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Carbon Footprint of a Windshield Reinforcement Component for a Sport Utility Vehicle

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Abstract: In this study, the carbon footprint of a steel-based windshield reinforcement component assembled in a sport utility vehicle was calculated in three different stages: steelmaking, stamping, and middle-of-use. Possible solutions to decrease carbon emissions were evidenced, such as the purchasing of steel made through low-impact technologies and the exploitation of the green energy grid to power up stamping machines. The life cycle assessment methodology was used to calculate the carbon footprint. Four different steels provided by different suppliers were compared in order to highlight the greenest material for both the steelmaking and stamping processes and the best supplier from an environmental point of view. In addition, the carbon footprint related to the component weight in vehicles with different traction set-ups, i.e., internal combustion engine, mild hybrid electric, and battery electric, was reported. To reduce the carbon footprint, electric arc furnace-based steelmaking and cold stamping were the best options. In addition, component weight reduction (for instance, changing materials) allowed a decrease in fuel and/or energy consumption, with carbon footprint benefits.

Keywords: automotive; LCA; AHSS

Citation: Tedesco, M.M.; Bruno, F.; Lazzari, S.; Lattore, M.; Palumbo, M.; Rizzi, P.; Baricco, M. Carbon Footprint of a Windshield Reinforcement Component for a Sport Utility Vehicle. *Sustainability* **2024**, *16*, 11263. https://doi.org/10.3390/su162411263

Academic Editors: Maja Trstenjak, Tihomir Opetuk, Nataša Tošanović and Hrvoje Cajner

Received: 13 November 2024
Revised: 18 December 2024
Accepted: 20 December 2024
Published: 22 December 2024

1. Introduction

On average, a vehicle contains approximately 900 kg of steel, divided as follows: 40% in the body in white, 35% in the power train, 20% in the chassis, and 5% in other components, such as interiors, seats, etc. The windshield reinforcement is a safety component that has a relevant rule during the crash, which is limiting the intrusion during the side pole impact and during the roll over. For these reasons, the materials have to be able to absorb the crash energy and, at the same time, limit the intrusion in order to guarantee safe space for the vehicle occupants. In the last decades, a new class of steel has been impacting car manufacturing, namely advanced high-strength steels (AHSSs). This family collects different steel grades, e.g., TRIP (transformation-induced plasticity), TWIP (twinning-induced plasticity), Q&P (quenching and partitioning), and Dual-Phase and Complex Phase steels. The main advantage is that they have higher yield strength than conventional high-strength steel (HSS), often combined with a better formability [1]. This behavior is due to microstructure differences between AHSS and HSS. Conventional HSSs are single-phase ferritic steels, with a potential for some pearlite in C-Mn steels. AHSSs have a microstructure containing a phase other than ferrite, pearlite, or cementite, for example, martensite, bainite, austenite, and/or retained austenite, in quantities sufficient to produce unique mechanical properties [2].

The production of steels and their transformation in vehicle components include five steps: smelting, rolling, galvanization, transport, and stamping. Considering steelmaking processes, the oldest (and most traditional) route is the blast furnace coupled with the basic oxygen furnace (BF-BOF). In the last decades, this process is being replaced with the electric arc furnace (EAF), wherein the smelting process is less impactful than BF-BOF [3]. In addition, it allows the consumption of four times the scrap amount (which is the main raw material in EAF steelmaking) than BF-BOF [3]. Recently, an innovative steelmaking route is being studied, namely direct reduced iron (DRI). In this process, a shaft furnace technology reduces iron oxides (as iron ores) in metal iron, without melting, by using a reductant gas (e.g., hydrogen) instead of coal [4]. The DRI process could be coupled with BF-BOF and EAF systems [5]. Currently, this technology is still not widely used, but, in the future, it could play an important role in steelmaking decarbonization. Concerning greenhouse gas (GHG) emissions, with DRI, if compared to BF-BOF, it is possible to reduce 33% of CO_{2eq} (which is the unit of measurement for carbon footprints) emissions using hydrogen [4]. This value can increase up to 57–67% if hydrogen is only produced from renewable energies [4]. Furthermore, to create automotive steel grades, beyond steel smelting and casting, other processes are exploited, such as rolling and zinc-coating or aluminum–silicon coating applications. Nonetheless, the decarbonization of these processes has not had notable advancement in the last decades. Concerning logistics, steel coils and scraps can be transported by means of trucks, freight trains, and ships. Environmental impacts of transportation strongly depend on traction technologies used in transportation modes [6]. Finally, to transform steel plates in car components, the stamping process is used. There are two different possibilities: hot or cold stamping. The choice depends on the component performance needs, complexity of the shape to be realized, and type of steel to stamp. Obviously, a cold stamping process is less impactful than a hot one because it consumes less energy.

For the same vehicle model, various engines are often available, e.g., gasoline internal combustion engine (ICE) vehicle, mild hybrid electric vehicle (MHEV), and battery electric vehicle (BEV). To estimate the vehicle middle-of-life, environmental impacts in use must be considered. Values are generally referred to as wheel-to-wheel (WTW), given by the sum of the wheel-to-tank (WTT), where the production of the energy source (fuel and/or electricity needed to recharge batteries) is considered, and the tank-to-wheel (TTW), wherein impacts due to energy source usage (fuel combustion) are taken into account. The TTW value is considered equal to zero in the cases of BEVs and MHEVs, since there are no emissions during battery use. On the contrary, in ICE vehicles, the fuel consumption must be considered. The most important parameter that affects environmental impact in vehicle use is weight. The greater the weight of the vehicle and therefore of the individual components, the greater the fuel and/or energy consumption will be.

The goal of this work was to identify some strategies to minimize the carbon footprint during the vehicle beginning-of-life and middle-of-life, considering current technologies and future trends. In particular, the stamping of a windshield reinforcement component and its use in a sport utility vehicle (SUV) sold in different traction versions (ICE, MHEV, and BEV) were considered. Three different use cases and four different steels provided by different suppliers were compared in order to assess the corresponding environmental impacts (Table 1).

Table 1. Use cases and steels.

Use Case	Aim	Functional Unit	Steels
(1) Vehicle CO_2 emissions.	Decrease environmental impacts of components during the middle-of-life stage.	1 component of windshield reinforcement (considering vehicle life of 225,000 km)	PHS1800 FBH440Y580T TBC700Y980T QPC850Y1180T
(2) Industrial and sites carbon footprint.	Increase percentage of renewable energy in the stamping line mix grid.	1 component of windshield reinforcement	
(3) Carbon footprint of the supply chain: purchasing and logistics.	Find the best suppliers from the environmental impacts point-of-view	1 ton of galvanized rolled coil/strip steel	

2. Materials and Methods

An SUV vehicle model produced in three different versions, i.e., ICE, BEV, and MHEV, was considered. The life cycle assessment (LCA) was performed according to ISO 14040/44:2021 [7,8]. Taking into consideration boundary conditions, the supply chain was modeled on GaBi software 2022.2 using data provided by software house processes (MLC database—Professional Core) and internal data. In all use cases, the global warming potential for 100 years (GWP-100) was used as the carbon footprint indicator, expressed as kg of CO_2 equivalent (kg CO_{2eq}). For each process, the GWP-100 was calculated by means of the CML 2001 method. This method is widely used for LCIA (life cycle impact assessment) calculation, especially in Europe. The impact assessment method implemented as the CML-IA 2001 method was defined for the midpoint approach [9]. As a functional unit, a single windshield reinforcement component was used to estimate the carbon footprint.

2.1. Use Case 1

The carbon footprint related to vehicle use was analyzed. Considered burdens for various traction types are listed in Table 2.

Table 2. Burdens considered for TTW and WWT in gasoline (ICE) and electric (BEV and MHEV) tractions.

	ICE	BEV and MHEV
TTW	Burdens consider fuel extraction, refining, and distribution.	Burdens consider electric energy production, taking into account the global energy grid.
WTT	Burdens consider emissions produced by fuel combustion.	No burdens were allocated because no pollutants are emitted.

2.2. Use Case 2

In this use case, the carbon footprint assessment of a windshield reinforcement stamping process was performed. The general scheme of the boundary conditions is reported in Figure 1.

In this use case, the steelmaking and the assembly burdens were not considered. Therefore, only energy consumption was the main burden considered in the stamping process. For this use case, energy meant both electrical current (for cold/hot stamping) and heat (only for hot stamping). Stamping was considered to be made in Italy, so the electricity grid mix and natural gas burdens of this country were considered.

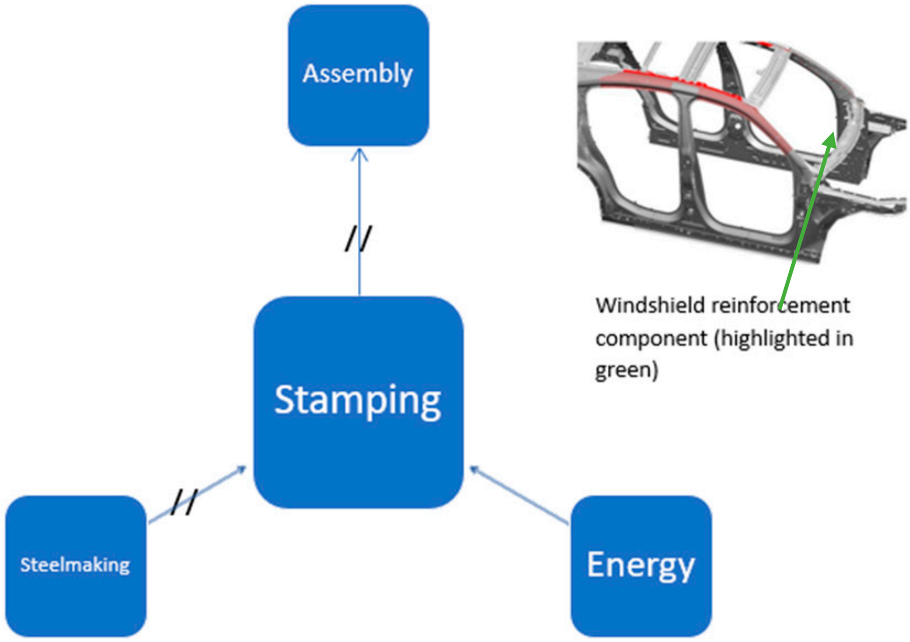

Figure 1. Scheme of stamping process cut-offs and the windshield reinforcement component installed in the SUV chassis. Steelmaking and assembly were not considered (black double lines).

The first selected material was PHS1800 steel, which is a hot-press-forming steel that is able to combine extremely high mechanical properties, yield, and tensile strength and high stampability, thanks to the process for which it is formed at a high temperature (930 °C) and quenched into the forming die. The second material was FBH440Y580T, a hot-rolled ferritic–bainitic TRIP steel, highly available in the market. This material was cold-stamped, and thanks to the obtained microstructure, it was able to absorb high energy during the crash; being available in the hot-rolled condition, it was possible to produce sheets with thicknesses higher 1.8 mm. The third considered material was TBC700Y980T, a TRIP steel with a bainitic microstructure and that retained austenite islands. The retained austenite, being a metastable phase at room temperature thanks to the mechanical energy provided during the crash deformation, progressively transformed into martensite, returning an increase in the work hardening rate at high strain levels [10]. The yield and tensile stress of this material were much higher than those of FBH440Y580T steel, i.e., 700 MPa vs. 440 MPa of yield stress and 980 MPa vs. 580 MPa in tensile; however, due to the complex microstructure, it was available and producible only as cold-rolled sheets, with a thickness less than 1.8 mm. The last considered material was QPC850Y1180T steel, which is a quenching and partitioning steel. It showed a higher yield strength than that of TBC700Y980T steel, i.e., 850 MPa compared with 700 MPa, and an ultimate tensile stress of 1180 MPa vs. 980 MPa, but it had a sufficient formability, making it possible to stamp it into complex geometries.

Table 3 summarizes the stamping process for each considered steel, together with corresponding gross and net weights. Net weight means the mass of the windshield component; conversely, gross weight is the sum of the net weight and the scrap mass generated during the stamping process.

Table 3. Type of stamping, together with gross and net weights, in steel stamping for considered steels.

Steel	Stamping	Gross Weight (Kg)	Net Weight (Kg)
PHS1800	Hot	8.8	4.75
FBH440Y580T	Cold	14.9	7.24
TBC700Y980T	Cold	12.19	10.5
QPC850Y1180T	Cold	5.92	5.1

2.3. Use Case 3

To compare environmental impacts of steels, the environmental product declarations (EPD) was used. The main reason for this choice lies in the fact that EPDs are standardized documents according to the EN15804 [11] normative. Moreover, the life cycle impact assessment is governed by product category rules (PCR), which provide the rules, the requirements, and guidelines for developing an EPD for a specific product category [12].

In EPD, it was possible to obtain environmental impacts of the manufacturing process. Notwithstanding, this document did not have many details about steelmaking stages and relative environmental impacts. Although some approximations could be made, it was difficult to find EPDs that used the same PCR. Nevertheless, use environmental impact values reported in EPDs were the best compromise to allow a due diligence study about environmental sustainability.

In this use case, rolled galvanized coils/strips of steels used in chassis components as the windshield reinforcement component were considered. Different steelmaking processes were considered, such as BF-BOF and EAF. All steels were considered as cold-rolled (CR). FBH440Y580T was hot-rolled, but an EPD of zinc-coated, hot-rolled steel was not available; therefore, it was assumed as cold-rolled. Two types of zinc coating were considered, i.e., electro-galvanization (EG) and hot-dip galvanization (HDG). Scrap credits were not considered because they should have already been counted in the smelting process.

Table 4 reports the GWP-100 impact values and the corresponding PCR for considered steels. The name code followed these rules: the first letter was the supplier; the second word was the steelmaking process; the third word was the type of rolling; and the fourth word was the type of zinc coating. Five different suppliers were considered in the analysis, as reported in Table 4. For F_BF_CR_HDG, the EPD was not available, and therefore, the GWP-100 value was replaced with the average value of the BF-BOF-based processes.

Table 4. GWP-100 impact values and relative PCR for considered steels.

Name	GWP-100 [kg $CO_{2eq.}$/t]	PCR
A_EAF_CR_HDG	877	2019.14 [13]
A_BF_CR_HDG	2560	2019.14 [13]
B_EAF_CR_HDG	1130	Structural steels [14]
C_BF_CR_EG	2410	Structural steels [14]
C_BF_CR_HDG	2350	2012.01 [15]
D_BF_CR_EG	2420	Structural steels [14]
E_EAF_CR_HDG	861	Structural steels [14]
F_BF_CR_HDG	2435	-

Every steel grade can be produced by one or more suppliers, as shown in Table 5.

Table 5. Steel grade production by steelmaker.

Steel Grade	Producer
PHS1800	A_BF_CR_HDG
FBH440Y580T	B_EAF_CR_HDG
TBC700Y980T	A_BF_CR_HDG and F_BF_CR_HDG
QPC850Y1180T	F_BF_CR_HDG

In order to estimate the carbon footprint in a cradle-to-gate approach, the steel production, taking data from EPDs of steel grade manufacturers reported in Table 4, and the transport were considered.

For coils transportation, the EcoTransIT tool [16] was used. This tool allowed us to calculate ship, train, and lorry route lengths from the steelmaker plant to the stamping lines placed in Italy. Considered values are reported in Table 6.

Table 6. Coils transportation distance between steelmakers and the Italian plant. As mentioned in Table 5, TBC700Y980T was produced by two different steelmakers. In this case, the reported distance was the average between routes from steelmaker A and F to the Italian plant.

Transport	Ship [km]	Train [km]	Lorry [km]
PHS1800		1145	262
FBH440Y580T			676
TBC700Y980T	7565	594	530
QPC850Y1180T	15,130		562

3. Results

Concerning use case 1, for different considered steels, the middle-of-life environmental impact given by the consumption of fuel (for ICE and MHEV vehicles) and electricity (for MHEV and BEV) was calculated. Obtained values were weighted on the mass of the component under study. Results of the calculated GWP-100 are reported in Figure 2.

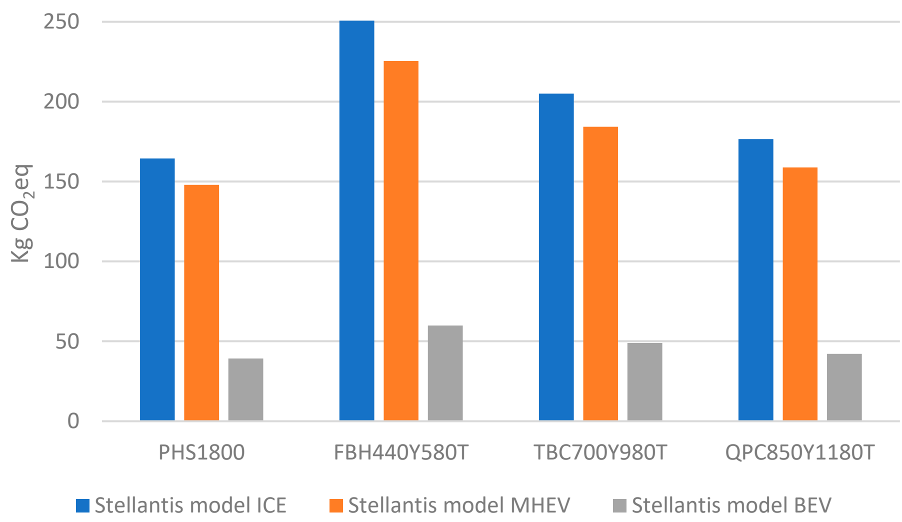

Figure 2. Relative middle-of-life environmental impact of a windshield reinforcement component produced with different steel grades and for different vehicle uses.

As can be observed in Figure 2, the electrification of vehicles would allow emissions to decrease the GWP-100. In fact, emissions for BEV were around 75% smaller than those of ICE.

Regarding use case 2, a comparison among obtained GWP-100 values of the stamping process for each steel grade was performed, and results are shown in Figure 3.

PHS1800 showed the worst environmental performance due to natural gas consumption in hot stamping. On the contrary, cold-rolled steels were the most sustainable, and their impacts depended on the final weight component.

The stamping process carbon footprint was strongly related to the electricity grid mix. In GaBi, considering that the stamping process occurred in Italy, it was possible to consider four different electricity grids. The first one described the current electricity grid mix, whereas the other three represented the potential future Italian energy mix in 2030, 2040, and 2050, following the forecasts collected in the EU energy trends report [17]. The main difference between the "now scenario" and the "future scenarios" was the renewable energy intake growing in the next decades. Moreover, in order to minimize the CO_2 emission relative energy consumption, the possibility of producing electrical energy from an in situ photovoltaic plant was evaluated. In this case, burdens about facility construction and maintenance were not considered; only the burden related to energy production was allocated.

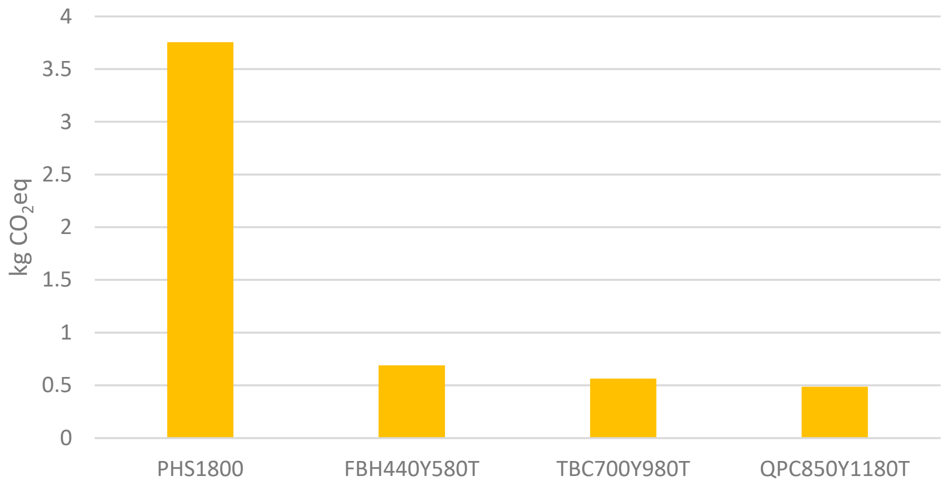

Figure 3. Comparison of environmental impacts for the stamping process with different steel grades considered for windshield reinforcement.

In PHS1800, which was hot-stamped, only the burden related to natural gas (NG) production was considered, while burdens about facility construction and maintenance were neglected.

GWP-100 values obtained for various scenarios are compared in Figure 4.

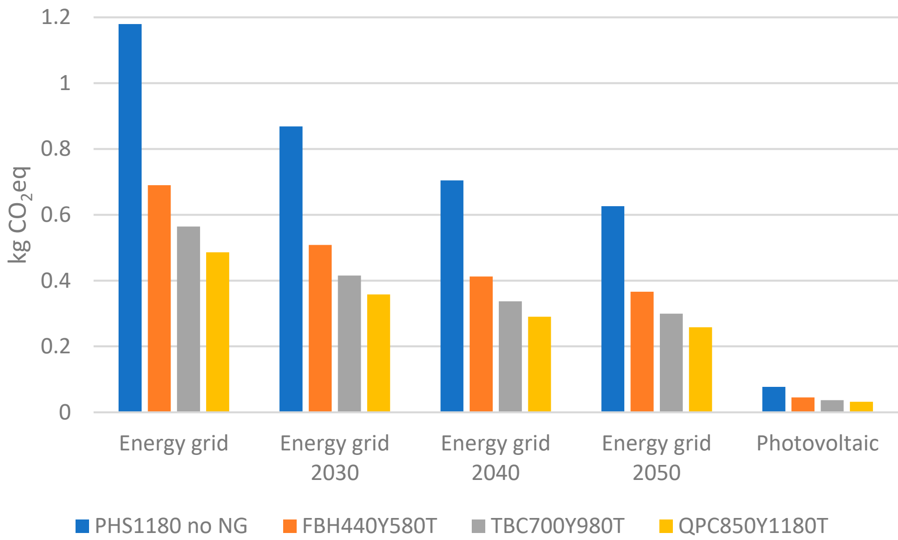

Figure 4. GWP-100 values for stamping lines in various energy grid scenarios.

As expected from data reported in Figure 5, it can be appreciated that the usage of renewable energy sources, which will increase in the next decades, contributed to the decreased GWP-100 of the stamping process.

According to European Commission forecasts about EU energy trends, carbon footprint, as far as electrical energy demand is concerned, should halve gradually in the next 26 years. In addition, the usage of electrical energy provided from the photovoltaic plant would allow 93.5% of GWP-100 emissions to be saved, compared to the actual Italian energy grid mix. This would bring a remarkable reduction of environmental impacts on vehicle production. However, before implementing this strategy, costs studies are needed to evaluate the feasibility and potential gain at a long, breakeven point.

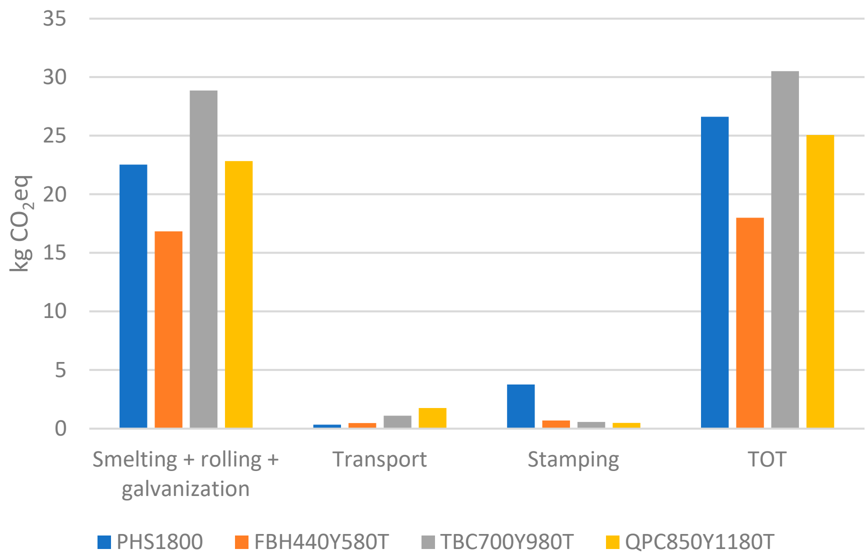

Figure 5. Cradle-to-gate GWP-100 for different steel grades considered for windshield reinforcement.

As far as use case 3 is concerned, the environmental impact for a cradle-to-gate approach was calculated, and the outcome of GWP-100 values obtained for considered steel grades is reported in Figure 5.

As can be pointed out from Figure 5, taking into account that the functional unit was the single windshield reinforcement component and considering the steelmaking process used by the manufacturer and the transport, the FBH440Y580T steel appeared the most eco-friendly. This was mainly due to its production by means of EAF technology, which, as mentioned in the previous subsections, is the most sustainable route. In addition, PHS1800 had a significantly high stamping impact, as shown in Figure 3, but its GWP-100 value was lower than that of TBC700Y980T and slightly higher than that of QPC850Y1180T. This was mainly due to the fact that the amount of steel utilized to produce a PHS1800-based windshield reinforcement component was lower than that consumed using other steels (Table 3).

After collecting all EPDs, GWP-100 emissions for considered steels were compared in order to understand which was the best supplier from the environmental point of view. Considering steels listed in Table 5, results of the calculation are reported in Figure 6.

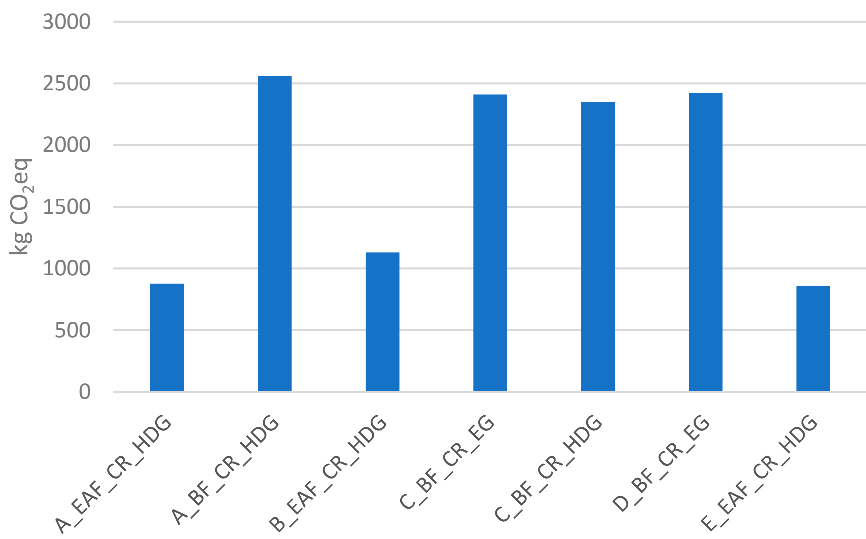

Figure 6. GWP-100 emissions for steels considered for windshield reinforcement.

As can be seen in Figure 6, the difference in GWP-100 among steels produced with BF-BOF and EAF was the largest, as widely reported in literature [2]. On the contrary, the difference between galvanization techniques was rather small, with the HDG production showing a slightly larger GWP-100 with respect to EG [18].

4. Discussion

The results obtained show that the decarbonization of the steel industry is based on EAF technology, which reduces emissions during the production of steel. This fact is confirmed by Liang T. et al. (2020) [3]. In fact, the casting process is the most expensive in terms of environmental impact, compared to other processes in the supply chain, such as rolling [3].

Concerning the stamping process, hot stamping requires more electricity and natural gas consumption with respect to the cold one. The only hot-stamped steel examined was PHS1800, whose carbon footprint was 4 times larger than other steels considered. The main burden in the stamping process is energy consumption. To reduce carbon footprint, the electric energy grid mix was studied because natural gas in hot stamping is essential for heating. Pushing towards an energy grid mix with a high percentage of renewables allows emissions relative to energy consumption to decrease. In addition, considering electrical energy produced in situ through photovoltaic cells, the carbon footprint can be reduced by 93.5%.

At the level of vehicle emissions, the weight of the component has a contribution towards emissions (endothermic engine) or energy consumption (batteries). The greater the mass of the component, the more energy it will take to move the vehicle. As a result, emissions will increase. To reduce the weight of cars, carmakers choose less dense steels (such as AHSS) or much lighter materials like aluminum alloys, which have less mechanical properties, such as a lower elastic modulus. In this work, the first case was considered, and the lightest material was the PHS1800.

Steel selections for automotive applications in a sustainable way have many variables. In this case, only steelmaking, stamping, and middle-of-life carbon footprints were considered. Other relevant factors must be taken into account, such as the welding process and component design. All of these factors contribute to the increase in the environmental impact of the finished components. Developing new tools is needed to help steelmakers and car manufacturers reach carbon net zero goals as soon as possible.

Nevertheless, purchasing strategies must be supported by price competitivity. Costs depend on the steelmaking processes, coil size, coating, and surface aspects. In every company, decisional models that allow them to choose the best materials that satisfy both environmental and economic needs are running.

5. Conclusions and Future Perspectives

In this paper, the environmental impacts of steels production and uses were analyzed. Various suppliers and steel grades were considered. The main conclusions can be summarized as follows:

- Suppliers that use EAF in the smelting process have a smaller carbon footprint than others that exploit the BF-BOF route.
- Hot stamping is much larger than cold stamping in terms of emissions because in the first process, there is greater electricity consumption, and a heat source is needed. In particular, when using cold stamping, it is possible to save 65% of the carbon footprint.
- When a cradle-to-gate calculation considering steelmaking and transport is applied, FBH440Y580T steel is the most eco-friendly because it is produced through the EAF route. In particular, using FBH440Y580T, which is produced by supplier A through EAF technology, it is possible to save 25–42% of the carbon footprint. Although PHS1800 has a significantly higher impact due to stamping, its total impact is lower than the TBC700Y980T and slightly higher than the QPC850Y1180T. This effect is

due to lower steel consumption in PHS1800-based windshield reinforcement component manufacturing.

- Using green energy from photovoltaic panels installed inside the production plant, the GWP-100 value can be reduced up to 93.5%.
- BEV vehicles have the lowest environmental impact score in the middle-of-life. This feature positively affects components assembled in this type of vehicle, such as in windshield reinforcement.

The automotive industry, being strongly addressed to global warming, is implementing plenty of decarbonization plans to soon reach carbon neutrality. For this reason, the attention to green and low CO_2-emitting products is increasing day by day. In fact, each original equipment manufacturer (OEM) introduced internal targets to reach the carbon net zero goals much earlier than targets officialized by the European Commission. It is possible to identify two main sources of CO_2 emissions in the automotive sector: vehicle exhaust smoke, which is reduced or eliminated by MHEV and BEV, and the materials used to build the car. For this second aspect, OEMs are forcing suppliers to anticipate their decarbonization plans to be aligned with their targets. This is the reason why steel mills are starting to invest in new technologies and to offer the best decarbonized products. In the near future, products obtained by BF will be replaced by those obtained with EAF or DRI. At the moment, the main limit for EAF technology is linked to scraps, which, in most of the cases, are rather mixed and have poor quality. Therefore, OEMs are pushing to implement the so-called "closed-loop approach" with suppliers, asking to take the pre-consumer scraps and then sending back them to the steel industry in order to produce the steel for the automotive products again. In such a way, the quality of scraps becomes high, allowing the production of advanced, high-strength steels. DRI is a technology in which most advanced steel mills are investing because it permits, also in the absence of good scrap quality, the production of high-quality steel, with the raw material iron ores reduced by means of hydrogen or natural gas. In early applications, natural gas will be used to reduce the iron ores until green hydrogen is available at low cost in the market.

Although the environmental benefits, due to the use of EAF and DRI, are widely discussed in literature, the production and sales costs also play a significant role. Precisely, the main features that affect costs are: the steelmaking process, coating application, coil shape, and surface aspect. The production costs of steels made through EAF are as competitive as those manufactured from BF-BOF.

The OEMs have already started to sign memorandums of understanding with the steel mills to secure green steel availability and to be sure to be able to reach their target of CO_2 reduction. Several research projects will be carried out in the near future to identify the maximum tramping elements that can be managed in the EAF steel without affecting the final material properties, as well as studies to reduce the vehicle weight, leading to less material consumption and reduced CO_2 emissions.

Author Contributions: Conceptualization, M.M.T., F.B., S.L., M.L., P.R. and M.B.; methodology, M.M.T., F.B., S.L. and M.L.; software, M.M.T., F.B., S.L. and M.L.; validation, M.M.T., F.B., S.L., M.L., P.R. and M.B.; formal analysis, M.M.T., F.B., S.L., M.L., P.R. and M.B.; investigation, M.M.T., F.B., S.L. and M.L.; resources, S.L. and M.L.; data curation, M.M.T., F.B., S.L. and M.L.; writing—original draft preparation, M.M.T., F.B., S.L. and M.L.; writing—review and editing, M.P., P.R. and M.B.; visualization, M.M.T., F.B., S.L. and M.L.; supervision, M.P., P.R. and M.B.; project administration, M.M.T. All authors have read and agreed to the published version of the manuscript.

Funding: Support from Project CH4.0 under the MUR program "Dipartimenti di Eccellenza 2023–2027" (CUP: D13C22003520001) is acknowledged.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: Author Silvia Lazzari and Marco Lattore were employed by the company Stellantis N.V. Michele Maria Tedesco was employed by the company Centro Ricerche Fiat S.C.p.A. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Available online: https://worldsteel.org/steel-topics/steel-markets/automotive/ (accessed on 18 June 2024).
2. Young, D. Available online: https://www.aedmetals.com/news/high-strength-steel-vs-advanced-high-strength-steel (accessed on 11 December 2024).
3. Liang, T.; Wang, S.; Lu, C.; Jiang, N.; Long, W.; Zhang, M.; Zhang, R. Environmental Impact Evaluation of an Iron and Steel Plant in China: Normalized Data and Direct/Indirect Contribution. *J. Clean. Prod.* **2020**, *264*, 121697. [CrossRef]
4. Zang, G.; Sun, P.; Elgowainy, A.; Bobba, P.; McMillan, C.; Ma, O.; Podkaminer, K.; Rustagi, N.; Melaina, M.; Koleva, M. Cost and Life Cycle Analysis for Deep CO_2 Emissions Reduction for Steel Making: Direct Reduced Iron Technologies. *Steel Res. Int.* **2023**, *94*, 2200297. [CrossRef]
5. Available online: https://www.midrex.com/ (accessed on 18 June 2024).
6. Kendra, M.; Skrúcaný, T.; Dolinayová, A.; Čamaj, J.; Jurkovič, M.; Csonka, B.; Abramović, B. Environmental Burden of Different Transport Modes—Real Case Study in Slovakia. *Transp. Res. D Transp. Environ.* **2023**, *114*, 103552. [CrossRef]
7. UNI—Ente Italiano di Normazione. Available online: https://store.uni.com/uni-en-iso-14040-2021 (accessed on 18 June 2024).
8. UNI—Ente Italiano di Normazione. Available online: https://store.uni.com/uni-en-iso-14044-2021 (accessed on 18 June 2024).
9. PRé Sustainability. *SimaPro Database Manual: Methods Library*; PRé Sustainability: Amersfoort, The Netherlands, 2020.
10. AHSS Application Guidelines—WorldAutoSteel. Available online: https://ahssinsights.org/metallurgy/steel-grades/3rdgen-ahss/transformation-induced-plasticity-trip/) (accessed on 18 June 2024).
11. Certifico S.r.l. Available online: https://www.certifico.com/normazione/209-documenti-riservati-normazione/organismi-normazione/documenti-uni/14647-uni-en-15804-2021 (accessed on 30 July 2024).
12. EPD International. Available online: https://www.environdec.com/product-category-rules-pcr/the-pcr (accessed on 30 July 2024).
13. EPD International. Available online: https://www.environdec.com/news/new-version-of-construction-products-pcr-2019-14 (accessed on 30 July 2024).
14. Felicitas Naumann. *PCR Guidance-Texts for Building-Related Products and Services. Part B: Requirements on the EPD for Structural Steels*; Felicitas Naumann: Berlin, Germany, 2023.
15. EPD International. Available online: https://data.environdec.com/resource/sources/af8dbdd3-99cf-43cf-a160-4b50c3d4320a/pcr2012-01+v2.2+Construction+products+and+construction+services.pdf?version=00.00.001 (accessed on 17 December 2024).
16. EcoTransIt World. Available online: https://www.ecotransit.org/en/emissioncalculator/ (accessed on 17 December 2024).
17. Capros, P.; De Vita, A.; Tasios, N.; Siskos, P.; Kannavou, M.; Petropoulos, A.; Evangelopoulou, S.; Zampara, M.; Papadopoulos, D.; Paroussos, L.; et al. *EU Reference Scenario 2016 Energy, Transport and GHG Emissions Trends to 2050*; Publications Office of the EU: Luxembourg, 2016.
18. Tongpool, R.; Jirajariyavech, A.; Yuvaniyama, C.; Mungcharoen, T. Analysis of Steel Production in Thailand: Environmental Impacts and Solutions. *Energy* **2010**, *35*, 4192–4200. [CrossRef]