Challenges in Real Emissions Deterioration Factors Determination for PHEV Vehicles Under Brazilian Legislation

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ABSTRACT

The market for alternative powertrain vehicles is rapidly expanding, with Brazil witnessing an increasing demand for Hybrid and Plug-In Hybrid Electric Vehicles (PHEVs). This growth is driven by the introduction of new models and rising consumer acceptance of these technologies, which offer environmental benefits.

The recently established Proconve L8 legislation by the Brazilian government establishes specific emissions and On-Board Diagnostics (OBD) homologation tests for Hybrid and PHEV vehicles. Furthermore, since Proconve L7 legislation, a durability target of 160,000 km for pollutant emissions has been introduced, with deterioration factor (DF) determination procedures defined in ABNT NBR 16897.

This paper explores the legislative framework for emissions testing and DF determination for PHEVs in Brazil, with emphasis on the application of NBR 16897 and the absence of a methodological differentiation for PHEV-specific characteristics.

To support the analysis, experimental data from emissions tests conducted on a PHEV under stabilized and aged catalyst conditions are presented. Deterioration factors were calculated using both CD+CS combined modes and CS-only mode, applying the methodology of NBR 16897 to determine multiplicative and additive values. These results provide a basis for further discussion on testing feasibility and representativeness within the current regulatory framework.

INTRODUCTION

The Brazilian automotive sector is undergoing a notable transformation, characterized by the steady rise of electrified powertrains. Although relatively nascent compared to regions like Europe or China, Brazilian automotive market has experienced consistent expansion of Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Battery Electric Vehicles (BEVs), reflecting global trends toward cleaner mobility solutions. This shift is driven by a combination of environmental awareness, fuel economy concerns, technological advances, and the gradual introduction of public policies aimed at reducing carbon emissions and urban air pollution.

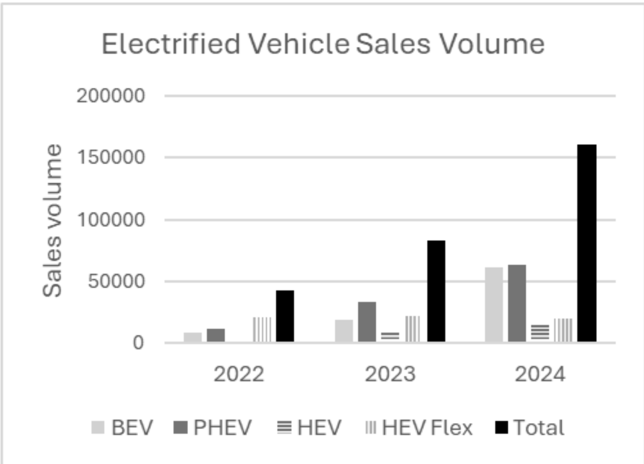


Figure 1. Evolution of Electrified Vehicle Sales Volume in Brazil [1]

Within this broader electrification movement, Plug-in Hybrid Electric Vehicles (PHEVs) have shown particularly significant growth in Brazil over the last few years. PHEVs serve as a transitional technology, offering the benefits of electric driving for urban trips / short routes, while retaining the flexibility and extended range of internal combustion engines for longer distances. This dual capability is especially valuable in a country as large and diverse as Brazil, where charging infrastructure is still in development and driving conditions vary widely.

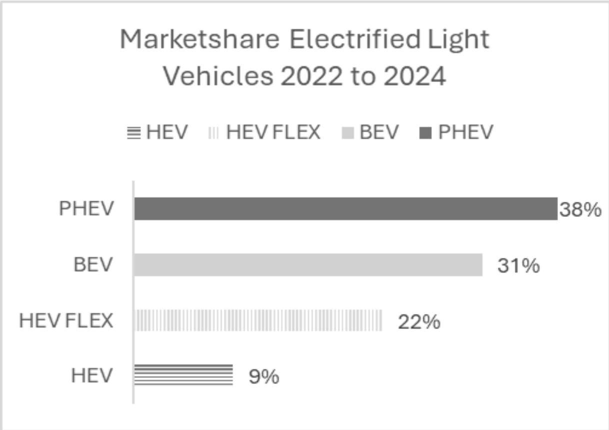


Figure 2. Marketshare Electrified Light Vehicles in the last three years [1]

The expansion of PHEVs in the Brazilian market has been supported by an increasing number of model offerings, as well as consumer demand for vehicles that reduce fuel consumption without completely relying on an electric grid that remains uneven in its accessibility across regions. However, this rapid market evolution brings new technical and regulatory challenges, especially concerning emissions testing and vehicle certification.

PHEVs present a unique challenge in emissions assessment due to their dual-mode operation—Charge Depleting (CD) and Charge Sustaining (CS). In Brazil, where fuel compositions, ambient temperatures, and driving behaviors differ from those in more established markets like Europe, China or the United States, the traditional methods for calculating real-world emissions deterioration factors and certifying On-Board Diagnostic (OBD) systems may not fully capture the actual impact of aging on pollutant emissions.

LEGISLATION

In Brazil, the regulatory framework for certifying emissions and determining deterioration factors (DFs) for Plug-in Hybrid Electric Vehicles (PHEVs) is structured around a series of technical standards aligned with international best practices, yet adapted to the country's unique fleet composition and fuel characteristics. Two key standards guide the national certification process: ABNT NBR 16567, which defines the methodology for regulated emissions testing of HEVs and PHEVs, and ABNT NBR 16897, which outlines procedures for establishing deterioration factors used in emissions compliance of light-duty internal combustion engines over a vehicle's useful life.

ABNT NBR 16567 establishes the criteria for conducting both Charge Depleting (CD) and Charge Sustaining (CS) emissions tests for PHEVs [2]. It incorporates test cycles, vehicle preparation procedures, and result calculation methods, accounting for the dual-mode operation typical of PHEVs. The standard also introduces the concept of a Utility Factor (UF) to proportionally weight emissions from CD and CS modes, reflecting real-world usage patterns. In the context of NBR 16567, PHEVs must undergo testing over a defined sequence of driving cycles, including urban and highway phases:

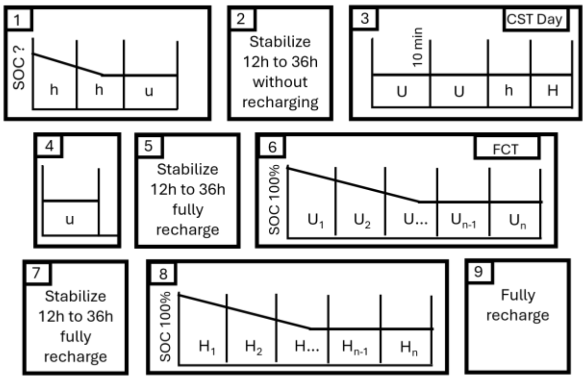


Figure 3. Sequence of Driving Cycles (Emissions and Fuel Consumption) for PHEV Vehicles according to NBR 16567 [2]

However, when the objective is the determination of emissions deterioration factors, only the emissions results from the cycles that directly influence the regulated pollutants are relevant. In this regard, it is important to highlight that the highway cycles, although part of the certification sequence, are not required for the calculation of deterioration factors, even if not specifically stated in the legislation.

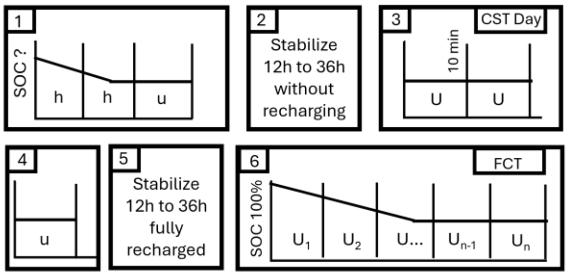


Figure 4. Sequence of Driving Cycles (Only Emissions) for PHEV Vehicles

Although Charge Depleting (CD) operation is an integral part of the testing sequence defined by NBR 16567 for emissions certification of PHEVs, its relevance in the context of emissions deterioration factors determination could be very limited. Since CD mode is characterized by predominant electric driving with minimal or no activation of the internal combustion engine, the contribution of this mode to tailpipe emissions is typically negligible. As a result, the inclusion of CD emissions data in DF calculations often has minimal or no influence on the final deterioration values. In that case, the sequence of tests for deterioration factor calculation could be simplified as shown in the following figure:

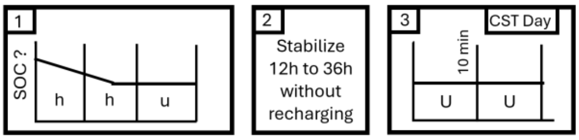


Figure 5. Sequence of Driving Cycles (Only Emissions in Charge Sustained Mode) for PHEV Vehicles

The Brazilian Standard ABNT 16897 published in 2021, specifies the requirements and procedures to determine the exhaust emission deterioration factors for light duty vehicles [3]. The deterioration factor is defined as a calculated value for determining the degradation of the vehicle's pollutant emissions after mileage accumulation in a full vehicle or bench aging of components. In other words, it defines the relation and influence in emissions between a stabilized exhaust aftertreatment system and a system which was passed for an ageing during mileage accumulation of 160.000 kms or equivalent methods on test benches though standardized cycles [4]. As an alternative, normative default multiplicative DFs were established in Resolution 492, from 20.12. 2018 as follows:

Cycle	NMHC	CO	NOx	Aldehydes	PM
Otto	1,4	1,4	1,2	1,2	1,0
Diesel	1,2	1,2	1,2	1,0	1,2

Table 1. Normative Default Multiplicative DFs [5]

However, NBR 16897 does not explicitly address the specific operational characteristics of PHEV vehicles. The standard applies a generic methodology that treats all powertrain types under a unified framework, without providing differentiated procedures or exceptions for vehicles capable of operating in both Charge Depleting (CD) and Charge Sustaining (CS) modes. As a result, technical decisions—such as whether to include CD-mode emissions in DF calculation—are left to interpretation or supplementary guidance, potentially leading to inconsistencies between testing campaigns and increased uncertainty in certification. This lack of clarity can pose challenges for manufacturers and technical services, particularly in the Brazilian context where infrastructure and regulatory precedents for PHEV testing are still maturing.

THE ROLE OF CHARGE-DEPLETING EMISSIONS IN DF CALCULATION

A significant debate in the regulatory treatment of PHEVs involves the role of Charge-Depleting (CD) emissions in the calculation of deterioration factors. From a practical standpoint, the regulated pollutants (CO, NOx, HCs including NMOG, PM and Aldehydes) in PHEVs are generated during CS operation, as CD driving tends to be electrically dominated with near-zero tailpipe emissions. Consequently, the emissions measured in CD mode typically do not represent a substantial portion of the total lifetime emissions, especially for users with longer daily drives or who infrequently recharge. Additionally, unburned Ethanol, Formaldehydes and Acetaldehydes for NMOG calculation, as well as PM and Aldehydes, are not possible to be collected during CD tests.

Taking the European market as an example, real-world emissions testing emphasizes CS conditions for DF calculation, with CD contributions often weighted or excluded depending on the energy utility factor (UF) method. The UF defines how often vehicles operate in CD versus CS mode based on user behavior. Deterioration factors are then applied primarily to CS-mode emissions, which represent worst-case aging impacts on emission control systems such as catalysts, oxygen sensors, and evaporative controls.

In Brazil, the necessity of CD emissions testing remains an open question. Given the lack of consistent charging infrastructure and differences in user behavior, many PHEVs operate predominantly in CS mode, especially in non-urban areas. Thus, requiring full CD emissions testing for DF purposes may add complexity and cost without significantly improving the accuracy of real-world emission estimation. One of the most pressing practical barriers in Brazil is the limited availability of certified emissions laboratories equipped to carry out both Charge Depleting (CD) and Charge Sustaining (CS) tests required for PHEV certification. While several laboratories are capable of conducting only CS-mode tests, far fewer are equipped or certified to perform the more complex CD-mode testing. As a result, the demand for fully equipped labs far exceeds the current national capacity, making it difficult to secure laboratory bookings within reasonable periods of time. This limitation may lead to delays in DF calculations, impacting manufacturers' ability to complete certification processes efficiently. Consequently, testing strategies that rely primarily on CS-mode data become not only technically justifiable in many cases, but also significantly more feasible within the local infrastructure constraints.

EXPERIMENTAL RESULTS

To evaluate the influence of Charge Depleting mode emissions on the determination of deterioration factors, an experimental campaign was conducted using a Plug-in Hybrid Electric Vehicle (PHEV) equipped with a spark-ignited internal combustion engine and a three-way catalyst (TWC) aftertreatment system. Emission tests were performed with the sequence shown in Figure 4 and the following aftertreatment systems:

- Stabilized aftertreatment system according to NBR16897 (6000km +/- 1000km)
- Aged aftertreatment system, following Standard Bench Cycle described in NBR16897

For each configuration, three repetitions of emissions test cycles were conducted in both CD and CS mode. These tests allowed for a comparative analysis of pollutant emissions before and after catalyst aging under both operating strategies. The specific numerical results of the emissions tests for stabilized and aged catalysts are subject to confidentiality restrictions. However, the DF values and trends presented in this work are calculated based on these results.

Deterioration Factor (DF) Calculation

Using the emissions results, multiplicative and additive DFs were calculated following the guidelines in NBR 16897. It is important to highlight that, due to methodological limitations, not all regulated pollutants are measured during Charge Depleting (CD) tests. Specifically:

- NMOG (Non-Methane Organic Gases)
- PM (Particulate Matter)
- Aldehydes

These pollutants are not reported during CD mode testing. As a result, for PM and Aldehydes, the deterioration factors (DFs) are calculated exclusively based on Charge Sustaining (CS) mode tests, while for NMOG-DF, the NMOG from CD mode was calculated as:

$$NMOG_{FCT} = NMHC_{FCT} * NMOG_{CST} / NMHC_{CST}$$

The results for the multiplicative deterioration factors are shown in the following table:

Pollutant	DF (CS Only)	DF (CD + CS)	Notes
THC	1,59	1,46	
NMHC	1,67	1,51	
NMOG	1,5	1,35	Not measured in CD mode (*)
NOx	1,36	1,34	
CO	1,12	1,1	
PM	1	–	Not measured in CD mode
Aldehydes	1,08	–	Not measured in CD mode

Table 2. Multiplicative Deterioration Factors using the results from only CS mode and CD+CS modes

The results presented in Table 2 indicate that the deterioration factors (DFs) calculated using only Charge Sustaining (CS) mode are slightly higher across all evaluated pollutants when compared to those derived from combined Charge Depleting (CD) and CS tests. Despite these differences, the values remain very close, typically within a narrow margin of 2–10%, confirming a high level of consistency between both methodologies. The fact that the CS-only DFs are consistently higher, although only marginally, implies that their use in emissions certification leads to conservative estimations - a technically robust approach that ensures regulatory compliance to remain on the safe side.

Additionally, for certain pollutants such as NMOG, PM, and Aldehydes, CD mode measurements are not technically feasible. In these cases, DFs are based solely on CS data, which further justifies the broader applicability of CS-only deterioration factors.

Following the same approach, the results for the additive deterioration factors are:

Pollutant	Add_DF (CS Only)	Add_DF (CD + CS)	Notes
THC	7,1	3,7	
NMHC	6,0	3,0	
NMOG	5,3	2,5	Not measured in CD mode (*)
NOx	4,2	2,2	
CO	27,5	14,5	
PM	0	–	Not measured in CD mode
Aldehydes	0,1	–	Not measured in CD mode

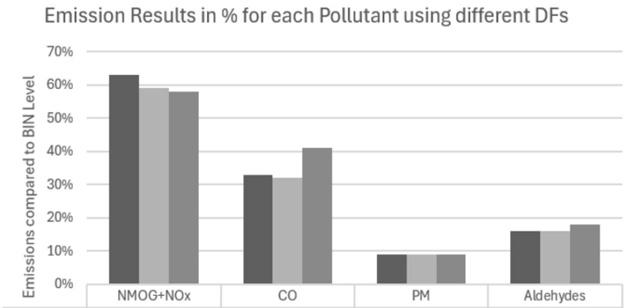
Table 3. Additive Deterioration Factors using the results from only CS mode and CD+CS modes

The additive deterioration factors presented in Table 3 reflect similar trends to those observed for the multiplicative DFs. In all measurable pollutants, DFs calculated using only Charge Sustaining (CS) tests are higher than those obtained using combined Charge Depleting and Charge Sustaining (CD+CS) results. As seen, the CS-based DFs are approximately double those derived from CD+CS tests in most cases, further reinforcing the conservative nature of using CS-only data. This occurs because CS mode better reflects the operation of the internal combustion engine, where emissions control devices are more directly stressed, especially after aging.

Application to Homologation Results

To evaluate the practical implications of using each DF calculation method, the results during emissions homologation were used. These values represent the final CD and CS emission results obtained during standard type-approval testing with stabilized aftertreatment (before applying DFs). The DFs obtained from both methods were applied to the emission results. For comparison, it was also applied the normative multiplicative DF values outlined in Table 1. The comparison aimed to answer:

- How much influence do CD emissions have on the final certified values?
- Does using CS-only DFs result in conservative (higher) final emissions?
- Could CS-only DF methodology be a valid and efficient simplification, considering final results and Brazil's current laboratory limitations?



	NMOG+NOx	CO	PM	Aldehydes
DF CS	63%	33%	9%	16%
DF CD+CS	59%	32%	9%	16%
DF Norm	58%	41%	9%	18%

Figure 6. Comparison of Emission Results in % of BIN Level, Applying different DFs

The comparison between the final emissions percentages obtained using deterioration factors (DFs) derived from Charge Sustaining (CS) mode only, the combined Charge Depleting + Charge Sustaining (CD+CS) approach, and the normative (default) values provides insightful conclusions. As shown in Figure 6, the application of DFs calculated exclusively from CS tests results in slightly higher final emissions values across all pollutants when compared to the CD+CS approach. For instance, the NMOG+NOx combined value is 63% of the regulatory limit using CS-derived DFs, while it drops to 59% using CD+CS DFs, both remaining very close to the default normative DF result of 58%.

A similar trend is observed for CO, where CS-based DFs yield 33% of the limit, slightly above the 32% from CD+CS and below the 41% obtained using normative DFs. For PM and Aldehydes, the results remain unchanged or very close across all approaches, reflecting the measurement constraints in CD mode. This difference highlights an important point: CS mode tests inherently reflect a more realistic picture of the aging and deterioration behavior of the aftertreatment system, since they represent scenarios where the internal combustion engine is more actively engaged and exposed to thermal and chemical stress. In contrast, CD mode typically features lower engine loads or even electric-only operation, which reduces the exposure of the aftertreatment system to aging mechanisms—making its inclusion less meaningful for DF purposes.

Moreover, CD-mode measurement limitations for certain pollutants (e.g., NMOG, PM, and Aldehydes) reinforce the practical limitations of incorporating CD tests into DF calculations. Therefore, while CS-only DFs may result in slightly higher final values, this is not merely a conservative estimate; it reflects the actual degradation dynamics of the aftertreatment system. The analysis supports the technical rationale for focusing deterioration factor assessments on CS mode only, offering a more meaningful and realistic approach for PHEVs.

SUMMARY AND CONCLUSIONS

This study explored the key challenges in determining emissions deterioration factors (DFs) for Plug-in Hybrid Electric Vehicles (PHEVs) in Brazil, a topic of growing importance given the rapid expansion of electrified powertrains in the national vehicle market. Starting with a contextual overview of the increasing market share of hybrid and plug-in hybrid vehicles, the paper discussed the regulatory landscape, particularly the requirements established by NBR 16567 for hybrid emissions certification and NBR 16897 for real DF calculation.

A crucial point of analysis was the necessity, or not, of performing Charge Depleting (CD) mode emissions testing as part of deterioration factor assessment. Given that most of the pollutant emissions in PHEVs are growth during Charge Sustaining (CS) operation, and considering the limited laboratory infrastructure in Brazil equipped to manage both CD and CS testing, we questioned the practical value of CD mode tests for DF purposes.

The experimental section presented comparative results of multiplicative and additive DFs calculated from a series of emissions tests on stabilized and aged aftertreatment systems. Both approaches—using only CS data and using combined CD+CS data—were analyzed. The results clearly indicated that DFs derived solely from CS mode are slightly higher but closely aligned with those from CD+CS mode. This suggests that relying exclusively on CS tests not only simplifies the testing process but also ensures a more conservative, and thus regulatory-safe, outcome. Furthermore, the relative contribution of each pollutant to final emissions calculations (expressed in percentage of the target BIN level) was examined. The analysis reinforced that CD mode testing adds limited value in representing aftertreatment deterioration and, in many cases, is impractical or infeasible due to measurement constraints (e.g., for NMOG, PM, and Aldehydes).

In conclusion, the findings support the proposition that DF calculations based solely on CS mode offer a more realistic, resource-efficient, and conservative approach. They better reflect the actual degradation of the internal combustion aftertreatment system in PHEVs, saving also unnecessary time and costs during the type approval process.

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ABBREVIATIONS

ABNT: Associação Brasileira de Normas Técnicas
BEV: Battery Electric Vehicle
CD: Charge Depleting Mode
CO: Carbon Monoxide
CS: Charge Sustaining Mode
CST: Charge Sustaining Test
DF: Deterioration Factor
FCT: Full Charging Test
HC: Hydrocarbon
HEV: Hybrid Electric Vehicle
NBR: Norma Brasileira
NMHC: Non-Methane Hydrocarbons
NMOG: Non-Methane Organic Gases
NO_X: Oxides of Nitrogen
OBD: On-Board Diagnostics
PHEV: Plug-In Hybrid Electric Vehicle
PM: Particulate Matter
PROCONVE: Programa de Controle de Emissões Veiculares
THC: Total Hydrocarbons
TWC: Three-Way Catalyst
UF: Utility Factor