* Corresponding author. Tel.: +39 049-827-1611. *E-mail address:* anna.mazzi@unipd.it

Abstract

Preliminary overview of environmental impacts associated to new lightweight applications in automotive industry has been conducted, with the aim of supporting LIGHTFORGE project, focused on the development of new Fe-Mn-Al-C low-density steels adapted to the industrial forging conditions as an alternative to the conventional steel currently used. Through the analysis of current production processes in this sector and the main scientific evidence relating to their environmental impacts, life cycle analysis will be implemented within the project to design new materials and manufacturing processes with increased recycled content and lower carbon footprint.

Keywords: Environmental impact assessment; Low-density steel forging; Automotive; Circular innovation; Carbon footprint reduction

1. Introduction

The European Union (EU) introduced the European Climate Law in 2021 with the aim of achieving climate neutrality by 2050 [1]. This law provides as an intermediate objective, to be achieved by 2030, a national Greenhouse Gas (GHG) reduction emissions by at least 55% compared to 1990 levels. According to the European Automobile Manufacturers Association, the transport sector is responsible for more than 20% of the EU's total greenhouse gas emissions. Manufacturers in the automotive sector have implemented different strategies to reduce emissions, including the development of electric and hybrid vehicles [2] and the use of lightweight materials [3] to reduce the weight of cars. To achieve the goal, the conventional materials used can be substituted with lightweight automotive materials, divisible into four main categories: light alloys, high speed steels, composite materials, and advanced materials [4]. Another option for lighter vehicles is to reduce the density of the conventional materials used. The "Sustainable forging steels for automotive Lightweighting" project, with the acronym LIGHTFORGE, fits into this context. The project is funded by the Coal and Steel Research Fund, a program managed by the European Commission. It began in July 2023 and will conclude at the end of 2026. The project is based on an interdisciplinary collaboration between research institutions and industries involved in the automotive supply chain. The universities involved are University of Padova, Universitat Politècnica de Catalunya-UPC (project coordinator) and Technische Universitaet Bergakademie Freiberg. There are two Spanish companies involved: Sidenor Investigacion Y

10.1016/j.procir.2025.08.010

Desarrollosa (SIDENOR I+A), the research and development centre of SIDENOR, specialized in the production of long products in special steel and Comercial De La Forja Slu (COMFORSA), which mainly produces forged components for the heavy automotive and industrial machinery sectors. The objective is to develop low-density Fe-Mn-Al-C steels adapted to industrial forging conditions for new lightweight applications in the automotive sector. The application of new materials to vehicles is a challenging operation, as several critical factors need to be considered, such as material production, component processing techniques, lifetime and end of life of the product. The material under development aims to reduce energy and CO2 emissions in the automotive sector, one of the largest sources of greenhouse gas emissions in the world. In fact, lightweight design in this sector can be a feasible strategy to reduce the environmental impact during the entire life cycle of a vehicle [5]. The environmental sustainability assessment of innovative material and manufacturing processes will be carried out according to the Life Cycle Assessment (LCA) methodology. The LCA study is developed according to international standards ISO 14040 [6] and 14044 [7] that define the following steps: (i) Goal and Scope of the study, (ii) Life Cycle inventory, (iii) Life Cycle Impact Assessment, (iv) Interpretation and conclusion. The results of the LCA study will support partners in optimizing the process, especially in the design phase, through the quantification of the environmental convenience associated with different technical solutions in the production processes. Furthermore, it will allow comparison with forged elements made with materials already on the market to highlight the environmental advantages throughout the entire life cycle of the product. In order to conduct a solid LCA study it is important to know existing sector guidelines. This research is focused on the study of Product Category Rules (PCR) and Environmental Product Declarations (EPD) relating to the production of steel. In accordance with international guidelines [8], the EPD is the ecolabelling specifically dedicated to communicate the environmental performance of a product [9]. These declarations are based on the LCA results [10] and contain environmental information relating to the life cycle of a product. The EPD development process is managed by a specific organization, program operator, which conducts an environmental declaration program [11]. The program operators develop the Product Category Rules [12], that describe how to set up the LCA study to obtain consistent environmental impact results and achieve the EPD certification. Declarations developed following the same PCR allow comparison between the analysed products [13]. The first objective of the research was to find PCRs related to steel production. The second was to analyse the PCR and related published EPDs to collect useful information for the design of the LCA study in the LIGHTFORGE project.

Nomenclature

EPD	Environmental Product Declaration
GHG	Greenhouse Gases
GWP	Global Warming Potential
LCA	Life Cycle Assessment
PCR	Product Category Rule

2. Methodology

To carry out this analysis, a research was carried out through the databases of the main European program operators. The objective is to search for PCRs relating to steel production, excluding those referring exclusively to products from non-automotive sectors, such as the construction sector. The second phase was the collection and analysis of the EPDs referring to the PCRs found. This research consists of the following 4 main phases:

1) *Screening*: the objective of this first phase is to collect all the EPDs relating to the PCR under study. The PCR reference code was entered as a keyword in the program operator's database. Published and valid, i.e. not expired, EPDs verified by third parties have been found and downloaded. This research was carried out in a limited period of time, in the month of July 2024.

2) *Preliminary analysis*: All EPDs detected by PCR were examined to identify some key information, such as EPD registration number, company, location of the production site, type of product.

3) *Cleaning*: EPDs that refer to products not comparable to those developed in the LIGHTFORGE project were excluded, with reference to semi-finished products developed in SIDENOR and finished products in COMFORSA.

4) *In-depth analysis*: The remaining EPDs were classified and investigated in detail with the aim of obtaining important information for the design of the LCA study in the LIGHTFORGE project. In particular, information was collected regarding the software and databases used to evaluate environmental impacts. Furthermore, some data on the environmental profile of the product reported in the EPDs were analysed and compared in depth.

3. Results

3.1. Overview of PCR and EPDs

The research identified a PCR developed by the EPD International programme operator. The reference PCR is: 2015:03 - Basic iron or steel products and special steels, excluding construction products [14]. The PCR contains some important information for conducting the LCA study, in particular with reference to the goal and scope phase:

- *Functional Unit*: the declared unit is 1000 kg of semi-finished steel product at the manufacturer gate;
- *System boundaries*: “cradle to gate”, Upstream and Core life cycle stages;
- *Cut-off criteria*: data for elementary flows to and from the product system contributing to a minimum of 99% of the declared environmental impacts shall be included.

The production processes, within the boundaries of the system, are divided into three macro modules:

- *Upstream*: extraction and production of raw materials, transportation of raw materials during the production chain and to the steel manufacturing facility, the manufacturing of primary and secondary packaging;
- *Core*: manufacturing process for steel, waste and emissions generated during manufacturing, electricity production;

- *Downstream:* transport to the consumer, use of the product, end of life.

Downstream processes are not included in the scope of the PCR under study. Referring to this PCR, 62 valid EPDs were found in the program operator portal. Subsequently, the cleaning phase was applied to the EPDs found, according to the following criteria: product similar in size to those produced in SIDENOR (billets and round bars) and COMFORSA (forged elements for automotive sector). Following this process, 21 EPDs were found, all relating to products comparable to those of SIDENOR, therefore long steel products.

3.2. In-depth analysis of EPDs

Table 1 highlights the locations of the production sites where the EPDs were developed. Europe, Asia and South America are represented. In particular, 13 refer to productions in Europe, where the most represented state is France, followed by Spain and Italy. After France, the second most represented territory is the Republic of Korea, with 5 EPDs. Table 2 shows the commercial software and databases used to calculate impacts in LCA studies. The PCR reports the environmental and inventory impact indicators and impact assessment methods for the EPDs defined by the program operator. The impact categories reported in the EPDs are: Global Warming Potential, Ozone depletion, Acidification, Eutrophication - aquatic freshwater, Eutrophication - marine, Eutrophication - terrestrial, Photochemical Ozone Creation Potential, Abiotic Depletion Potential - Elements, Abiotic Depletion Potential - Fossil, Water deprivation potential. Furthermore, data relating to the use of resources are reported, such as primary energy resources and the use of fresh water, and waste produced.

Table 1. Geographic location of the site where the EPD was developed

Macro-area	State	EPDs
Asia	India	1
	Republic of Korea	5
Europe	Finland	1
	France	6
	Italy	2
	Spain	3
	Sweden	1
South-America	Chile	2

Table 2. Commercial software and Database used in EPDs

Software	EPDs
SimaPro	9
Gabi	5
EIME	4
Open LCA	2
Internal software	1
Database	
Ecoinvent	16
Gabi	5

The Global Warming Potential (GWP) category is analysed in depth, which gives us the GHG emission of the process studied in terms of kg of CO2eq. Furthermore, the data referring to the use of resources were compared, in particular the use of primary energy from renewable and non-renewable sources and the use of fresh water. All this data is related to the quantity of recycled material present in the products with the aim of observing if there are better environmental performances when the recycled content increases. In the Figure 1 the content of recycled material is related to the GWP impact category. The contribution of recycled material ranges from a minimum of 24% to a maximum of 100%. The total contribution of CO2eq emissions returned by the category is divided into the two areas which the processes are divided, Upstream and Core. There is no correlation between the recycled content of the product and the GWP value associated with it. In fact, increasing the recycled content does not systematically correspond to a decrease in GWP. Also, it is highlighted that as many as 8 EPDs have emissions exceeding 2000 kg of CO2eq per functional unit. The production sites where these EDPs were developed are located outside the borders of the EU. Figures 2 and 3 show the primary energy and fresh water used for the analysed steel products. There is a direct correlation between the GWP category and the use of energy required in the production processes. The use of energy from non-renewable sources is significantly higher than that from renewable sources in all the EPDs.

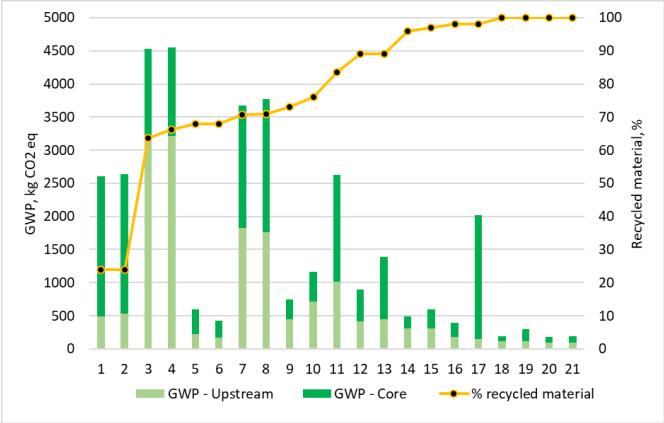

Fig. 1. GWP for 1000 kg of product and rate of recycled material – Geographic locations of production site: Global

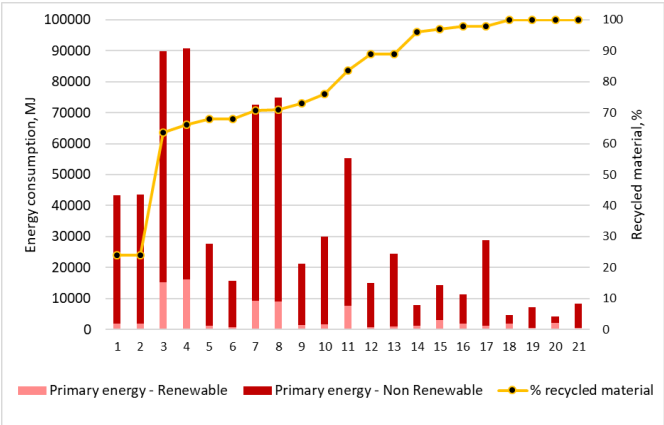

Fig. 2. Renewable and non-renewable energy consumption and rate of recycled material – Geographic locations of production site: Global

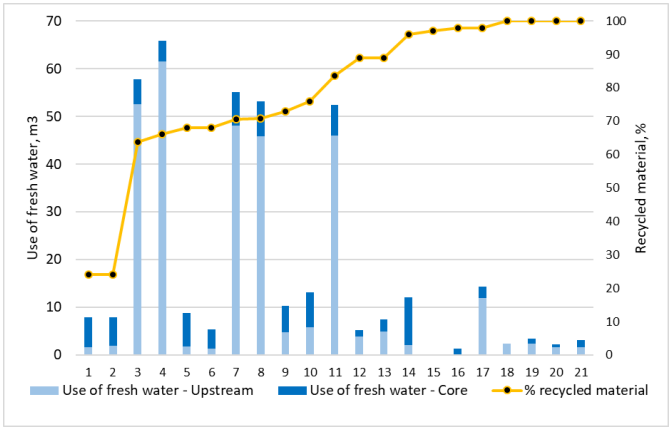

Fig. 3. Fresh water consumption for 1000 kg of product and rate of recycled material – Geographic locations of production site: Global

The amount of fresh water used is not related to the amount of recycled material used in the product. The analysis highlights how in EPDs that have higher GWP values, the water consumption referred to the Upstream is significantly greater than the Core phases. Use attributed to the extraction and production processes of the raw materials used in the final product. The EPD number 15 does not report data about use of fresh water, an optional information requested by the PCR.

3.3. Focus on EPDs developed in European production sites

A focus was carried out on EPDs developed in European production sites, as the companies involved in the project are located in Spain. Of the 21 declarations analysed, 13 have a geographical location in the EU. Figures 4, 5, 6 show the relationship between the recycled content of the products to which the EPDs refer with the GWP impact category, the use of energy from renewable and non-renewable sources and the use of fresh water. Also, in this case the non-correlation between recycled content and GWP value is highlighted. Furthermore, companies located in Europe have lower quantities of kgCO2eq emitted per functional unit than those in other parts of the world. The highest value is approximately 1400 kgCO2 eq for one ton of product. The energy consumption in the processes included in all EPDs underlines the dependence on non-renewable sources.

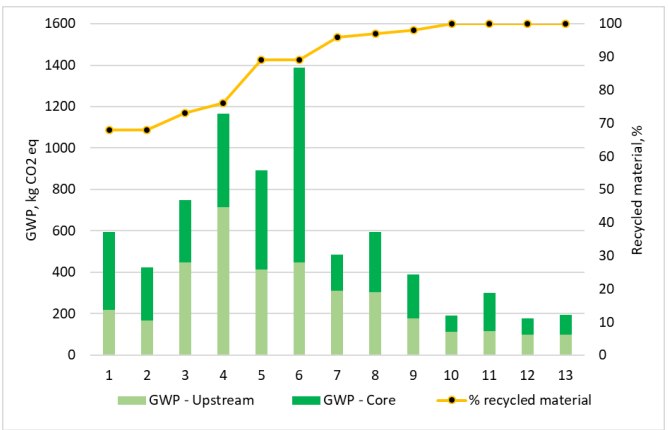

Fig. 4. GWP for 1000 kg of product and rate of recycled material – Geographic locations of production site: Europe

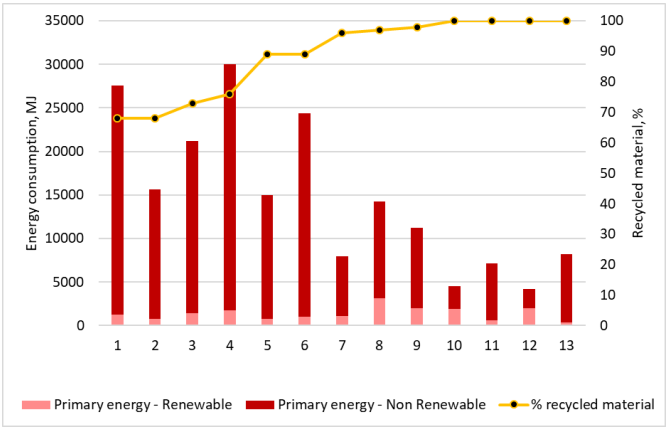

Fig. 5. Renewable and non-renewable energy consumption for 1000 kg of product and rate of recycled material – Geographic locations of production site: Europe

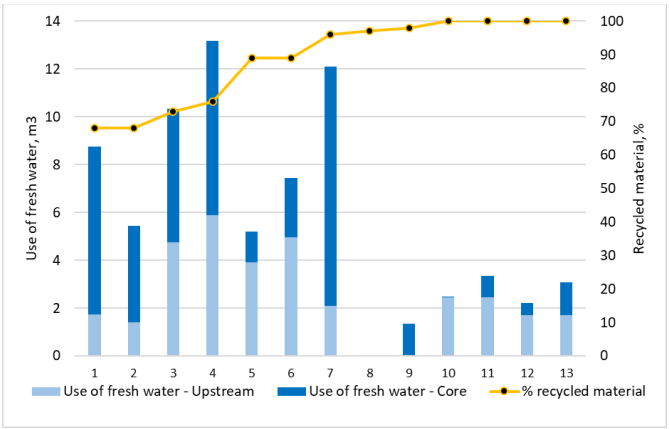

Fig. 6. Fresh water consumption for 1000 kg of product and rate of recycled material – Geographic locations of production site: Europe

4. Conclusion

The transportation sector contributes significantly to the emission of Greenhouse gases into the atmosphere. The LIGHTFORGE project aims to develop low-density steel forged elements for automotive applications, with the objective of reducing the weight of vehicles and consequently reducing the environmental impact associated with their use. This preliminary study has the purpose of identifying and collecting important information for the LCA study design of the products developed in the project.

The study of PCRs on the market allowed the identification of significant information for the study referring to LIGHTFORGE, such as the functional unit, system boundaries, and exclusion criteria to be adopted. In addition, the analysis of EPDs related to these PCRs and dealing with products comparable to those developed in the project was carried out, particularly with reference to semi-finished products such as billets and round bars. There is no evident correlation between the rate of recycled material in the product and GWP. While the GWP associated with the product has a high correlation with the use of primary energy in the processes, which is still prevalently produced from non-renewable sources. Finally, the use of fresh water in the processes in the Upstream is greater than the processes in the Core.

These results will allow the environmental profile of the product developed in the project to be compared with others already on the market in order to identify critical phases to be modified in the design phase. After studying the production process, the analysis will need to be extended to the product's use phase. The objective will be to verify and quantify the reduction in vehicle emissions associated with weight loss due to the use of low-density steel elements.

Acknowledgements

This project has received funding from the Research Fund for Coal and Steel, a programme managed by the European Commission, supporting research in the coal and steel sectors in Europe under grant agreement No. 101112392.

References

[1] EU Commision, 2021. Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 Establishing the Framework for Achieving Climate Neutrality and Amending Regulations (EC) No 401/2009 and (EU) 2018/1999 (‘European Climate Law’).
[2] Inci M, Büyük M, Demir MH, Ilbey G. A review and research on fuel cell electric vehicles: topologies, power electronic converters, energy management methods, technical challenges, marketing and future aspects. Renewable and Sustainable Energy Reviews. 2021;137:110648.
[3] Pu Y, Ma F, Zhang J, Yang M. Optimal lightweight material selection for automobile applications considering multi-perspective indices. IEEE Access. 2018;6:8591-8598.
[4] Zhang W, Xu J. Advanced lightweight materials for Automobiles: A review. Materials & Design. 2022;221:110994.
[5] Herrmann C, Dewulf W, Hauschild M, Kaluza A, Kara S, Skerlos S. Life cycle engineering of lightweight structures. CIRP Annals. 2018;67(2):651–72.
[6] International Organization for Standardization, 2006. ISO 14040:2006 Environmental management - Life cycle Assessment - Principles and Framework.
[7] International Organization for Standardization, 2006. ISO 14044:2006 Environmental management - Life Cycle Assessment - requirements and Guidelines.
[8] Toniolo S, Mazzi A, Simonetto M, Zuliani F, Scipioni A. Mapping diffusion of Environmental Product Declarations released by European program operators. Sustainable Production and Consumption. 2019;17:85–94.
[9] Grahl B, Schmincke E. The part of LCA in ISO type III environmental declarations. International Journal of Life Cycle Assessment. 2007;12(1):38–45.
[10] Del Borghi A. LCA and communication: Environmental Product Declaration. International Journal of Life Cycle Assessment. 2013;18(2):293–5.
[11] Ingwersen WW, Stevenson MJ. Can we compare the environmental performance of this product to that one? An update on the development of product category rules and future challenges toward alignment. Journal of Cleaner Production. 2012;24:102–8.
[12] Strazza C, Del Borghi A, Gallo M. Development of Specific Rules for the Application of Life Cycle Assessment to Carbon Capture and Storage. Energies. 2013;6(3):1250–65.
[13] Modahl IS, Askham C, Lyng KA, Skjerve-Nielssen C, Nereng G. Comparison of two versions of an EPD, using generic and specific data for the foreground system, and some methodological implications. International Journal of Life Cycle Assessment. 2013;18(1):241–51.
[14] International EPD System (IES), 2024. Product category rule (PCR) 2015:03: Basic iron or steel products & special steels, except construction steel products (Version 2.1.1).