Carbon Footprint of Automotive Transmissions and Engines Components – Auto Parts Manufacturer Point of View

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ABSTRACT

The road transport sector accounts for about 9% of Greenhouse Gas emissions in Brazil. The Product Carbon Footprint (PCF) analysis helps to understand the origin of these emissions. From the vehicle's point of view, the largest contributor to the equivalent emissions is the use phase of the vehicle, followed by emissions from raw materials and manufacturing of components; therefore, the decarbonization of auto parts manufacturers is important to limit the global warming. The objective of this study is to investigate the PCF of components for automotive transmission and engine systems. A methodology is proposed to break down the PCF into material categories with a cradle-to-gate scope, complementing similar studies conducted from the perspective of car manufacturers. The PCF is the method established by ISO 14067 to determine the climate impact of a product, which, throughout its life cycle, is represented in the form of equivalent carbon dioxide emissions. This study is based on the product portfolio of Schaeffler for transmission and engine systems of passenger vehicles. Preliminary results show that most emissions up to the gate are generated by steel and plastic materials, among 7 different categories analyzed.

INTRODUCTION AND MOTIVATION

The phenomenon of climate change refers to alterations in the Earth's climate patterns, observable on local, regional, and global scales, primarily driven by the intensification of the greenhouse effect due to anthropogenic emissions of gases. According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [1], global warming of approximately 1.1°C is already causing severe impacts on both natural ecosystems and human societies.

Among the main effects observed are the increase in the global average temperature, the rise in ocean levels, ocean acidification and the intensification of extreme weather events such as prolonged droughts, hurricanes, and floods [2]. These phenomena directly impact biodiversity, food security, public health, and the global economy.

In the industrial realm, sectors such as automotive face the urgent need for adaptation. Specifically for auto parts manufacturers, it becomes imperative to measure, manage, and reduce greenhouse gas (GHG) emissions associated with operations and products, as a condition for business sustainability and compliance with regulatory requirements. According to the International Energy Agency [3], the transportation sector is responsible for about 24% of global energy-related CO_2 emissions, highlighting the strategic role of the automotive industry in mitigating climate change.

In this context, international instruments such as the Kyoto Protocol and the Paris Agreement play a fundamental role in establishing mitigation targets against climate effects. The Kyoto Protocol, adopted in 1997 and in force since 2005, set legally binding emission reduction targets for developed countries, starting the era of multilateral climate commitments. Subsequently, the Paris Agreement, signed in 2015 under the United Nations Framework Convention on Climate Change (UNFCCC), established the main objective of limiting the increase in the global average temperature to well below 2°C above pre-industrial levels, with efforts to restrict it to 1.5°C. Unlike Kyoto, the Paris Agreement involves all signatory countries in commitments to mitigation, adaptation, and climate financing, reinforcing the need for transformation in productive sectors, such as automotive, to build a low-carbon economy [4].

In Brazil, the transportation sector represents a significant fraction of GHG emissions. In 2020, this sector accounted for approximately 13% of total national emissions, with road transport being the main contributor [5].

Focusing on the state of São Paulo, there was a noted increase in vehicle emissions in 2023: about 45 million tons of CO_2 equivalent were emitted by road vehicles, representing a 3% increase compared to the previous year. Automobiles were responsible for the highest emission of carbon monoxide (CO) and non-methane hydrocarbons (NMHC), while trucks were the main emitters of particulate matter (PM), nitrogen oxides (NO_x), and sulfur dioxide (SO_2) [6].

The automotive supply chain, which includes the production of auto parts and vehicle assembly, is particularly relevant in this context. Each step in the lifecycle of automotive components — from the extraction of raw materials to disposal — contributes to the global emissions inventory. Therefore, the quantification and mitigation of these emissions become essential for regulatory compliance and business competitiveness [7].

Considering this scenario Brazilian government is already preparing and enforcing new laws and regulations to ensure that the goals requested by international institutes and signed agreements be reached such as the MOVER program [8] which specify and request the fulfillment of relevant targets for CO_2e emissions, recyclability and energy efficiency for the automotive industry. Also we can see that Brazilian Car producers are acting to reach these targets with the release of decarbonization programs such as VW do Brasil with Way to Zero Program and the publication of the paper “Decarbonization Index as a Compass for the Way to Zero CO_2e Emission of Light Vehicles in Brazil” [9] which proposes the creation of a general decarbonization index to guide the decarbonization initiatives, but already shows where we have the main emissions of CO2e during the vehicle lifetime like the vehicle use and production. This paper intent is to show the participation of an Auto Parts Manufacturer in the emissions for the car manufacturing process from Cradle to Gate.

METHODOLOGY

For the purposes of measuring and comparing the climate impacts of various greenhouse gases, the concept of carbon dioxide equivalent (CO_2e) is used. CO_2e represents the amount of CO_2 that would have the same global warming potential as a given amount of another greenhouse gas, considering their respective global warming potentials (GWP) over a standard 100-year time horizon [10]. Thus, CO_2e provides a common basis for quantifying and reporting the aggregated emissions of multiple greenhouse gases.

The GHG Protocol is the primary global methodology for quantification and management of GHG emissions [11]. Developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), the protocol provides standards for creating emissions inventories in organizations, products, and supply chains. It aims to establish clear guidelines for organizations across different sectors to measure, monitor, and reduce their GHG emissions transparently and consistently. The GHG Protocol allows companies to calculate and communicate their emissions in compliance with international sustainability best practices.

In Brazil, the Brazilian GHG Protocol Program, an initiative of the Fundação Getulio Vargas Center for Sustainability Studies, adapts these guidelines to the national context [12]. The program provides tools for the systematic quantification and reporting of emissions, addressing the specific needs of sectors like automotive.

Within the automotive industry, the GHG Protocol enables the identification of major emission sources throughout the product lifecycle, providing insights for effective decarbonization strategies [13].

The GHG Protocol organizes greenhouse gas emissions into three scopes to provide a clear and structured view of the sources of emissions from an organization, product, or supply chain.

- **Scope 1:** Refers to emissions from sources owned or controlled by the organization. This includes, for example, the combustion of fuels in company-owned fleet vehicles or the use of fossil fuels in internal industrial processes.

- **Scope 2:** Covers indirect emissions resulting from the generation of electricity, heat, or steam that an organization purchases from third parties. Although the organization does not directly control these emissions, its choice of energy suppliers can have a significant impact on total emissions.

- **Scope 3:** Other indirect emissions throughout the value stream, such as transportation, product disposal, and supplier activities.

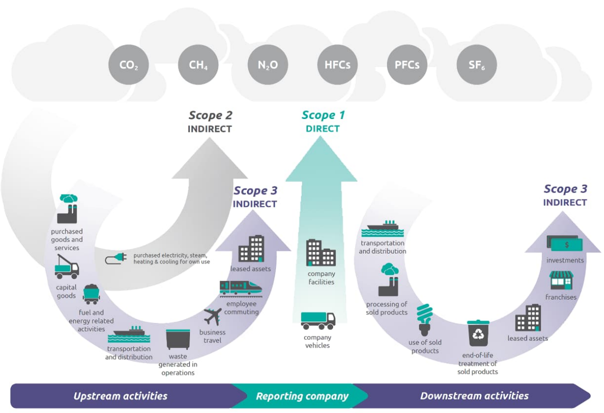

Figure 1. Overview of GHG Protocol scopes and emissions across the value chain.

Within the context of the GHG Protocol, Upstream and Downstream activities refer to distinct phases of an organization's value stream, primarily identified within Scope 3 (indirect emissions). These activities encompass the emissions associated with processes and operations that happen before (upstream) or after (downstream) the main production process of a company but still form part of the value stream.

Upstream Activities: These are activities that happen before the production of goods or services by the company. In terms of the value stream, they include all activities involving the supply of raw materials, components, energy, and services that the company uses for its core operations. These activities can happen directly with suppliers or in the acquisition of supplies, transportation, and storage before the products are manufactured.

Downstream Activities: Refer to all operations occurring after the production of the good or service. They encompass the distribution, use, and disposal of the final product, as well as all subsequent stages involving the product while it remains part of the company's value stream.

The corporate emissions inventory involves the systematic accounting of direct and indirect GHG emissions of an organization, according to the GHG Protocol and ISO 14064 [14]. Its development allows the identification of reduction opportunities, supports the definition of climate targets, and adequately addresses stakeholder demands. For auto parts manufacturers, such practices have become not only a regulatory obligation but also a critical factor for competitiveness, especially in global value streams.

Product Carbon Footprint (PCF): It quantifies the GHG emissions associated with all phases of a product's lifecycle, from raw material extraction to final disposal. ISO 14067:2018 standardizes the PCF calculation methodology [15] in alignment with Lifecycle Assessment (LCA) standards (ISO 14040 and ISO 14044).

Lifecycle Assessment (LCA): A scientific methodology for measuring the environmental impacts of products, processes, or services throughout their lifecycle [16];[17]. LCA is divided into four phases:

- **Goal and Scope Definition**: Establishes the functional unit and system boundaries.

- **Inventory Analysis**: Quantifies material and energy inputs and outputs.

- **Impact Assessment**: Classifies and characterizes environmental effects.

- **Interpretation**: Identifies hotspots and proposes improvements.

In the automotive sector, the production of metallic components, such as steel parts, accounts for a sizable portion of vehicle emissions. Steel production alone is responsible for about 7% of global GHG emissions [18]. Additionally, machining and precision manufacturing processes significantly contribute to the carbon footprint due to high energy consumption [19].

Applications in the automotive industry show that decisions on materials and manufacturing processes can significantly reduce environmental impacts [20]. Integrating the carbon footprint into the LCA context expands the systemic view of the climate impacts of components, contributing to more sustainable practices and compliance with international agreements, such as the Paris Agreement [4].

Therefore it shows the importance of the analysis by the point of view of an Auto Part manufacturer, even though LCA analysis of the proposed systems can reach from Cradle to Gate and not until the Grave from the vehicle LCA it still is possible to verify the impact of raw materials used in the components production and their manufacturing processes.

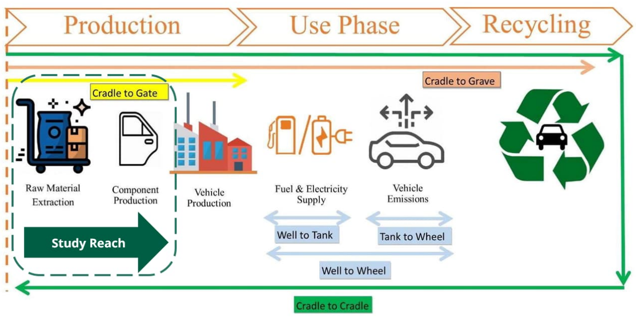

Figure 2. Vehicle Life Cycle Assessment Stages [21].

Main objectives of this study are map emissions of components supplied to automotive engines and transmission of relevant Brazilian car manufacturers; find major contributors of CO_2e emissions between analyzed emission categories; show opportunities and synergies between car makers and auto parts manufacturers for better management of CO_2e emissions; and bring another view (auto parts manufacturer) of the vehicle manufacturing value stream regarding the generation of CO_2e.

The PCF analysis for this study uses components supplied by Schaeffler Brazil for Engine and Transmission systems of light vehicle for several car makers. For the engines the selection criteria were 3 different car maker engines which were Flex fuel, naturally aspirated with 3 cylinders and 1,0L displacement, for the 3 transmissions the criteria used was manual type transmissions with 5 gears of the same car maker of the engines.

For the engines systems the selected components / systems for PCF analysis were:

- **Variable Cam Phaser (VCP):** is a mechanism integrated into internal combustion engines to enable the continuous adjustment of camshaft timing. It employs either hydraulic or electric actuation to precisely alter the camshaft position, facilitating optimized valve overlap and timing for improved combustion processes.

- **Finger Follower:** is a component within the valve train of an internal combustion engine, serving as a mechanical lever that translates camshaft rotational movement into linear action to actuate the valves.

- **Hydraulic Pivot:** component integrated with the engine Finger Follower within the valve train of internal combustion engines, designed to provide precise and dynamic adjustment of valve actuation. The hydraulic pivot uses engine oil pressure to adjust the rocker arm's position relative to the valve stem, thereby compensating for variations in thermal expansion and wear.

- **Water Pump Bearing:** component designed to support the rotational movement of the water pump pulley in automotive cooling systems. The design facilitates optimal heat dissipation and coolant circulation, which are crucial for maintaining engine temperature within the desired range and preventing overheating.

- **Idler Pulley:** is a component within the accessory belt drive system of internal combustion engines, specifically designed to guide and maintain tension in the drive belt. This pulley plays a crucial role in ensuring the efficient operation of various engine accessories such as the alternator, air conditioning compressor, and power steering pump.

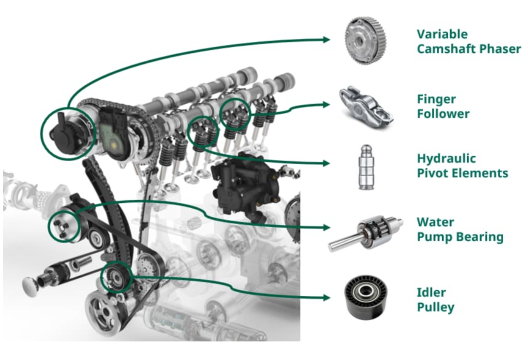

Figure 3. Engine system components overview.

For the transmission systems the selected components / systems for PCF analysis were:

- **Synchronizer Ring:** designed to facilitate gear shifting by synchronizing the rotational speeds of gears before engagement. These rings employ friction surfaces to adjust the speed between the engaging gear and the corresponding shaft enabling precise gear changes.

- **Synchro Detent Pin:** this component pin works with the synchronizer mechanism to provide a tactile stopping point for the shift collar, facilitating gear selection. Helping to hold the shift fork in place, it prevents unintended gear disengagement and contributes to the stability and smoothness of the gear shifting process.

- **Needle Cage:** facilitate the smooth rotational movement of transmission shafts and gears. By providing uniform distribution of forces, they minimize friction and wear between interacting surfaces, thus improving the performance and reliability of the transmission.

- **Inner Ring:** inner rings serve as the raceway for the bearings, ensuring smooth, efficient rotation and maintaining the alignment of transmission shafts and gears.

- **Roller Bearing:** support the rotational movement of the shaft, facilitating the power transmission within the gearbox. These bearings handle both radial and axial loads, ensuring precise alignment and reducing friction and wear during operation.

- **Clutch Release Bearing:** tasked with facilitating the smooth engagement and disengagement of the clutch. During clutch operation, the release bearing enables the transfer of force from the clutch pedal to the clutch pressure plate, allowing for the interruption of power flow to the transmission.

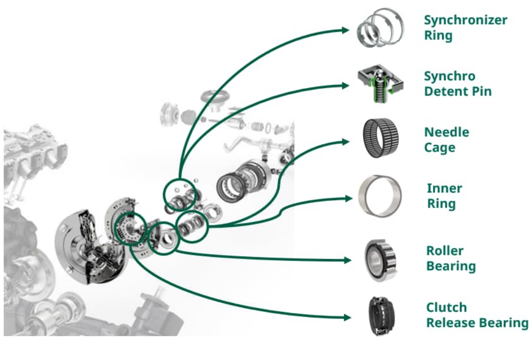

Figure 4. Transmission system components overview.

The next step was collect the PCF´s of the components for Transmission and Engines for the three Auto Maker selected using the SUMA (Sustainability Manager) which is a digital solution developed in-house that helps to identify the right measures for long-term emission reduction scenarios and to draw up decarbonization scenarios [22].

In the search for the component through SUMA there is the possibility of 2 results, first is the PCF of the requested components and second is the PCF of a reference product. A reference product is always the same type of product searched (same general design and materials), but with different dimensions. In case when the output of the search is a reference product, it was necessary to adjust the PCF values of each emission category using a correction factor, which is the ratio between the target weight product and the reference product weight. This correction factor is to multiply the values of CO_2e and mass of each emission category of the reference product to obtain the corrected values of both for the target product. The portfolio of analyzed products for each system is shown in Table 1 and Table 2.

COMPONENT		A	B	C
Variable Camshaft Phaser		2	2	2
Finger Follower		12	12	6
Hydraulic Pivot Elements		12	12	6
Water Pump Bearing		1	1	1
Idler Pulley		1	1	1

Table 1. Engine matrix.

COMPONENT		A	B	C
Synchronizer Ring		6	2	2
Synchro Detent Pin		9	9	9
Needle Cage		4	5	5
Inner Ring		1	2	1
Roller Bearing		2	2	2
Clutch Release Bearing		1	1	1

Table 2. Transmission matrix.

Finally, was possible to get the average PCF for components analyzed for the 3 engines and 3 transmissions systems selected previously. With the average engine and transmission system we could identify the first valuable information in the analysis, the CO2e emissions and weight percentages for each individual component inside the average engine and transmission system.

And, we could group all emission categories for the components inside each average system and check the participation of each one of them in the total CO2e emissions and weight percentages in the total of the systems. For these emission categories we decided to group them in the following categories:

- **Metallics (all materials which are metals):**
  - **Aluminum:** all aluminum material used in the components.
  - **Sintered steel:** Powdered steel produced through powder metallurgy.
  - **Forged steel:** steel submitted to forging process**.**
  - **Forming steel:** steel post processed through a forming process such wires, coiled and bars**.**
- **Non-Metallics (materials without metals):**
  - **Plastic:** plastic used for injection process.
  - **Elastomer:** rubber materials.
  - **Oil & grease:** material used for part lubrication.
- **Others (emissions categories which doesn´t add mass in the part, such as Scope 2, Scrap and Logistics).**

The categories explained are used only for this paper with the intention to facilitate the data interpretation and not a standard form to group emission categories and neither a proposal to be used across the industry.

RESULTS AND DISCUSSION

The first results show the participation of each component inside the average engine system, as shown in Figure 5. It is possible to clearly identify the direct correlation between mass and CO_2e emissions, the two VCP components correspond to 61% of mass of all components supplied into the system and has 75% participation of total emissions.

Component	Mass Share	CO_{2eq} Emissions Share
VCP	61%	75%
Pivot	7%	4%
Rocker Arm	24%	13%
Water Pump Bearing	4%	2%
Pulley	5%	5%
Total	**100%**	**100%**

Figure 5. Components Average Mass and CO_2e for Engine System

Next is the distribution of average mass and CO2e of components for Transmission system, as shown in Figure 6.

Component	Mass Share	CO_{2eq} Emissions Share
Inner Ring	12%	12%
Synchronizer Ring	24%	20%
Roller Bearing	12%	14%
Needle Bearing	18%	13%
Synchro Detent Pin	5%	4%
Clutch Release Bearing	29%	37%
Total	**100%**	**100%**

Figure 6. Components Average Mass and CO_2e for Transmission System.

In the transmission system the distribution of mass and CO2e emission is more balanced than in the engine system, the bearings (roller bearing and clutch release bearing) correspond to the majority of mass and emissions reaching combined 41% of mass and 51% of CO2e emissions.

Combining all emissions categories for the components for each system gives the next level of assessment of emission generators showing a new point of view to manage the carbon emissions for the components portfolios, in this way is possible to combine and find parallels between the two systems analyzed (engine and transmission) since many of the emission categories are common between them and helping level the analysis from the point of view of a auto part manufacturer to the car automaker for the same reason.

For the average engine system, the distribution of mass and CO_2e for the emissions categories defined in this analysis is shown in Figure 7.

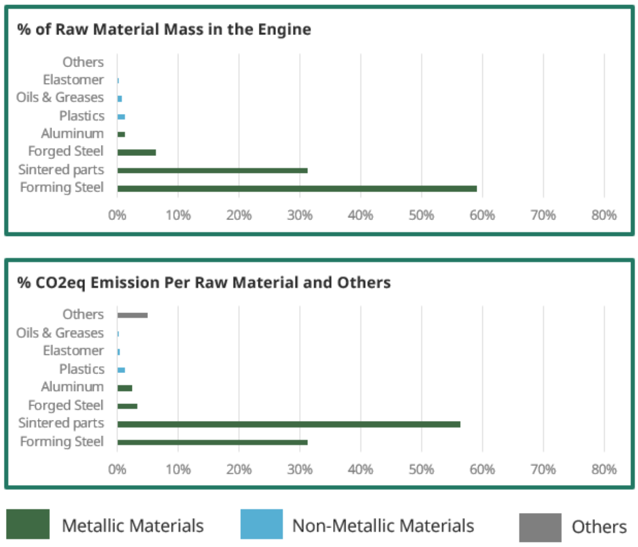

Figure 7. Emission categories average for Engine System

In the emission categories analysis for the engine system it´s clear that the metallic materials are the biggest contributors for the mass and CO_2e emissions corresponding to more than 90% for both (92% of CO2e emissions and 96% mass). Other important point is that inside of the Metallic Materials the sintered steel has the biggest CO2e emission factor corresponding to 31% of mass of all components, but to 56% of all emissions.

The distribution of mass and CO_2e for the emissions categories for the average transmission system is according to Figure 8.

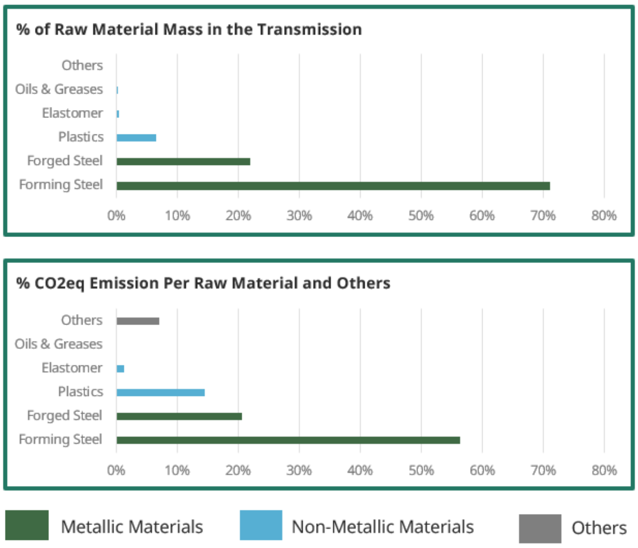

Figure 8. Emission categories average for Transmission System

The transmission system emission category analysis clearly demonstrates the metallic materials category is the most important in terms of emissions, since is where we have the highest amount of mass. Also, we can see that plastic materials have a high potential of emissions with only 6% of total mass but is responsible for 15% of CO_2e emissions in the system.

CONCLUSION

Considering the car LCA cradle to gate scope for the PCF both auto part manufacturer and car makers has the metallic materials as biggest contributor for the CO2e emissions. In the product portfolio for engine and transmission analyzed they are responsible for more than 80% of the emissions. Attention also for Plastic materials which has a high CO_2e emission factor and is largely used in the automotive industry. The study shows a huge potential of reduction of carbon emission if car makers and auto parts manufacturers work together with the metallurgic industry to reduce the emissions using low carbon materials and improving steel manufacturing processes.

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