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Regulatory adjustments for plug-in hybrid vehicles in Europe

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Report on the project Scientific Support for Climate Policy and Action Program (14-BE-2203)

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Summary

Background and objective

Plug-in hybrid vehicles (PHEVs) can be driven using either a combustion engine or battery-electric and can be charged via the power grid. These vehicles only offer climate benefits over conventional combustion engines when operating in battery-electric mode. PHEVs contribute significantly to European car manufacturers' compliance with CO_2 fleet targets in Europe, but their real-world CO_2 emissions are three to five times higher than the type-approval values, as shown by recent evaluations of real-world consumption data (On-Board Fuel Consumption Monitoring (OBFCM) data) from approximately one million PHEVs in Europe (Plötz & Gnann 2025, EEA 2025).

This study analyzes the regulatory implications of these deviations. Realistic values are derived for the so-called utility factor (UF), which combines the standard consumption values collected during type-approval with the combined consumption value. Furthermore, current suggestions by the German car makers association (VDA) regarding the regulatory treatment of PHEVs are evaluated and a scenario analysis is used to show the climate policy consequences that would result from the implementation of these demands. The aim is to create an evidence-based reference for political decisions on the further development of PHEV regulation.

Data and methodology

The analysis is based on OBFCM data from the European Environment Agency (EEA) for approximately one million PHEVs registered in Europe between 2021 and 2023. The data covers the entire vehicle life cycle and includes total mileage, fuel consumption, the proportion of kilometers driven in charge depleting (CD) mode, in CD mode with the combustion engine off, in charge sustaining (CS) mode, as well as technical vehicle data such as electric range and official CO_2 values, broken down by manufacturer, model, year of production, and fuel type.

Regression analyses were performed to determine realistic UF curves based on the actual proportion of electric driving as a function of electric range. The current and regulatory planned UF curves were compared with the empirical data. Technical feasibility analyses were carried out using simulations for the proposed geofencing and inducement measures. Scenario modeling was used to quantify the CO_2 impacts of various regulatory options for Germany and the EU27 until 2040.

Results

Average real-world fuel consumption of a PHEV is 5.9 l/100 km, with electric driving accounting for a quarter

The average real-world fuel consumption is 5.9 l/100 km, which is about 300% above the type-approval consumption. PHEVs thus show fuel consumption on the road in the same order of magnitude as conventional internal combustion vehicles. The reason for this can be seen in the proportion of electric driving according to OBFCM data: this is only around a quarter (proportion of distance with the combustion engine switched off in CD mode and energy-based proportion of electric driving: 27–31%).

Type-approval metrics do not indicate the proportion of electric driving

Regulatory authorities distinguish between *charge depleting mode* (CD mode) and *charge sustaining mode* (CS mode). CD mode is defined by regulations in such a way that a certain minimum amount of driving energy must come from the battery over a WLTP cycle, but there is no requirement as to

what proportion of the distance must be covered purely by electric power. This opens considerable scope for the use of the combustion engine, even in discharge mode. This opens considerable scope for the use of the combustion engine in CD mode as well. The OBFCM data show that PHEVs travel about 40% of their distance in CD mode, resulting in an average real-world consumption of about 2.8 l/100 km, which is significantly more than in type-approval. This shows that the combustion engine also plays a significant role in this mode in practice. In CS mode, however, fuel consumption is still significantly higher, averaging 7.4 l/100 km.

Charging only increases the CD mode share and hardly increases the electric driving share

Until now, one key approach to increasing the climate benefits of PHEVs has been to enable frequent charging. The OBFCM data was therefore analyzed to determine how consistent charging of the vehicles (= high observed CD mode share) affects consumption. Average fuel consumption decreases with the CD mode share and thus with the charging frequency. However, fuel consumption does not generally fall below the CD mode consumption of 2.8 l/100 km. Current PHEVs therefore consume no less than 2.8 l/100 km or 64 gCO_2/km on average in the fleet, regardless of how often they are charged (Figure1).

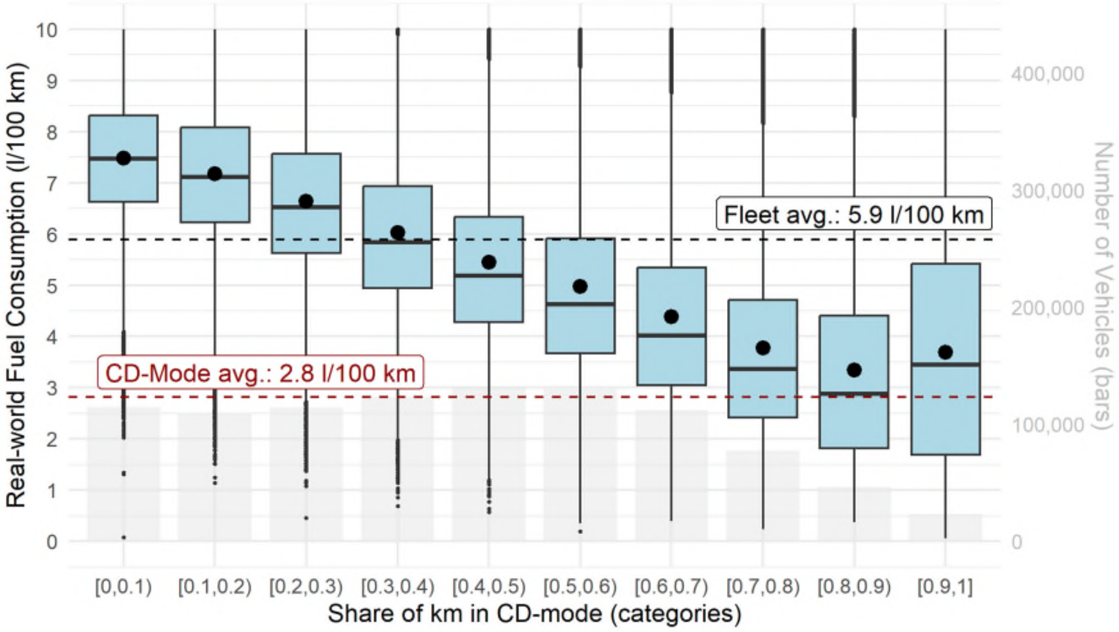

Figure 1: **Fuel consumption depending on the CD mode share.**

Source: Own calculations

The utility factor curve must be further adjusted than in 2027

According to the EU fleet target regulation, the utility factor (i.e., the relationship between range in CD mode and CD mode share in the combined WLTP consumption value) will be adjusted for all newly registered PHEVs from the beginning of 2026 and from the beginning of 2028; for newly homologated vehicles, the adjustments will come into force one year earlier. The VDA proposed suspending the upcoming adjustments to the utility factor curve. Based on OBFCM data and type-approval values, calculations were made in the present study to determine how much the actual consumption of current PHEVs would deviate from type approval values for different configurations of the utility factor curve. Figure 2 shows the gap between actual and nominal fuel consumption of PHEVs according to the UF curve valid to date and for the two adjustments 2025 and 2027. In addition, calculations were made to determine how the UF curve would have to be parameterized so that PHEVs would still consume 20% more on average than according to type approval, as is the case with pure combustion engine vehicles today.

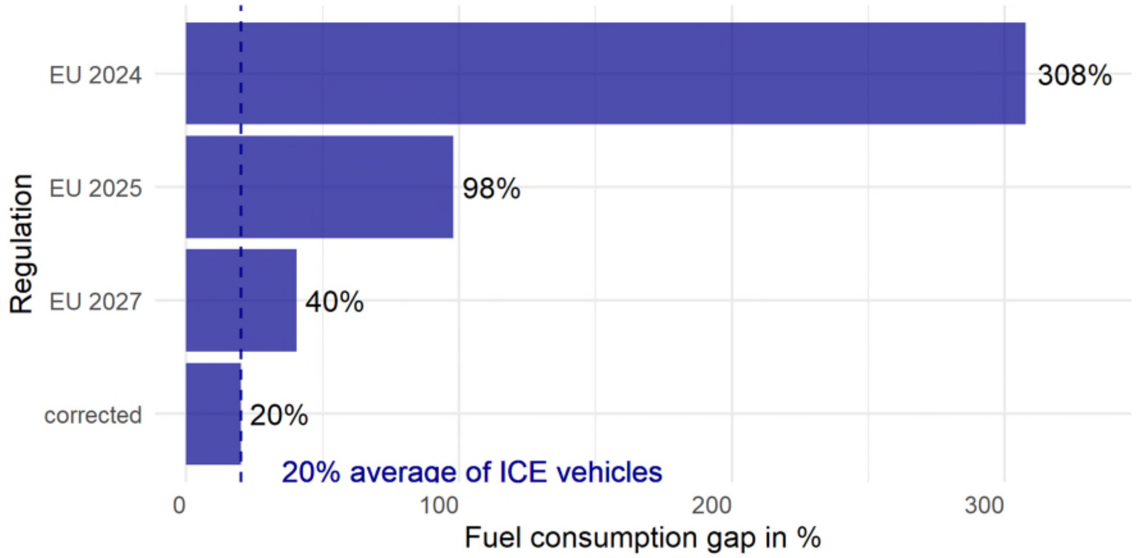

Figure 2: Difference between WLTP and real-world fuel consumption of PHEVs in Europe according to various regulations

Source: Own calculations.

Table 1: Overview of scaling parameters and consumption gaps according to utility factors

Utility factor curve approach	d_n [km]	Average consumption gap
EU regulation until 2024	800	>300%
EU regulation 2025–2026	2,200	ca. 100%
EU regulation from 2027	4,260	ca. 40%
Empirically corrected UF	ca. 7,200	ca. 20%
Further real data UF approaches	4,700 – 5,900	ca. 25–35%

Source: Own calculations

All PHEVs in the sample were registered after the regulation came into force in 2024 and are on average about 300% above the type-approval. This gap between real and nominal consumption would still be around 100% on average if the vehicles had been registered after the 2025 regulation and 40% after the regulation planned for 2027. In order for the gap to narrow to approximately 20%, the scaling parameter adjusted in the regulation would have to increase from $d_n = 2{,}200\ \text{km}$ for 2025 and $d_n = 4{,}260\ \text{km}$ for 2027 to $d_n > 5{,}000\ \text{km}$. Modeling the UF with other real-world data based approaches yields scaling parameters $d_n > 4260\ km$ and an average consumption gap of well over 20%, so that all approaches argue in favor of further tightening the UF curve to further reduce the real-world fuel consumption gap. Including only long-ranged with PHEV to account for growing PHEV ranges also leads to higher scaling factors in all empirical UF calculations.

Display transparency and inducement result in very small reductions in emissions

Existing proposals that PHEV users should be shown the proportion of electric driving transparently on the display ("display transparency") or be forced to charge at least every 500 km ("inducement"), for example, may reduce the real emissions of PHEVs slightly. Based on the literature, the display transparency measure is assumed to reduce real-world emissions by a maximum of 5% or 7 g CO_2/km. From a simulation of PHEV journeys, we find that inducement could enable an additional reduction in real-world emissions of approximately 2–3 g CO_2/km. Figure 3 shows the effect of these measures in relation to the real-world emission values of the PHEV fleet and in comparison to the WLTP values with different UF curves, see above. It can be observed that the average real-world emission value of PHEVs of approximately 145 g CO_2/km can only be reduced slightly by the proposed measures. The measures are therefore far from sufficient to significantly reduce the gap between real-world and nominal emissions. This highlights the importance of the planned adjustments to the UF curve.

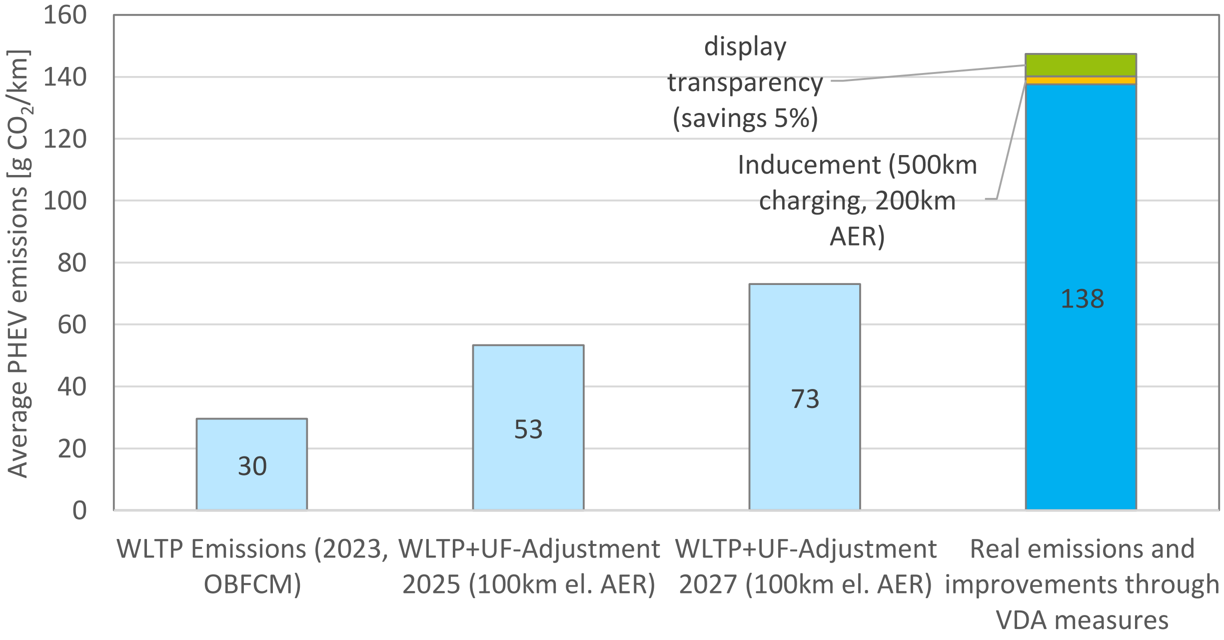

Figure 3: Average PHEV CO_2 emissions in various adjustments

Source: Own calculations

Impact on GHG emissions

Using the TEMPS model, four scenarios with different considerations of PHEVs are examined based on the framework data from the 2025 German greenhouse gas (GHG) projection report (Förster et al. 2025) and compared with each other in terms of GHG emissions. Scenario S0 is the reference scenario, in which the currently legally valid adjustments to the scaling parameter d_n for 2025 and 2027 are used as the basis for the modeling of CO_2 emissions in type-approval. The two scenarios S1a and S1b reflect the VDA's requirement that there be no adjustment of the scaling parameter d_n for the years 2025 and 2027. The two scenarios differ in that scenario S1b assumes 5% lower real-world consumption of PHEVs for usage-based measures such as inducement and geofencing. Scenario S2 is a scenario in which the scaling parameter d_n is adjusted in 2025, but no further adjustment of the scaling parameter is planned in 2027.

The different consideration of PHEVs in the scenarios leads to different drive distributions for new car registrations up to 2035. The TEMPS model includes cost optimization from the perspective of vehicle manufacturers, such that the lower WLTP CO_2 emissions of PHEVs in scenarios S1a, S1b, and S2 until 2030 compared to reference S0 lead to lower new registration shares of PHEVs and battery electric vehicles (BEVs) and higher shares of combustion engine passenger cars. After 2030, however, the shares of new PHEV and combustion engine registrations in scenarios S1a, S1b, and S2 are higher than in the S0 reference.

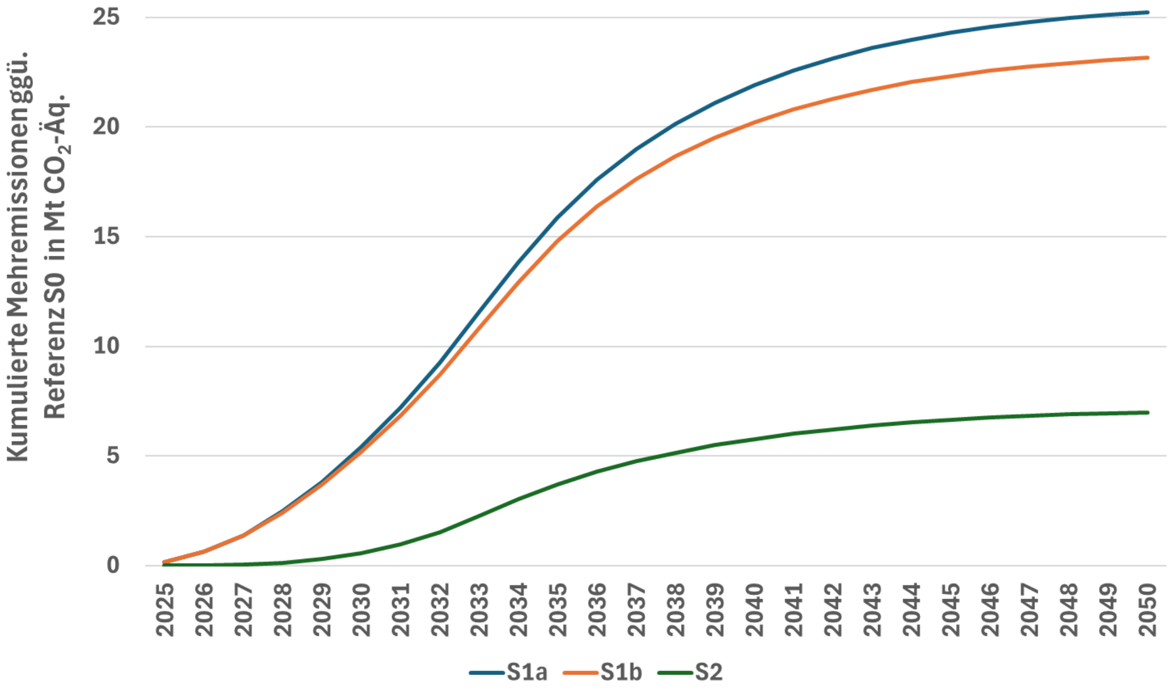

Figure 4: **Cumulative additional GHG emissions compared to the S0 reference**

Source: Own calculations

The changed new registration structures and higher proportions of new registrations for passenger cars with combustion engines lead to higher GHG emissions in scenarios S1a, S1b, and S2 than in the reference S0, which accounts for the two adjustments to the scaling parameter d_n for the years 2025 and 2027. If the two adjustment steps for the scaling parameter are not effective (scenarios S1a and S1b), the additional GHG emissions will accumulate to 23.2 and 25.2 Mt CO_2 eq, respectively, by 2045. If the adjustment of the scaling parameter is suspended in 2027 (S2), the cumulative additional emissions will rise to a total of 7 Mt CO_2 eq.

The emission calculation for PHEVs must be further adjusted to reflect reality

As shown in this paper, evidence-based utility factors can be determined from real-world fuel consumption data (OBFCM data). This allows the real-world fuel consumption deviation of PHEVs to be reduced to a level similar to that of pure combustion vehicles, thus creating a level playing field between the drive systems. Such adjustments should be made regularly in the future based on continuously collected OBFCM data. In any case, adjustments to the utility factor currently provided by law should be implemented, as they at least significantly reduce the gap between standard and real-world fuel consumption compared to the previous situation.

1. Introduction

1.1. Motivation, objectives, and background

Plug-in hybrid vehicles (PHEVs) combine an electric drive with a conventional combustion engine and have been regarded in the European Union (EU) for many years as a building block in the decarbonization of the passenger car fleet. Within the CO_2 fleet target regulation (EC 2019/631), they make a significant contribution to achieving the target in mathematical terms, as their attributable emissions are calculated based on the type-approval procedure. This concept was attractive from a regulatory perspective, as PHEVs require less infrastructure transformation than battery electric vehicles (BEVs) and at the same time enable short-term relief within the framework of CO_2 regulation.

The current revision of the fleet regulation and the introduction and further development of the utility factor methodology, including the planned tightening of type-approval emissions for PHEVs from 2027, are shifting the focus towards more realistic electric driving shares and real-world emissions. In particular, the real-world usage data now available based on on-board fuel consumption metering (OBCFM) shows that PHEVs have significantly lower electric driving shares in everyday use than assumed in type approval. Against this backdrop, industry representatives such as the German Association of the Automotive Industry (VDA) are calling for an adjusted calculation of electric kilometers and more flexible transition periods.

This study classifies PHEVs within this regulatory framework, analyzes comprehensive real-world data, and evaluates the proportion of electric driving and emissions crediting. The aim is to relate technical definitions, regulatory assessments, and real-world performance and to highlight the resulting implications for future fleet regulations.

We also evaluate the VDA's individual proposals for regulating plug-in hybrid vehicles (PHEVs) within the framework of European CO_2 fleet regulations. In two position papers (May and October 2025), the VDA formulated the following main demands:

1. Suspension of the planned tightening of the utility factor from 2026
2. Introduction of measures such as geofencing, display transparency, and inducement to increase the proportion of electric driving
3. Recognition of PHEVs as an eligible vehicle category even after 2035

The assessment is scientifically neutral, based on current empirical data and considering climate policy, technical, and economic aspects.

This report is structured as follows. The next section, 1.2, provides a detailed overview of the regulatory background, operating modes, and definitions of PHEVs for the purpose of this study. Chapter 2 briefly presents the data and methods used, while Chapter 3 contains the results of the empirical analyses of the OBFCM data (Section 3.1), the assessment of the VDA requirements (Section 3.2), the effects on the market ramp-up of alternative drive systems (Section 3.3), and a discussion of a possible further development of the European CO_2 fleet targets with regard to PHEVs even after 2035.

1.2. Background PHEV

1.2.1. Overview and operating modes of PHEVs

PHEVs obtain an electric motor, an internal combustion engine, and a battery that can be charged from the power grid. For this reason, PHEVs can usually drive certain distances purely on electric power and use the combustion engine for high power requirements or long distances. The regulation distinguishes between a predominantly electric operating mode and a predominantly combustion engine operating mode. The definitions according to Regulation (EU) 2017/1151, Annex XXI, 3.3 are as follows:

- "Charge-depleting operating condition" (CD mode) means an operating mode in which, while the vehicle is in motion, the energy stored in the rechargeable electrical energy storage system (REESS) fluctuates but decreases on average until the transition to charge-sustaining operating condition is reached.[1]
- "Charge-sustaining operating condition" (CS mode) refers to an operating mode in which, while the vehicle is in motion, the energy stored in the REESS fluctuates but remains on average at a neutral, charge-balancing level.[2]

This means that in discharge mode "CD mode", a relevant portion of the energy for moving the vehicle comes from the battery. However, this mode is not purely electric, i.e., the combustion engine can and will be used. Nonetheless, this mode is considered predominantly electric in public and science (for the exact definition and real results, see below).

Depending on the battery and vehicle, different ranges are defined in CD mode and purely electric mode. According to Regulation (EU) 2017/1151, Annex XXI, 3.3, these are:

- *"Charge-depleting actual range*" (**R_{CDA}**) refers to the distance traveled in a series of WLTC cycles during discharge until the rechargeable electrical energy storage system (REESS) is depleted.[3]
- "*Charge-depleting cycle range*" (**R_{CDC}**) refers to the distance traveled from the start of the test under discharge conditions to the end of the last cycle that occurred before the cycle or cycles that met the criterion for termination, including the transition cycle in which the vehicle was operated under both discharge and constant charge conditions.[4]
- "*All-electric range* (hybrid)" (**AER**) refers to the total distance covered by an externally chargeable vehicle with a hybrid electric drive, calculated from the start of the test with discharge until the point during the test when the combustion engine begins to consume fuel.

PHEV type-approval now essentially works as follows: the vehicles are first fully charged and then complete several WLTP test cycles one after the other. Each cycle checks how much energy was used from the battery to complete the cycle and how much energy was required in total. After a certain amount of time, when the battery is heavily discharged or driving conditions are particularly demanding, the combustion engine will also start up. The range at which the combustion engine started up for the first time is referred to as the electric range and is always included in the official vehicle specifications. The rest of the test cycle and one or more cycles are then driven using the

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[1] Verbatim according to Regulation (EU) 2017/1151, Annex XXI, 3.3

[2] Verbatim according to Regulation (EU) 2017/1151, Annex XXI, 3.3

[3] Verbatim according to Regulation (EU) 2017/1151, Annex XXI, 3.3

[4] Verbatim according to Regulation (EU) 2017/1151, Annex XXI, 3.3

combustion engine. This measurement procedure for PHEVs according to WLTP is shown schematically in Figure 5.

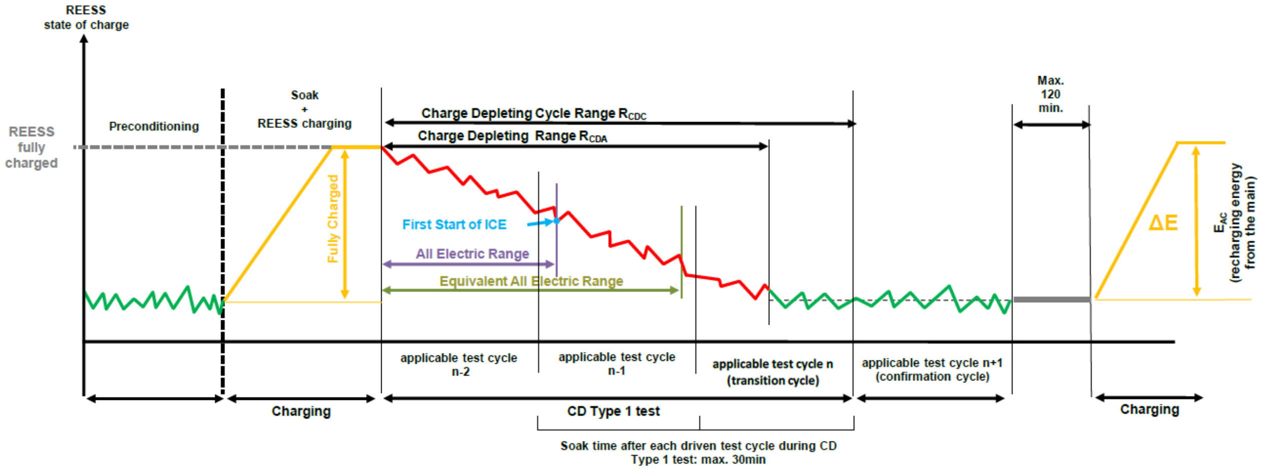

Figure 5: Schematic WLTP measurement procedure for PHEVs

Source: Regulation (EU) 2017/1151, Annex XXI

Depending on the electric range and design of the vehicle, different distances can be covered purely electrically or predominantly electrically. In the type-approval procedure, the vehicle is therefore measured both in predominantly electric CD mode and in predominantly combustion engine CS mode. One important factor for real CO_2 emissions is the question of what proportion of the distance these vehicles cover in predominantly electric mode and what proportion they cover predominantly in non-electric mode. The *utility factor* parameter was introduced for this purpose. Regulation (EU) 2017/1151, Annex XXI, 3.3 defines these utility factors as follows:

- *"Utility factors"* (**UFs**) are ratios based on driving statistics; they depend on the range achieved in operation when discharged and are used to weigh the connections between exhaust emissions when discharged and at a constant state of charge, CO_2 emissions and fuel consumption of externally chargeable hybrid electric vehicles.[5]

In principle, UFs are weighting factors for calculating fuel consumption, exhaust emissions, and CO_2 emissions, which indicate which driving segments are predominantly electric and which are predominantly combustion engine powered. It should be emphasized once again that the regulation does not weigh distances with the combustion engine on and off, but only between distances in CD and CS mode. How close CD mode comes to pure electric operation depends on the details of the CD mode definition and the vehicle operation.

1.2.2. Definition of charge-depleting mode

The WLTP test procedure for plug-in hybrid vehicles does not end the charge-depleting phase (CD mode) via a fixed SOC value, but via an energetic "break-off" criterion that considers the relative net withdrawal of electrical energy during a complete WLTP cycle. Formally, the standard defines the relative electrical energy change $REEC_i$ for cycle i as the ratio of the absolute net energy change of the battery (Rechargeable Energy Storage System – REESS) and the energy requirement of the WLTP cycle (including the conversion factor 1/3600 for unit transformation):

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[5] Verbatim according to Regulation (EU) 2017/1151, Annex XXI, 3.3

$$REEC_i = \frac{|\ \Delta E_{\text{REESS},i}\ |}{E_{\text{cycle}}/3600}$$

The break-off condition of the charge-depleting test is reached when the relative electrical energy change of the high-voltage storage device (REEC) in a WLTP cycle falls below 4% of the standardized cycle energy. Thus, the state of charge of the battery changes only slightly over the cycle and the vehicle has entered a quasi-stationary operating state in terms of energy. However, the definition does not specify what proportion of the drive energy is actually provided electrically or by the combustion engine. According to the regulations, the first cycle in which this behavior occurs marks the end of the CD sequence and initiates transition and confirmation cycles. This regulation is formally laid down in UN-ECE Regulation No. 154 / WLTP Annex and is also documented in the relevant EU implementation.[6]

Even though the WLTP break-off condition does not specify an explicit electric driving share, a plausible range can be derived from typical vehicle designs and operating strategies of today's PHEVs. In practice, the combustion engine is regularly switched on towards the end of CD mode in many models, for example to provide power support at higher loads, for thermal conditioning, or to stabilize the state of charge. At the same time, the electric motor often remains active, especially at low loads, in the urban cycle portion, or via recuperation. As a result, the electrically supplied portion of the drive energy in the last CD cycle is typically well below 100% and should often be in the range of about 20 to 50%. Depending on the vehicle concept, performance requirements, and operating strategy, significantly lower proportions are also possible, while very high electrical proportions occur primarily in highly electrified, electric-first-oriented, or range extender-like vehicle concepts.

Figure 6 illustrates the WLTP measurement procedure and the CD mode definition. The upper panel shows the repeated speed profile of the WLTP cycles, which are driven consecutively in CD mode. The middle panel shows the cumulative distance traveled and marks the all-electric range, while at the same time showing the point at which fuel flow occurs and the combustion engine becomes increasingly involved. The lower panel is decisive as it shows the development of battery energy and the relative electrical energy contribution (REEC). Here it becomes evident that CD mode is not equivalent to fully electric operation but ends with a transition cycle in which the electrical contribution decreases significantly. The break-off condition is only met when the REEC value in the confirmation cycle falls below the regulatory threshold, which shows that CD mode formally continues even when combustion is already dominant. The figure thus illustrates the central regulatory logic according to which CD mode is defined in terms of energy and not by an explicit electric driving share.

It is important to mention that CD mode in the WLTP is not an electrically defined driving mode, but rather an energetically balanced transition area between discharge and charge maintenance operation. The 4% threshold refers exclusively to the net change in battery energy content and thus allows for a wide range of real-world drive strategies, from predominantly electric operation to heavily combustion-dominated hybrid operation. Consequently, the utility factor based on CD mode does not represent the electric driving share but only the proportion of driving performance achieved under these energy constraints. This explains why high UF values are possible from a regulatory perspective without necessarily achieving correspondingly low real CO_2 emissions, and why OBFCM data

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[6] Technically, it should be emphasized that $\Delta E_{\text{REESS},i}$ is a net energy value determined by integrating battery voltage and current over the cycle duration (measured variable:$U_{REESS}(t) \cdot I_{REESS}(t)$ viat_{start} tot_{end}). In contrast, E_{cycle} describes the mechanical or traction-side energy requirement of the WLTP driving cycle, calculated from the instantaneous power required to cover the standardized speed time series (i.e., acceleration work plus driving resistance, minus recuperation effects). $REEC_i$ is thus a dimensionless quantity that indicates how large the net battery consumption was relative to the cycle energy. Furthermore, the standard deliberately chooses net energy as an objective, technology-neutral reference value instead of a manufacturer-specific SOC percentage in order to make manipulation via SOC offsets more difficult and to increase the comparability of the tests.

systematically show that the real emissions of many PHEVs are significantly higher than the values derived from the type-approval procedure.

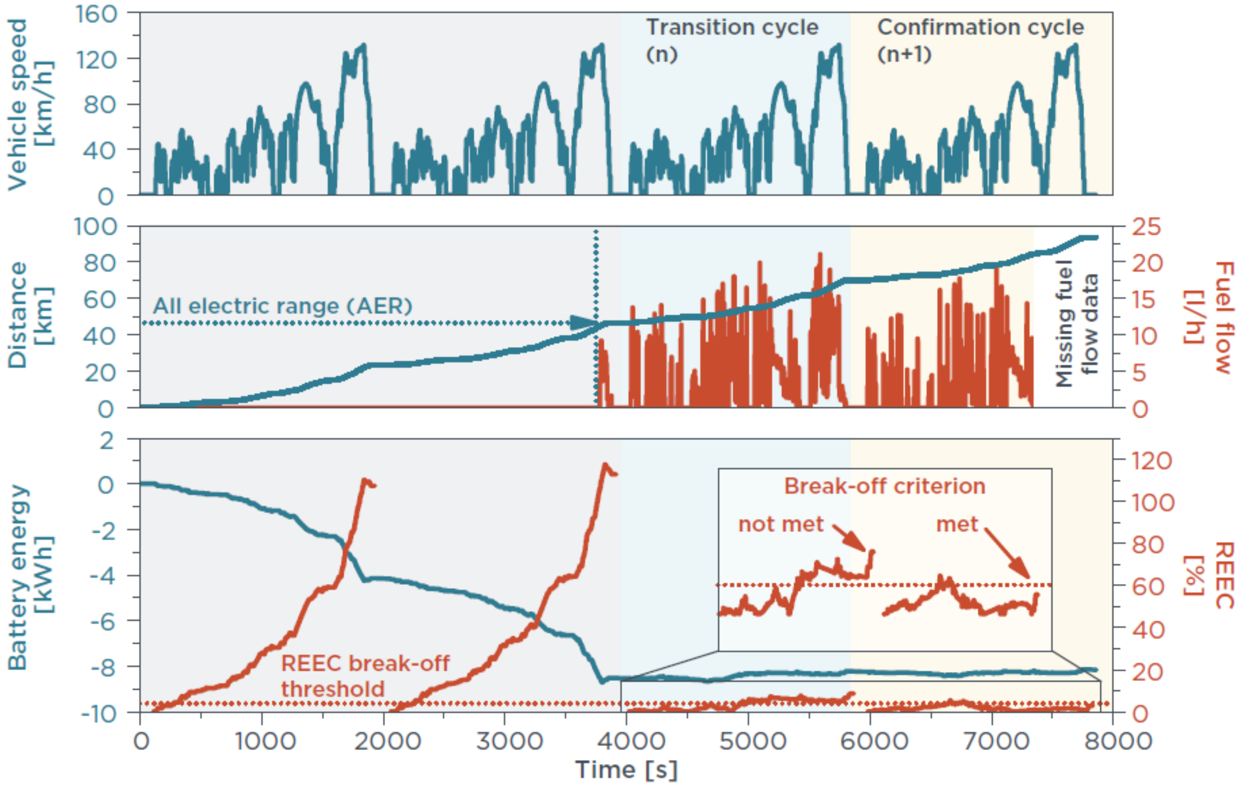

Figure 6: **Definition of charge-depleting mode using a vehicle example**

Source: Dornoff (2021)

In practice, the low threshold value of 4% energy content means that the CD phase is terminated very late; it is therefore possible and regulatory permissible for very high combustion engine shares to prevail in the final CD cycles, even though the break-off criterion has not yet been formally reached. Hence, the normative CD range can be interpreted generously, and consequently the electric shares used in regulatory UF models are overestimated. In other words, the REEC criterion protects the standardizability of the test procedure, but at the same time allows for a considerable remaining ICE contribution before the CD mode is officially terminated. This property partly explains the observed discrepancy between WLTP-based assumptions (UF curves) and real OBFCM measurements of kilometers driven electrically.

From a regulatory perspective, the choice of this threshold has advantages and disadvantages. On the one hand, an excessively high REEC threshold prevents arbitrary advancement of the termination by manufacturer software or SOC buffering; on the other hand, a very low threshold causes a systematic overestimation of the "electrically possible" driving share, provided that only the CD range is used to estimate real-world usage.[7]

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[7] Based on the available OBFCM data (see results chapter below), it is more advisable to retain the CD test definition but change the regulatory weighting: CD mode range (R_{CDC}) and electric range (AER) are suitable as minimum technical requirements, while emissions-related compliance should be based on real, OBFCM-supported metrics (e.g., km-weighted UF_{real}). Such data-based validations close the gap between net energy test definition and actual emissions-effective use.

To conclude, CD mode according to WLTP is not an electric driving mode, but an energy-defined transition range. The utility factor (see below) is a CD mode share in the regulation and is therefore not an electric driving share.

1.2.3. Utility Factors

Utility factors (UF) or usage shares play a central role in assessing the real-world emissions performance of PHEVs. There are basically two categories of UF that are used in regulation, type testing, and empirical mileage analysis with OBFCM data: the CD mode-based utility factor (UF_{CD}) and the electric driving share (UF_{real}). Both variables are related to the electric usability of PHEVs but serve different purposes and are based on different data sources.

The UF_{CD} describes the proportion of kilometers driven in CD mode in relation to total mileage. In the WLTP type-approval procedure, this proportion is modeled as a function of the CD mode range R_{CDC}. The UF_{CD} is therefore a behavior- and technology-related parameter. It provides information about the proportion of the route that a PHEV can typically cover without range limitation in predominantly electric but not purely electric mode before the vehicle switches to charge-sustaining mode. In contrast, the range in purely electric mode is called all-electric range (AER), which is the range covered in the test cycle before the combustion engine starts up for the first time. In a regulatory context, UF_{CD} serves to derive the maximum permissible electric driving share in the type-approval process from the certified electric range. UF_{CD} is therefore primarily a calculation tool that influences the emissions assessment of manufacturer fleets in accordance with CO_2 requirements.

In contrast, UF_{real} represents the actual proportion of kilometers traveled electrically in relation to the total mileage, i.e., the proportion of all kilometers traveled with the combustion engine in relation to the total kilometers. Unlike UF_{CD}, UF_{real} is not defined by technology or type testing, but is emission-relevant: UF_{real} determines the actual electric efficiency of a PHEV in driving mode and thus correlates directly with CO_2 and fuel consumption values. This distinction is important as UF_{CD} is always greater than or equal to UF_{real}, since CD mode kilometers are not necessarily driven purely electrically (see previous section), while UF_{real} only considers those kilometers that are driven without the internal combustion engine.

The question of the comparability of the two concepts arises from the fact that they are based on different system boundaries. UF_{CD} measures the electric operation window offered by the vehicle, while UF_{real} measures the actual use of electric driving in this window in traffic. Directly equating the two indicators was advantageous under WLTP regulatory logic, as sufficiently accurate real-world usage data was lacking and CD mode ranges served as a structural proxy. With the introduction of OBFCM systems, this workaround is no longer necessary. OBFCM provides specific metrics on the proportion of kilometers driven on electric and combustion engines, as well as on driving conditions, so that UF_{CD} and UF_{real} can be empirically separated, quantified, and correlated for the first time.

In regulation, UF explicitly appears in the calculation of average CO_2 emissions and fuel consumption, as well as phase weighting in the test cycle. For average fuel consumption, UF indicates the assumed proportion of CD mode trips of a PHEV depending on its CD mode range R_{CDC}:

$$\mathrm{UF}(\mathrm{x},\, d_n) = 1 - \exp\left[-\sum\nolimits_{i=1}^{10} c_i \left(\frac{\mathrm{x}}{d_n}\right)^i\right],$$

x is a range in km, the numerical constants are $c_1 = 26.25, c_2 = -38.94,$ $c_3 = -631.05, c_4 = 5964.83, c_5 = -25095,\ c_6 = 60380.2, c_7 = -87517, c_8 = 75513.8,$ $c_9 = -35749, c_{10} = 7154.94$ (Regulation (EU) 2017/1151, Annex XXI). The scaling factor is

$d_n = 800\,\mathrm{km}$ for all PHEVs newly registered before 2025. To weigh the emissions of a test cycle phase, the same UF is applied successively to the subsequent phases, i.e., the UF for phase j is:

$$\mathrm{UF}_j(\mathrm{x},\ d_n) = 1 - \exp\left[-\sum_{i=1}^{10} c_i \left(\frac{\mathrm{x}}{d_n}\right)^i\right] - \sum_{l=1}^{j-1} \mathrm{UF}_l \ ,$$

Where x is the distance traveled in km up to the end of phase j.

1.2.4. Existing and planned changes to utility factors

Due to the high discrepancies between real emissions and type-approval values, the EU has tightened the utility factor calculation for PHEVs. The tightening is achieved by changing the scaling parameter d_n: Up to and including 2024, the scaling factor $d_n = 800\,\mathrm{km}$. From 2025 (valid since January 1, 2025, for new types, from January 1, 2026, for all newly registered PHEVs), the following applies: $d_n = 2.200\,\mathrm{km}$. And from 2027 (planned from January 1, 2027, for new types, from January 1, 2028, for all), the $d_n = 4.260\,\mathrm{km}$ applies.

Also, in China, the large discrepancies between the real and nominal consumption of PHEVs have led to a change in the utility factors (ICCT 2025). The previous, current, and future UF curves for Europe and China are shown in Figure 7.

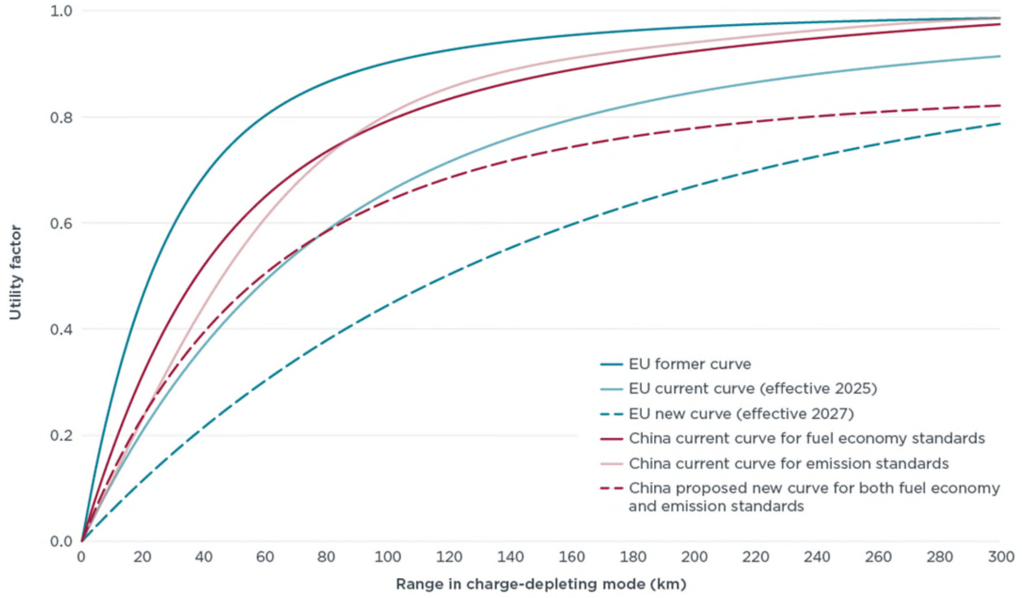

Figure 7: Utility factor curves for Europe and China.

Source: ICCT (2025)

2. Data and methodology

2.1. Empirical basis: OBFCM data

The analysis is based on On-Board Fuel Consumption Monitoring (OBFCM) data from the European Environment Agency (EEA) for PHEVs newly registered in Europe between 2021 and 2023 (see EEA 2025). The data covers three reporting periods (2021–2023) with a total of 1,378,211 observations. The largest proportion is from 2023 (approx. 61%).

Table 2: Number of PHV by fuel and year

Year	Gasoline PHEV	Diesel PHEV
2023	757,087	85,210
2022	350,625	64,938
2021	95,456	24,895
Total	1,203,168	175,043

Source: Own calculations

Gasoline PHEVs dominate with a total of 1,203,168 vehicles (~87%). Diesel PHEVs account for 175,043 cars (~13%). The share of diesel PHEVs has remained constantly low over the years.

Vehicles may have been reported multiple times in the data. Therefore, each vehicle (according to the variable "vehicleID") was only kept once, with the most recent value (i.e., if the same vehicle appears in the reporting years 2021 and 2023, only the value from 2023 was kept). This results in a total of N = 981,139 unique vehicles.

The calculation of the energy-based usage share UF_{ener} and the conversion between fuel consumption and emissions directly follows the methodology in (European Commission 2024) as well as Gohlke & Gimbert (2025) and Suarez et al. (2025). The share of kilometers in charge-depleting mode or the share of kilometers in charge-depleting mode with combustion engine off are calculated directly from the OBFCM data. A further calculation of the electric *driving share* (EDS) follows according to Appendix B in Plötz et al. (2022).

We also continue to use the energy-based utility factor (UF_{ener}) in accordance with *Commission Staff Working Document SWD (2024) 59*. This energy-based utility factor is used to represent the share of electrical energy in the total energy used to power the vehicle. In contrast to the distance-based utility factor, which is based on the proportion of kilometers traveled in charge-depleting mode, the energy-based approach explicitly considers the electrical energy charged from the power grid and the chemical energy provided by fuel. This enables a more realistic representation of electrical usage, especially in situations where the electric motor and internal combustion engine are operating in parallel. The energy-based utility factor is defined as follows:[8]

$$UF_{ener} = \frac{E_{grid,tot} \cdot \eta_{elec} \cdot \eta_{charging}}{E_{grid,tot} \cdot \eta_{charging} \cdot \eta_{elec} + fuel_{tot} \cdot \rho_{fuel} \cdot LHV \cdot \eta_{ICE}}$$

$E_{elec,tot}$ is the total electrical energy in kilowatt hours (kWh) charged from the power grid to the vehicle's high-voltage storage system during the period under consideration (OBFCM variable

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[8] The Commission Staff Working Document SWD(2024) 59 incorrectly omits charging efficiency from the formula. We would like to thank Jan Dornoff (ICCT) for pointing this out and have corrected the formula accordingly here.

grid_tot), $\eta_{elec} = 85\%$ is a flat-rate electrical efficiency for the electric powertrain, $\eta_{charging} = 1/0.85$ the charging efficiency required to convert "grid energy into the battery" to "total grid energy", taking charging losses into account, $fuel_{tot}$ the total amount of fuel refueled, ρ_{fuel} the density of the fuel (0.7475 kg/l for gasoline and 0.8325 kg/l for diesel), LHV the lower heating value of the fuel (41.5/3.6 kWh/kg for gasoline and 42.7/3.6 kWh/kg for diesel) and η_{ICE} an average conversion efficiency of the chemical potential energy in the fuel into kinetic energy (30.7% for gasoline and 36.9% for diesel engines).

The energy-based utility factor thus indicates the proportion of electrical energy effectively used for propulsion in relation to the total propulsion energy. By explicitly considering average efficiencies and heating values, this approach represents a methodological difference from purely distance-based utility factor concepts. It allows for consistent use of OBFCM energy data. However, the use of average values for efficiencies at the individual vehicle level can lead to inaccuracies, and an evaluation at the model level appears to be more appropriate.

2.2. Methodology

The current study is divided into four work packages (WPs).

WP1: Evaluation of the VDA's demands for PHEV regulation

Objective: Systematic analysis and evaluation of the VDA's demands for the suspension of utility factor adjustments and measures such as geofencing and inducement in terms of their technical feasibility and realistic CO_2 reduction effect.

The first work package involves a systematic analysis of the German Association of the Automotive Industry's demands for the suspension of the planned utility factor adjustments and additional measures such as geofencing and inducement. The aim is to conduct a technical and emissions-related assessment of these proposals, considering their realistic effectiveness in terms of CO_2 reduction. Methodologically, impact scenarios are first developed based on modeling of the electric driving shares. This is based on the available OBFCM measurement data, supplemented by our own derivations of the sensitivity of the usage shares to various regulatory interventions. The VDA's proposals are then evaluated in terms of their feasibility, monitorability, and possible conflicts of interest. This includes a differentiated analysis of the technical maturity and regulatory enforceability of geofencing and inducement approaches, as well as their potential contribution to reliable CO_2 reduction. The overall assessment is carried out using a structured criteria grid that brings together advantages, disadvantages, and expected effects.

WP2: In-depth empirical analyses of OBFCM real-world emissions data

Objective: Extended statistical evaluation of EEA OBFCM data to derive updated utility factor curves and identify best-practice vehicles and usage patterns with low real-world emissions.

The second work package is dedicated to a comprehensive statistical evaluation of the European Environment Agency's OBFCM data with the aim of generating updated utility factor curves and identifying best-practice vehicles with low real CO_2 emissions. Different definitions of the utility factor are examined. These include the proportion of kilometers driven in CD mode, the proportion of purely electrically powered CD kilometers (engine off), energy-based variants, and quotients of the measured real-world emissions and the hypothetical emissions calculated when using CS mode exclusively. For each of these definitions, an assessment is made of the extent to which it reflects the actual emissions-relevant use of PHEVs and thus offers "real world representativeness" relevant for type-approval and regulation. Based on the results, vehicles with particularly high electric driving shares are identified. In addition, extended regression models are developed where necessary, for example to better reflect nonlinear relationships between electric range, user behavior, and utility factor.

WP3: Development of specific regulatory requirements for low-emission PHEVs

Objective: Development of a consistent regulatory framework for PHEVs that ensures real CO_2 reduction and reconciles industrial policy with environmental policy goals.

Work package 3 focuses on the development of a consistent, sustainable regulatory concept for plug-in hybrids that ensures real CO_2 reductions and reconciles industrial policy and environmental policy goals. First, minimum technical requirements are defined, including electric range, permissible real-world CO_2 emissions, and the implementation of an electric-first driving logic that minimizes combustion engine use. These requirements explicitly include range extender configurations. Behavior-based requirements will then be developed, including verification systems for charging frequency, minimum utility factors, and requirements for OBFCM-based compliance. In addition, possible regulatory mechanisms will be outlined that enable effective interaction between incentives and enforcement, such as market share limits, time limits for transitional rules, and bonus and penalty-based elements.

WP4: Scenario modeling of CO_2 emission impacts

Objective: Quantitative assessment of the climate impacts of various regulatory options for Germany and the EU27 by 2035/2040, presented as fleet target equivalents for political communication.

The fourth work package involves a quantitative assessment of the climate impacts of different regulatory options for Germany and the EU27 until 2035 and 2040. To this end, a set of scenarios will be developed that reflects the various developments in utility factor regulation and additional PHEV requirements. Modeling of the following scenarios:

- **Reference development:** Implementation of planned UF updates (2025: d=2200km, 2027: d=4260km)
- **Option 1a:** Suspension of UF updates in 2025 & 2027
- **Option 1b:** Option 1a + VDA measures (geofencing, inducement)
- **Option 2:** Suspension of UF update 2027 only

In addition to a reference scenario that reflects the implementation of the planned UF updates (2025 d=2200 km, 2027 d=4260 km), scenarios are considered that contain a complete or partial suspension of these adjustments, as well as combinations of regulatory suspension and VDA requirements such as geofencing and inducement. Another scenario integrates possible subsidized low-emission PHEVs resulting from work package 3. For each scenario, the annual CO_2 emissions of the vehicle fleet for Germany are calculated and converted into CO_2 equivalents for European fleet regulation. The presentation of results does not follow the order of the work packages but a more logical flow.

3. Results

3.1. Empirical analyses of OBFCM real-world emissions data

The OBCFM data allows for comprehensive evaluations of the real-world use of nearly one million PHEVs in Europe. The relevant evaluations are presented in several steps below.

3.1.1. Descriptive statistics

Figure 8 shows the normalized frequency distributions of consumption in CS, CD, and mixed operation, as well as the proportions of km in CD mode, in CD mode with the combustion engine off, and the proportion of electric driving energy (mean values as vertical red lines).

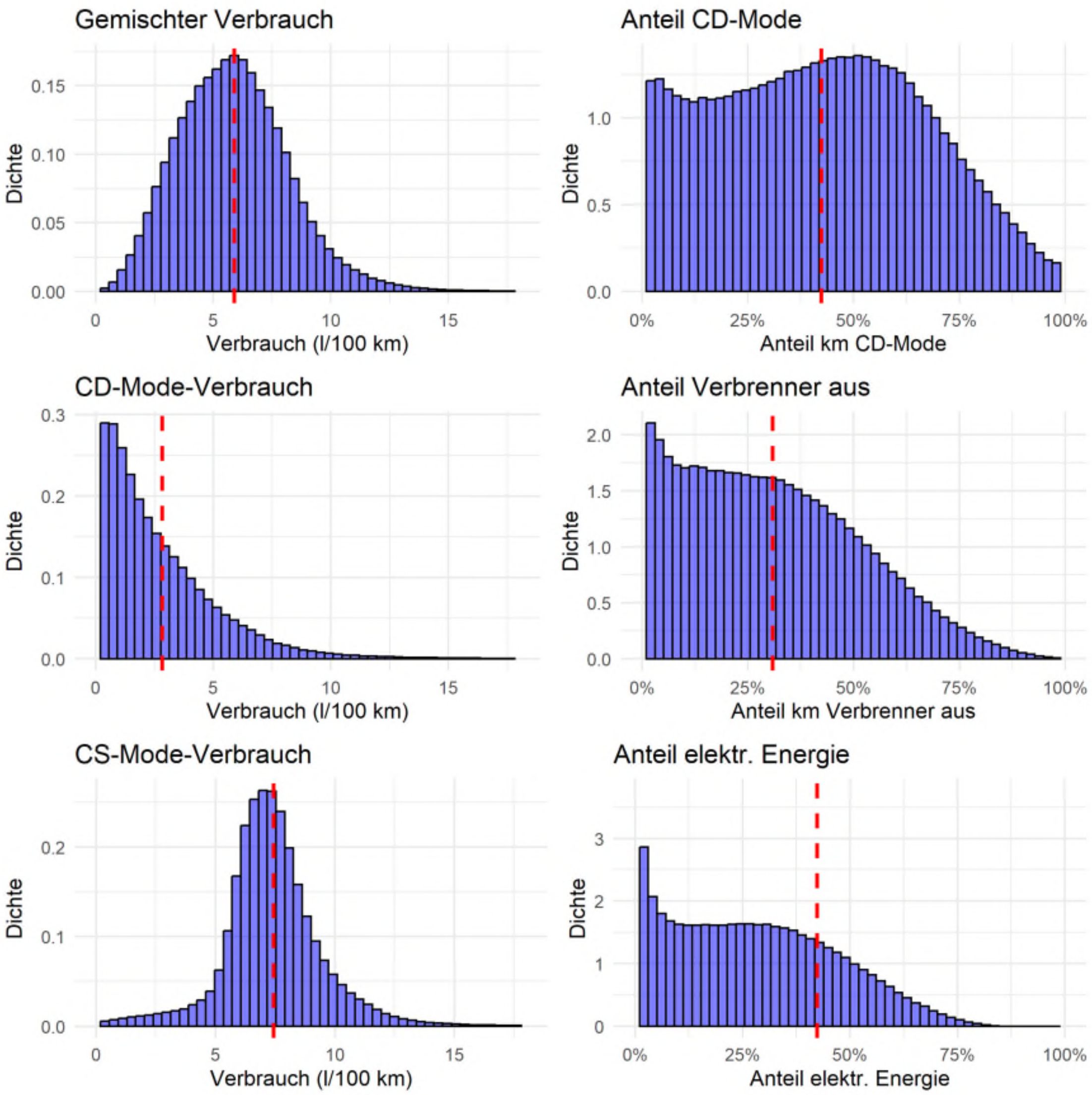

Figure 8: **Relative frequency distribution of the most important observation variables**

Source: Own calculations

The distributions show that mixed and CS mode consumption have a clear peak, while CD mode is clearly skewed to the right, i.e. there are many low values but also some high values on the right. The distribution of the proportion of km in CD mode is rather broad, with a slight peak around 50%

from a mean value of approximately 42%. The proportion of km in CD mode with the combustion engine off and the proportion of electrical energy in energy consumption are relatively flat, slightly right-skewed distributions from 0–50% and then falling sharply above 50%. The mean values are correspondingly lower at 30.9% and 24.7%.

The mean values, medians, and total km-weighted mean values of the six measured variables and additional information are shown in the following table.

Table 3: Key parameters for actual consumption of PHEVs

Measure	Median	Mean	km-weighted mean	N
Combined WLTP consumption in l/100 km	1.40	1.53	1.57	981,035
Combined WLTP consumption in gCO_2 /km	32.0	35.3	36.5	981,035
Combined fuel consumption in l/100 km	5.76	5.89	6.12	981,035
Deviation between actual and nominal consumption*	281%	323%	326%	981,035
CD mode consumption in l/100 km	2.07	2.82	2.98	979.639
CS mode consumption in l/100 km	7.27	7.44	7.40	966,392
Proportion of CD mode km UF_{CD}	42.3%	42.4%	39.0%	981,035
Share of CD mode km with combustion engine from UF_{real}	28.7%	30.9%	27.4%	981,035
Share of electrical energy UF_{ener}	29.1%	31.0%	31.0%	972,200

Source: Own calculations. * Calculated as actual consumption / nominal consumption – 1

The average combined consumption is 5.8–6.1 l/100 km and the CS mode consumption is 7.3–7.4 l/100 km. The average CD mode consumption is also striking, with a median of 2.1 l/100 km, an average of 2.8 l/100 km, and a km-weighted average of just under 3 l/100 km. The values of the various UF correspond to the results of the European Commission for the data from 2021 only (EC 2024), with a deviation of approximately one percentage point.

It is also striking that not only are the average real-world fuel consumption values significantly higher than the mixed WLTP consumption values of 1.4 – 1.6 l/100 km, but even the CD mode consumption values are significantly higher. The mixed real-world consumption figures are approximately 300% above the mixed WLTP values, and CD mode values are on average 93% (99% in the km-weighted average) and in the median 44% above the CD mode values from type-approval (not shown in the table).

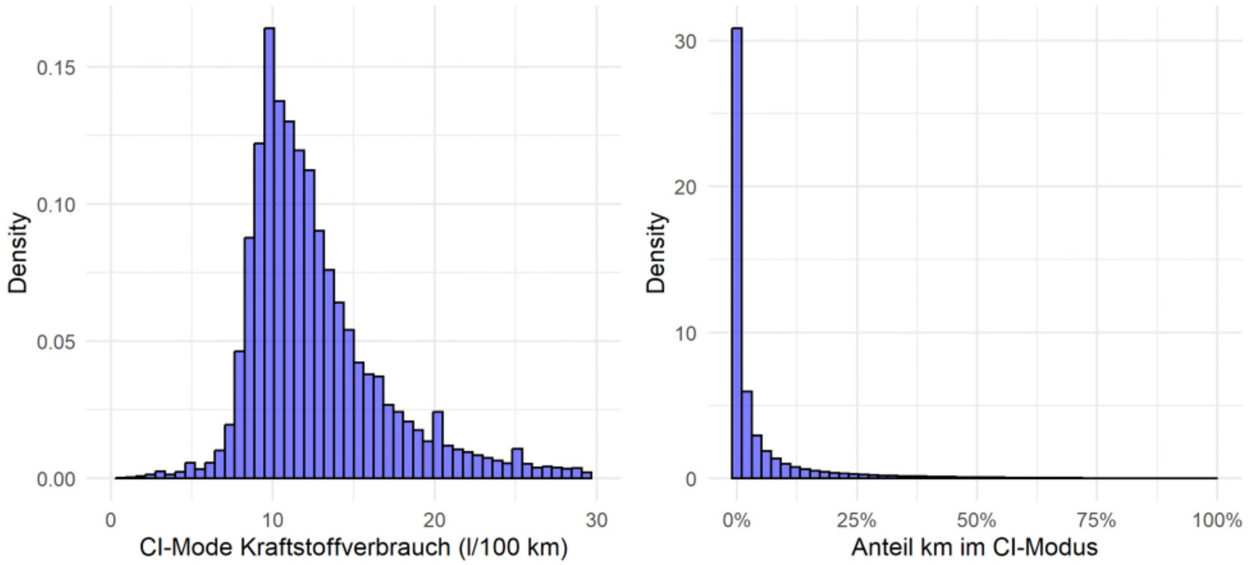

Figure 9: **Frequency distribution of fuel consumption and share of km in CI mode.**

Source: Own calculations

Figure 9 shows the empirical distributions of two further parameters of real PHEV operation. On the left is the density distribution of fuel consumption in charge-increasing (CI) mode. It shows a clear maximum in the range of approximately 9 to 12 l/100 km and is skewed to the right, indicating a relevant dispersion with individual vehicles and driving profiles with significantly higher consumption of over 20 l/100 km. This illustrates that CI mode is associated with high specific fuel consumption in real-world operation, as the combustion engine is used not only for propulsion but also for charging the battery. The right-hand side shows the distribution of the proportion of kilometers traveled in CI mode. This is heavily concentrated on small values and drops off rapidly, showing that although CI mode accounts for only a small proportion of total mileage, it is nevertheless relevant in terms of energy and emissions. Together, both figures underscore that rare but consumption-intensive CI phases also have an impact on the real CO_2 emissions of PHEVs.

Figure 10 shows the frequency distribution of the amount of electricity charged from the power grid (not consumed but charged) per 100 km driven. The standardization with respect to the distance traveled is performed to make vehicles with high and low total mileage comparable. The evaluation shows that different brands and models charge very different amounts of electricity. Typically, between 5 and 10 kWh are charged per 100 km of distance traveled, but for some brands and vehicles, it is significantly less or significantly more. It is also striking that the peak is close to zero for all brands. These are PHEVs that are hardly ever charged. Porsche is particularly striking in this context: there are 11,307 PHEVs in the database that have driven an average of 27,000 km in their vehicle life at the time of data transmission, but have only charged a total of 7 kWh on average.

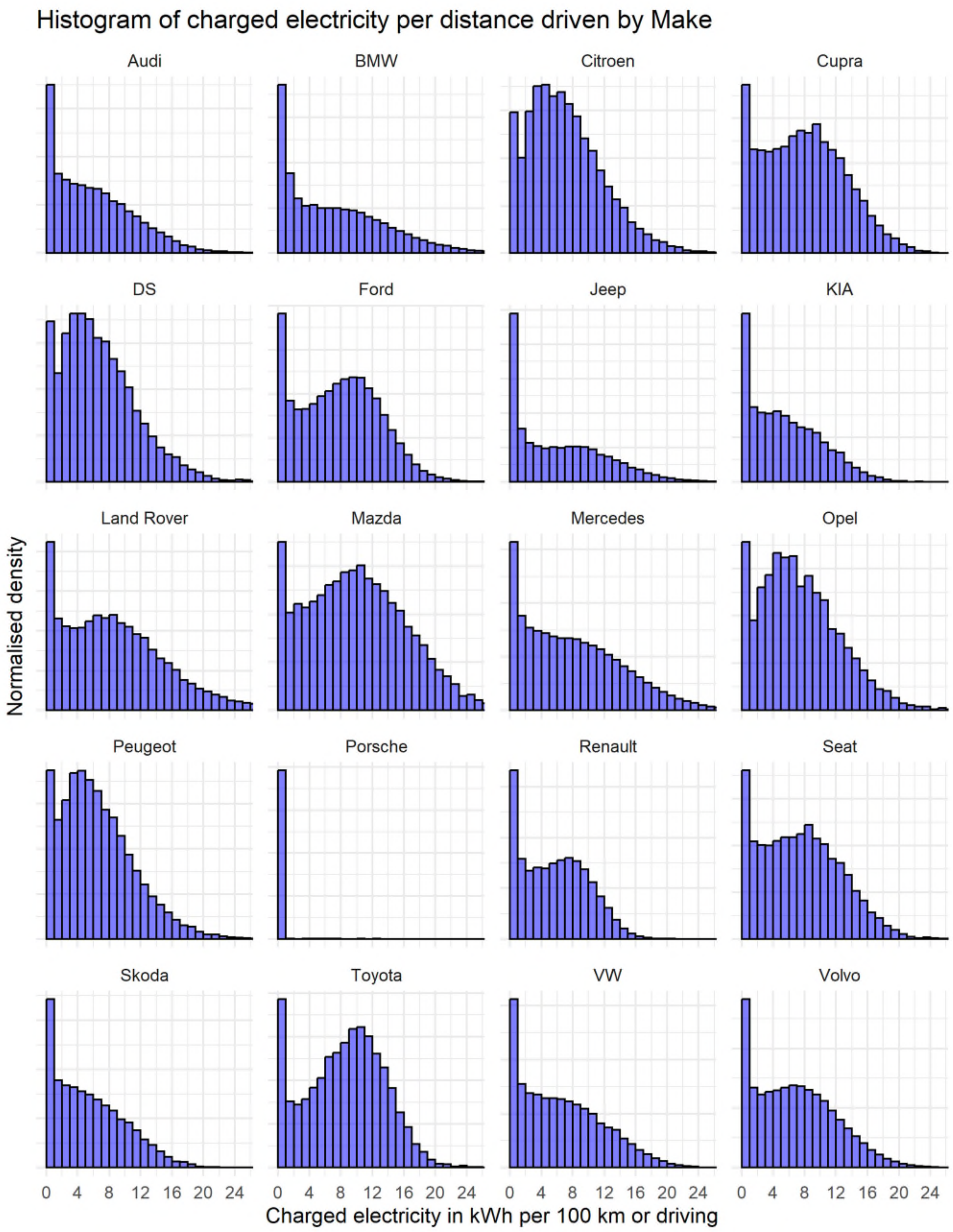

Figure 10: Relative frequency distribution of charged electricity in kWh per 100 km driving distance.

Source: Own calculations

3.1.2. Correlations

In addition to distributions and mean values, correlations between key variables are also interesting for understanding the real-world usage and energy consumption of PHEVs.

The extensive real-world usage data enables an empirical examination of the correlation between charging frequency and fuel consumption of PHEVs. Figure 11 shows that although average fuel consumption decreases with the proportion of CD mode and thus with charging frequency, it does not fall below the CD mode consumption of 2.8 l/100 km. For this reason, current PHEVs consume no less than 2.8 l/100 km or 64 gCO_2/km on average in the fleet, regardless of how often they are charged. It also shows that the average proportion of kilometers driven with the combustion engine off is between 25 and 31% (see UF_{ener} and UF_{real}). However, fuel consumption in CD mode is approximately 2.8 l/100 km, regardless of how often the vehicle is charged. Hence, even frequent charging leads to higher electric driving distances, but does not change CD mode consumption.

Figure 12 shows that there is no relevant correlation between CD mode consumption and the proportion of CD mode kilometers in the fleet average. In other words, vehicles that are charged very frequently and therefore have a high CD mode share of, for example, over 80%, have a similarly high CD mode consumption of approx. 2.7 l/100 km as vehicles that are charged very rarely and therefore drive little in CD mode, e.g., less than 30%. It would also have been conceivable here that with a high loading frequency, the combustion engine would be switched off more often and more electric driving would take place, but this is not reflected in the average CD mode consumption of the fleet. It should be further noted that the consumption in CD mode is shown overall and not only in CD mode with the combustion engine switched off.

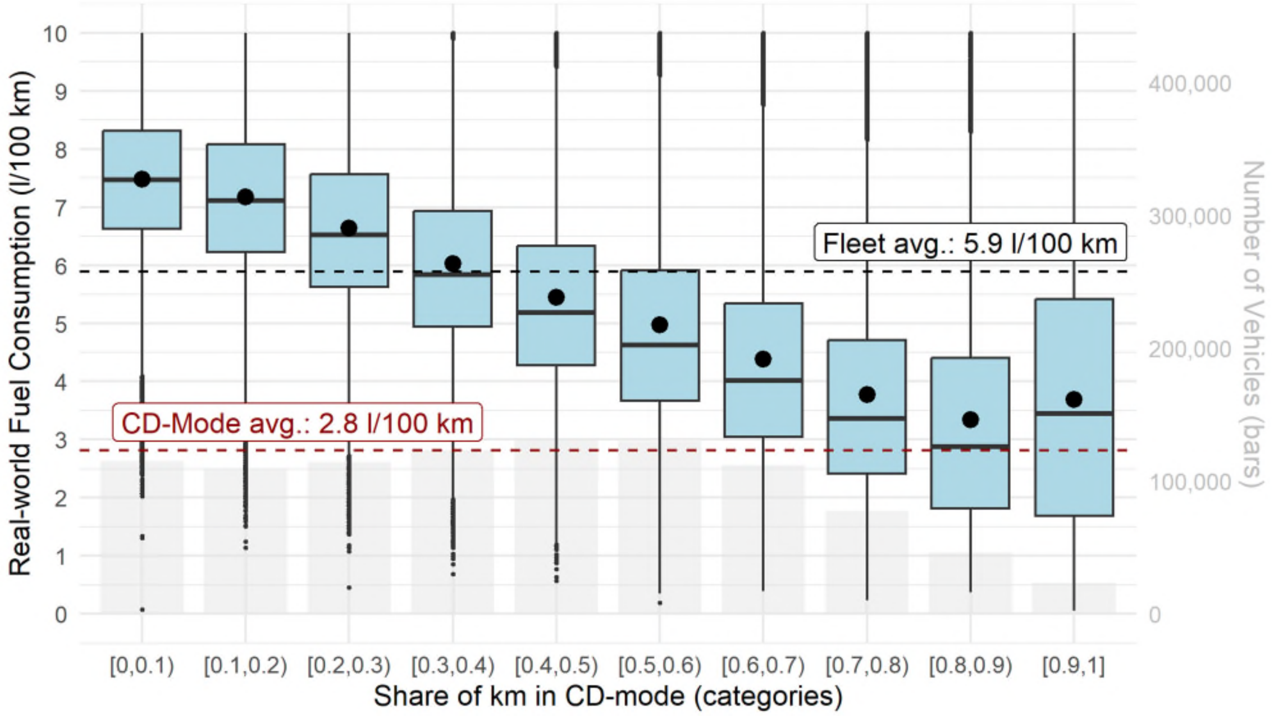

Figure 11: Real-world fuel consumption depending on the CD mode share.

Source: Own calculations

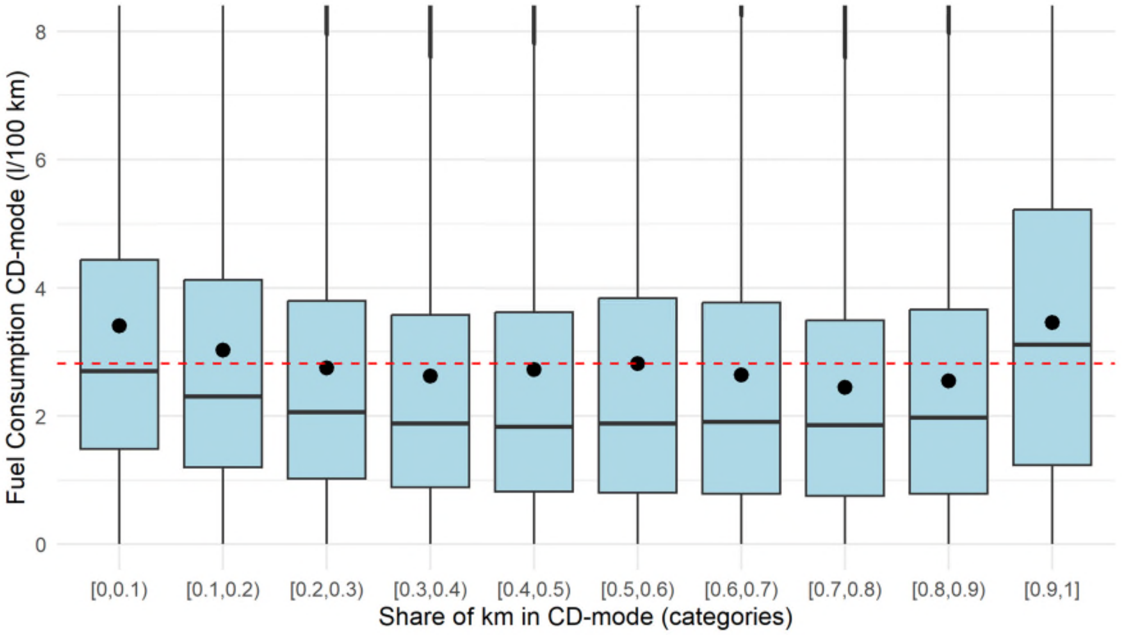

Figure 12: Relation between CD mode consumption and CD mode km share (fleet average 2.8 L/100 km as horizontal dotted line)

Source: Own calculations

Some obvious correlations are also evident in the real data. Figure 13 shows that the proportion of kilometers driven with combustion engines increases with the charging frequency measured as a proportion of CD mode kilometers. The correlation is very clear, but at the same time purely electric driving share (here as UF_{real}, the proportion of CD mode km with combustion engines off) is never greater than 65% even with very frequent charging (proportion of CD mode km >80%), i.e., despite frequent charging, the internal combustion engine is on average running for one-third of the km.

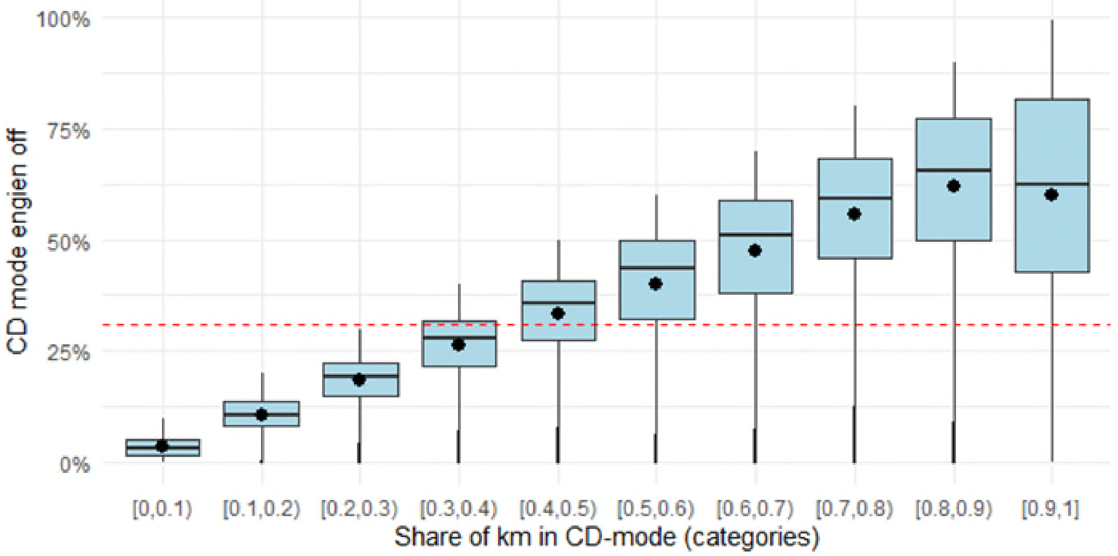

Figure 13: Relation between the proportion of CD mode km with the combustion engine switched off and the proportion of CD mode km

Source: Own calculations

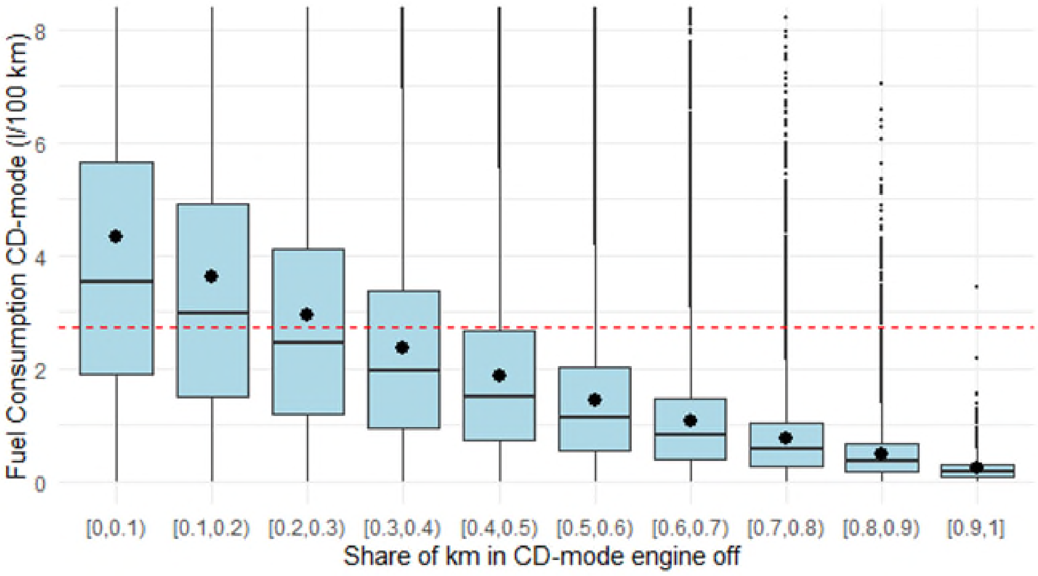

Figure 14: **CD mode consumption vs. CD mode share with combustion engine off**

Source: Own calculations

In Figure 14, we find that more electric driving leads to lower consumption in CD mode. Since electric driving is part of CD mode, high proportions of electric driving lead to low CD mode consumption.

However, CD mode is not the same as electric driving (see chapter 1). Nonetheless, there are some significant differences between manufacturers, probably due to different PHEV operating strategies (customer-specific charging behavior is explicitly shown via the CD mode share on the x-axis – see Figure 15). The overall fleet average of 2.8 l/100 km is shown as a horizontal dotted line.

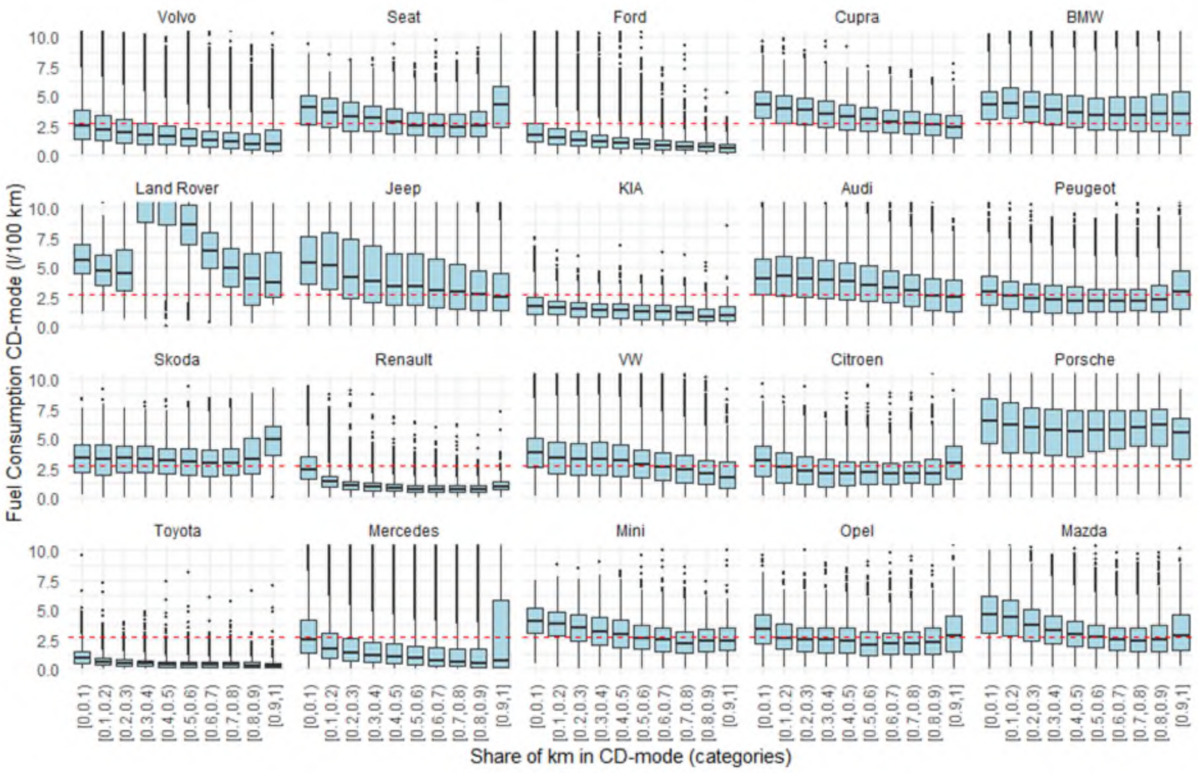

Figure 15: CD mode fuel consumption and CD mode share by brand (fleet avg. dashed)

Source: Own calculations

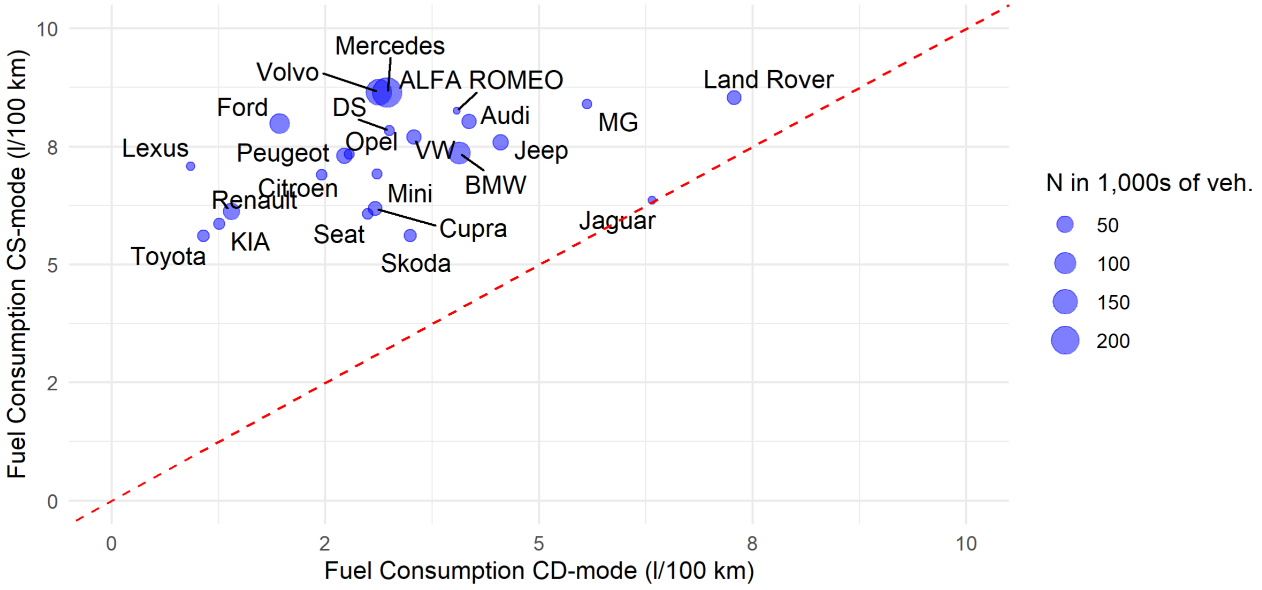

Figure 16: Average real-world fuel consumption in CD and CS mode by brand (for brands with >1000 vehicles in the sample)

Source: Own calculations

Some brands, such as Ford, Kia, Toyota, and Renault show a significant decline in CD mode consumption with increasing CD mode km share, or low overall CD mode consumption due to predominantly electric operation (especially Toyota and Renault). For other brands, such as Ford, Audi, BMW, Cooper, and Seat, the correlation is very weak and CD mode consumption is almost independent of the CD mode share.

The average values for CD mode and CS mode consumption by brand are shown in Figure 16. Some brands, such as Toyota, Renault, and Kia, achieve both low CS mode consumption and low CD mode consumption. Overall, there is a wide variation in average consumption values between brands.

3.2. Empirical Utility Factor Curves

3.2.1. Introduction and definitions

Based on the OBCFM data for PHEVs, this section determines empirical UF curves and calculates what the UF would need to be to reduce the gap between real and nominal consumption to be comparable with the gap seen in combustion engine cars. To date, there are four definitions for the UF as shown in Table 4.

Table 4: Utility factor definitions

Approach	Purpose	Abbre-viation	Definition	Source
CD mode share	Matches regulation	$\mathrm{UF_{CD}}$	$\mathrm{UF_{CD}} = \frac{dist_{CD}}{dist_{tot}}$	OBFCM data
Share of CD mode Combustion engine off	Electric driving share	$\mathrm{UF_{real}}$	$\mathrm{UF_{real}} = \frac{dist_{CD,\ engine-off}}{dist_{tot}}$	OBFCM data
Based on actual consumption	Electric driving share	$\mathrm{UF_{EDS}}$	$\mathrm{UF_{EDS}} = 1 - \frac{FC_{tot}^{real}}{FC_{CS}^{real}}$	OBFCM data & Plötz et al. 2022
Energy-based	Electric driving share	$\mathrm{UF_{ener}}$	$UF_{ener} = \frac{E_{grid,tot} \cdot \eta_{elec} \cdot \eta_{charging}}{E_{grid,tot}\, \eta_{charging}\, \eta_{elec} + fuel_{tot}\, \rho_{fuel}\, LHV\, \eta_{ICE}}$	According to EC (2024)

Source: Own representation

The first three definitions can be calculated directly using OBCFM data, while the energy-based approach requires some additional assumptions (see also section 2.1). Furthermore, we present a new UF calculation here which sets the UF to meet a specific gap between actual and type-approval fuel consumption, 20 % in the present case.

In addition, we present a new UF calculation in which the UF is set to achieve a certain gap between the actual and type-approved fuel consumption, in this case 20%. In the following, all UF values are calculated for each vehicle and aggregated at the model level. The values are compared with each other and with the regulation.

3.2.2. Correlations between the UF

Figure 17 shows the relationship between the CD mode share with the combustion engine switched off on the x-axis and the energy-based utility factor ($\mathrm{UF_{ener}}$) on the y-axis. Each point represents one of the 1,436 vehicle models from the OBFCM data, which accounts for just under one million PHEVs. As expected, there is a positive, approximately linear correlation between the two UF definitions. Vehicles with a higher proportion of CD mode kilometers with the combustion engine switched off also have a higher average energy-based electric driving share. The black regression line with gray confidence band quantifies this correlation and illustrates that the $\mathrm{UF_{ener}}$ increases systematically with the CD mode engine-off share. At the same time, however, the variation is considerable, especially in the range between approximately 10 and 40 percent CD mode share, which indicates different electrical energy consumption, and varying driving profiles. The red dotted diagonal corresponds to the 1:1 line, where the energy-based electric share would exactly match the CD mode engine-off share. Most observations lie below this line. Thus, a given share of CD mode kilometers typically leads to a lower energy-based electric share. Overall, the figure illustrates that although the CD mode engine-off portion is a suitable proxy for electric driving, it can vary greatly at the vehicle and model level and is systematically smaller than the energy-derived UF. This underscores the conceptual differences between distance-based and energy-based utility factor definitions. The evaluation at the model level also reveals that a relevant proportion of PHEVs have no energy-based electric driving share at all according to Energy UF_{ener}. Of a total of 1,436 models in the sample, 101 show UF_{ener}= 0 (7 percent of models, 0.4 percent of vehicles).

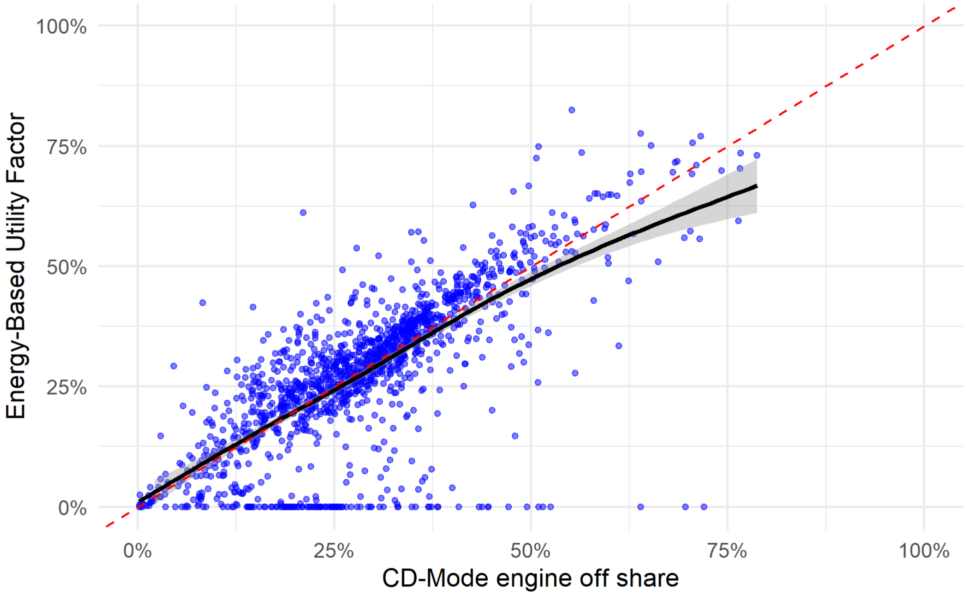

Figure 17: **Correlation between the proportion of km in CD mode with combustion engine from UF_{real} and energy-based UF_{ener}.**

Source: Own calculations. Shown are mean values at model level (blue dots) and local expected value (black)

Figure 18 continues to show the relationship between the CD mode share according to the utility factor definition (UF_{CD}) on the x-axis and the share of CD mode kilometers with the combustion engine off UF_{real}. There is a clear positive correlation, but with a systematic deviation from the 1:1 line (red dotted line). The regression line lies well below the diagonal across the entire range of values, indicating that a high UF_{CD} is not synonymous with a correspondingly high proportion of purely electric CD mode kilometers. The variation increases significantly, especially at higher UF_{CD} values, and many vehicles show substantial combustion engine use within CD mode despite high CD mode proportions. The figure underscores that UF_{CD} systematically and significantly overestimates electric use and that the distinction between overall CD mode and electric driving proportion is central for PHEVs.

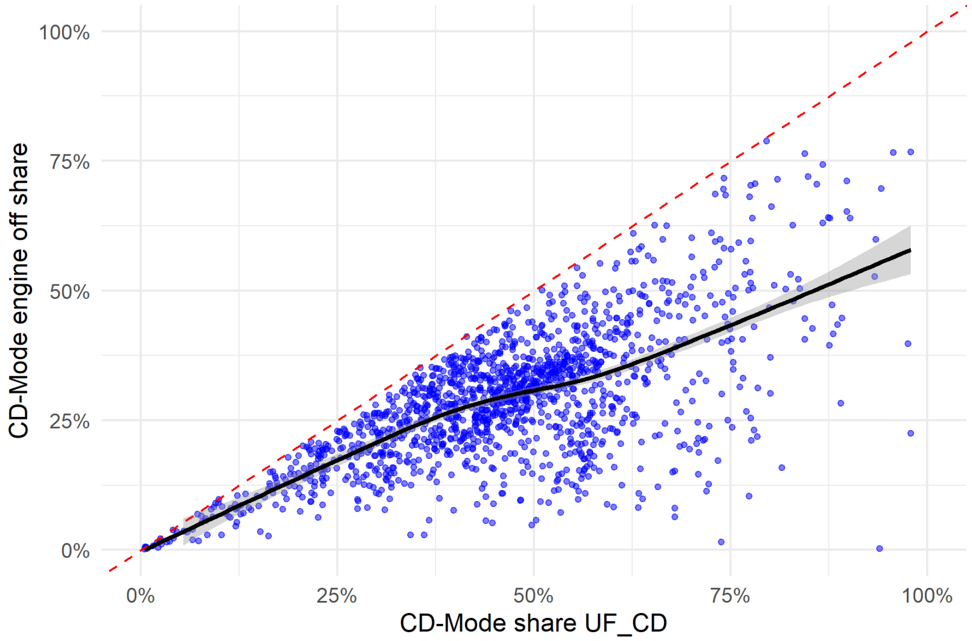

Figure 18: **Correlation between the proportion of km in CD mode with combustion engines from UF_{real} (y-axis) and the proportion of km in CD mode UF_{CD}**

Source: Own calculations. Shown are mean values at model level (blue dots) and local expected value (black)

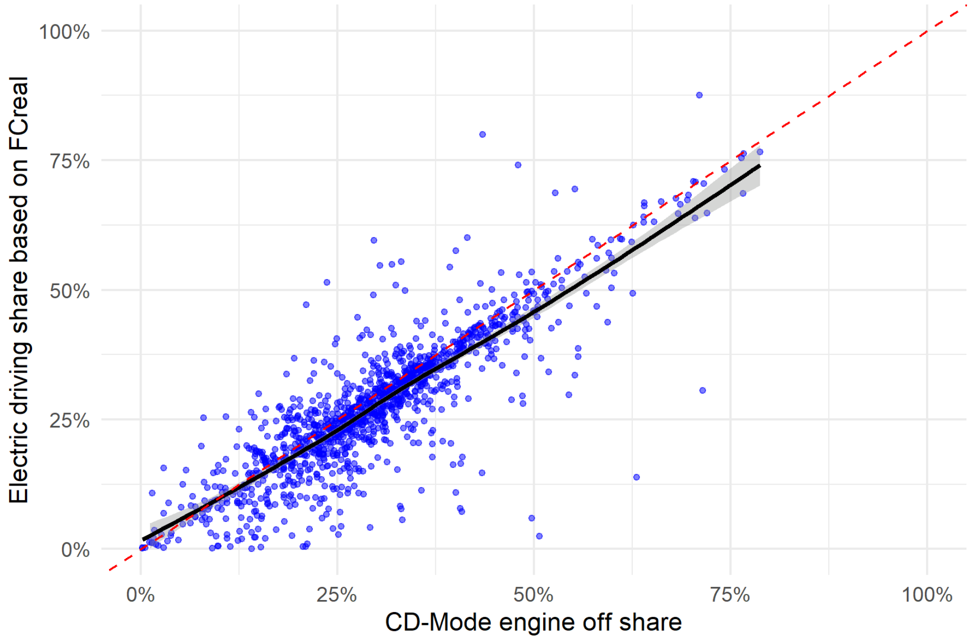

Figure 19: **Correlation between the proportion of km in CD mode with combustion engine from UF_{real} (x-axis) and the proportion of electric driving UF_{EDS} according to Plötz et al. (2022).**

Source: Own calculations. Shown are mean values at model level (blue dots) and local expected value (black)

Figure 19 shows the relationship between the proportion of km in CD mode with combustion engine from UF_{real} and the proportion of electric driving UF_{EDS} according to Plötz et al. (2022) (mean values at model level (blue dots) and local expected value (black)

Table 5 compares the mean values of manufacturer-specific UF indicators. Both the average proportion of kilometers driven in CD mode with internal combustion engine (UF_{real}) and the energy utility factor (UF_{ener}) are shown, based on aggregated vehicle and observation data per brand. In addition, the median of the energy utility factor is given to show the distribution in a way that is more robust to outliers.

Table 5: Average UF key figures by brand, sorted in ascending order by UF_{ener}

Brand	Number Models	Number Vehicles	Average UF_{real} [%]	Average UF_{ener} [%]	Median UF_{ener} [%]
Porsche	94	11,307	23.3	0.8	0.0
Ferrari	12	1,242	12.3	2.9	2.9
Bentley	12	135	20.6	10.4	4.7
Mini	3	8 227	36.0	12.8	12.8
Lexus	3	4,045	33.9	21.3	27.5
MG	29	7 175	19.6	22.5	24.1
VW	29	32,936	30.0	24.7	22.9
Volvo	71	162,693	27.8	26.5	26.0
Audi	100	30,884	30.1	26.5	25.0
BMW	58	107,708	30.0	27.0	28.0
Hyundai	41	879	26.7	27.5	27.0
Mercedes-Benz	70	233,954	28.1	27.7	28.7
Jeep	39	40,873	24.7	27.7	29.7
DS	124	8,536	28.8	28.6	29.5
Mazda	9	18	28.8	29.4	32.3
Land Rover	162	30,080	20.9	30.1	29.2
Renault	6	47,587	30.8	20.3	30.1
Opel	42	9,004	32.6	30.4	34.0
Peugeot	197	40,075	33.1	31.0	32.0
Suzuki	11	808	28.5	31.6	30.4
Jaguar	34	3,471	23.7	31.7	28.9
Alfa Romeo	3	1,848	31.6	33.4	34.1
Citroën	67	11,070	35.5	33.5	32.0
Škoda	21	18,950	35.1	34.0	31.2
Kia	43	13,467	33.4	34.8	33.3
Mitsubishi	10	629	33.9	35.4	36.3
Cupra	36	29,805	33.2	36.1	36.7
Ford	59	79	33.4	36.7	38.5
Seat	31	10,389	35.9	38.9	37.1
Toyota	6	15,707	40.1	42.8	44.2

Source: Own calculations

The results show considerable variation between manufacturers. While individual brands achieve average energy utility factors UF_{ener} of less than 10%, other manufacturers exceed 30%, and in some cases even more. This indicates substantial differences both in the technical design of the vehicles and in actual usage behavior. A comparison of the mean and median also shows that several manufacturers have a right-skewed distribution with a high proportion of very low electric driving shares.

3.2.3. Results for UF curves

Since the regulation with the UF makes an explicit assumption about the relationship between UF_{CD} and R_{CDC}, this relationship is considered first. For each vehicle, the CD mode range R_{CDC} was calculated approximately (since no conformity certificates are available) as the next integer multiple of a WLTP length to the electric range. The data was then aggregated at the vehicle model level. Therefore, most of the X values in the figure are close to integer multiples of the WLTP cycle length of 23.3 km, and some values are averages between model variants with different integer multiples of the WLTP cycle length.

Figure 20 shows the proportion of CD mode km UF_{CD} as a function of CD mode range, including vehicle values aggregated at model level, as well as the WLTP curve up to and including 2024 (gray), the curves from 2025 and 2027 (upper blue line 2025, lower 2027) and the best fit for the data (orange).

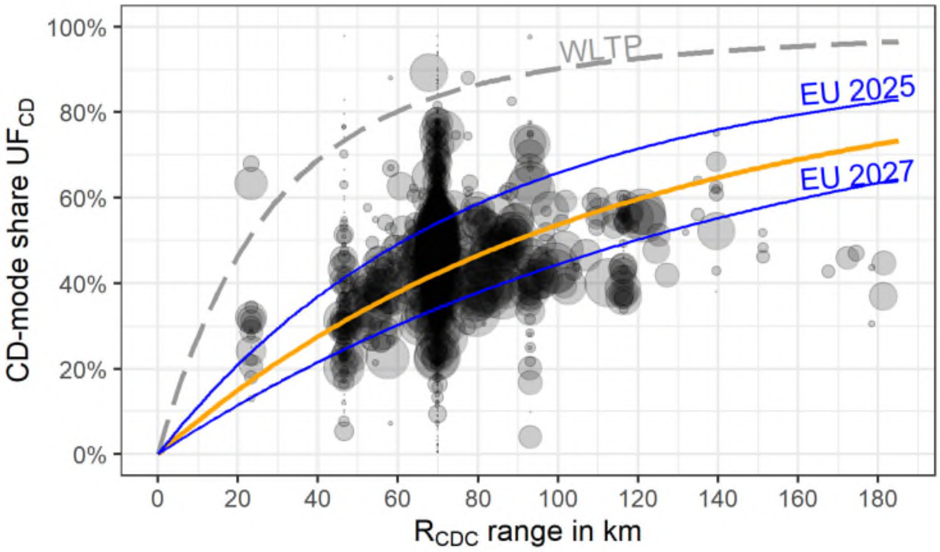

Figure 20: Proportion of CD mode km UF_{CD} as a function of CD mode range R_{CDC}

Source: Own calculations

The nonlinear estimation of the utility factor curve based on the relationship between the proportion of kilometers driven in CD mode UF_{CD} and the CD mode range R_{CDC} in the WLTP UF function with d_n as a free parameter yields a scaling parameter $d_n = 3190 \pm 70\,\mathrm{km}$ (point estimate ± 2 standard errors).[9] This parameter determines the steepness of the UF curve and, like the curve in the figure, lies between the values for 2025 ($d_n = 2200\,\mathrm{km}$) and 2027 ($d_n = 4260\,\mathrm{km}$). Thus, the actual CD usage share lies between the current and future regulatory assumptions regarding CD mode usage. However, since real CD fuel consumption is much higher than WLTP CD mode fuel consumption, this UF does not provide a realistic calculation of average real-world fuel consumption or average CO_2 emissions. If, by adjusting the UF in the regulation, the average real-world fuel consumption is to be approximately 20% above the average standard consumption, as is the case for combustion engine passenger cars, the UF must be significantly lower than the 2027 curve or d_n significantly higher than the 2027 value (see below).

The evaluation also shows several individual PHEV models that have very high proportions of over 60% in CD mode when driving. However, detailed analyses show that these models also achieve

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[9] An analog nonlinear regression based on km-weighted model averages instead of single-vehicle averages yields $d_n = 3448 \pm 82\,\mathrm{km}$ as the best estimate.

significantly lower proportions of purely electric driving with the combustion engine switched off. This pattern occurs in both premium vehicles such as the BMW X5 xDrive45e and high-volume models such as the Skoda Superb or Seat Tarraco. A CD mode share of over 60% initially means that these vehicles cover a large proportion of the kilometers driven with the electric driving strategy activated. However, the actual electric driving shares show that the combustion engine continues to run at least partially during a considerable portion of these CD mode kilometers. This indicates a significant discrepancy between the technically activated electric mode and the actual emission-free distances covered. In the entire sample of PHEVs from 2023, there is only one model with more than 10 vehicles and at least 50% electric driving share. This difference is particularly pronounced in models with medium electric range, such as the Skoda Superb (CD mode share around 75%, share of km with combustion engine around 36%, electric range approx. 130–140 km) or various MG models, which only drive around a quarter of the kilometers purely electrically with similar CD mode shares. Reasons for this may be model- or software-related engine running strategies, for example to ensure performance requirements, heating requirements, battery temperature management, or due to specific hybrid calibration. In powerful PHEVs such as the Mercedes AMG GT 63 S E Performance, this effect is further amplified: Despite high CD mode proportions, the actual electric driving proportion is minimal, as the combustion engine is often switched on for dynamic driving requirements or system support. These patterns illustrate that although CD mode is an important technical criterion, it is not possible to make a reliable statement about how much driving is done without the combustion engine.

A second evaluation below in Figure 21 shows the km-weighted average values at model level instead of the vehicle-averaged UF values, i.e., vehicles with higher mileage are weighted more heavily. This makes sense when it comes to the emissions of the entire PHEV fleet and less so for a randomly selected vehicle. As expected, the average UF decreases with km weighting, as vehicles with higher mileage tend to make longer trips more often and drive electrically less often. This further highlights that the 2025 UF curve is too optimistic compared to real usage data and that the 2027 curves are at least appropriate.

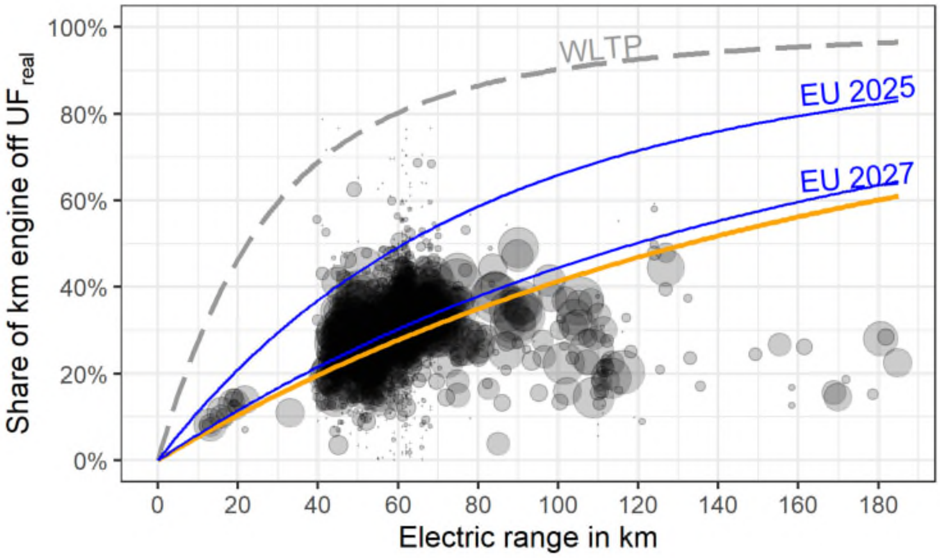

Figure 21: **UF_{real} (proportion of CD mode km with combustion engine off) as a function of electric range.**

Source: Own calculations

Since the difference between the proportion of CD mode km and the proportion of electric driving is relatively pronounced, the figure below shows once again the average UF_{real} at model level, i.e., the proportion of electric driving as a proportion of CD mode km with the combustion engine switched off. Then there are only very few individual vehicles with UF_{real} above 50%. The best fit of the UF curve to the data with d_n as a free parameter yields a scaling parameter $d_n = 4730 \pm\ 110\ \mathrm{km}$ (point estimate ± 2 standard errors), and accordingly, the curve for UF is lower than the 2027 curve with $d_n = 4260\ \mathrm{km}$.

Finally, Figure 22 shows the UF curve for the energy-based UF_{ener} as a function of electric range. The best fit of the UF curve to the data with d_n as a free parameter yields a scaling parameter $d_n = 4764 \pm\ 123\ \mathrm{km}$ (point estimate ± 2 standard errors) and, accordingly, the curve for the UF is lower than the 2027 curve with $d_n = 4260\ \mathrm{km}$.

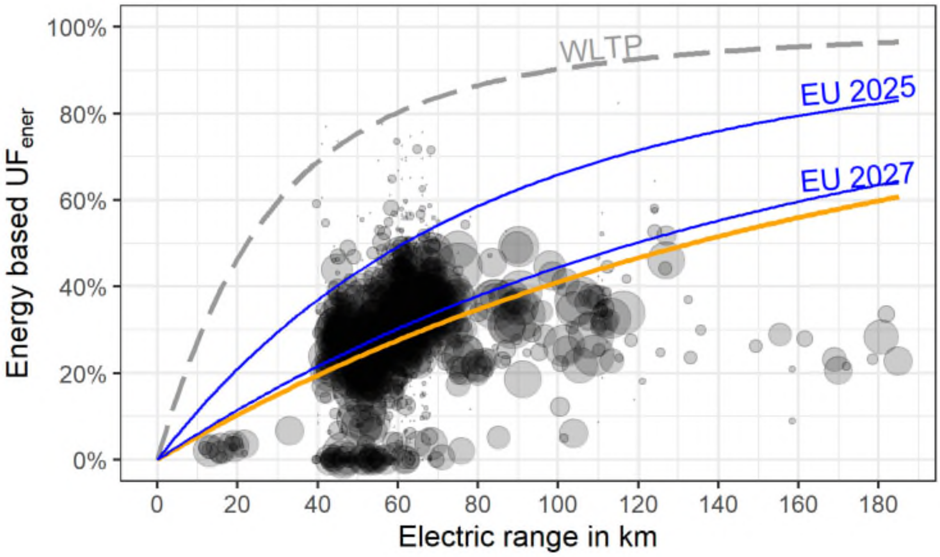

Figure 22: Energy-based UF_{ener} as a function of electric range

Source: Own calculations

Also interesting is the systematic comparison of the average UF as a function of electric range (see Figure 23).

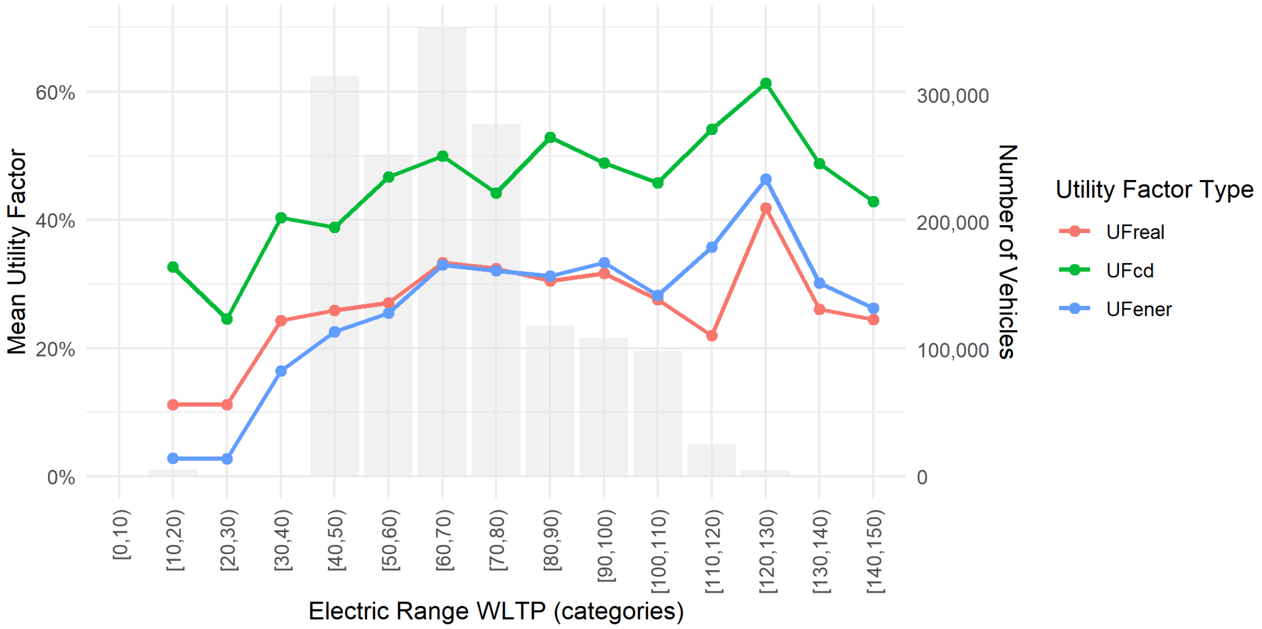

Figure 23: Average UF by range interval and UF definition.

Source: Own calculations

The average CD mode share UF_{CD} is always the highest, UF_{ener} and UF_{real}, which are both intended to measure electric driving shares, are close to each other. Furthermore, a slight increase in the average UF can be seen with the range up to approx. 80 km. After that, the UF values tend to remain constant despite the range continuing to increase and only rise again from a range of 120 km, although there are few vehicles with a range >120 km in the sample.

Finally, the UF was also calculated as the electric driving share according to the methodology in Appendix B of Plötz et al. (2022): $\mathrm{UF}_{\mathrm{EDS}} = 1 - FC_{tot}^{real}/FC_{CS}^{real}$ using the OBFCM data on CS mode consumption and total consumption. As shown above, this UF_{EDS} correlates very well with the UF_{real}, i.e., the proportion in CD mode with a combustion engine. The resulting UF curve as a function of electric range is shown in Figure 24, as in previous studies (cf. Plötz et al. 2022). The best fit of the UF curve to the data with d_n as a free parameter yields a scaling parameter $d_n = 5147 \pm 135\ \mathrm{km}$ (point estimate ± 2 standard errors) and, accordingly, the curve for UF is lower than the 2027 curve with $d_n = 4260\ \mathrm{km}$. Hence, a continuation of the previous methodology according to Plötz et al. (2022), which was used to plan the currently planned tightening of the UF curve, results in the need for a further tightening of the UF curve for PHEVs in Europe.

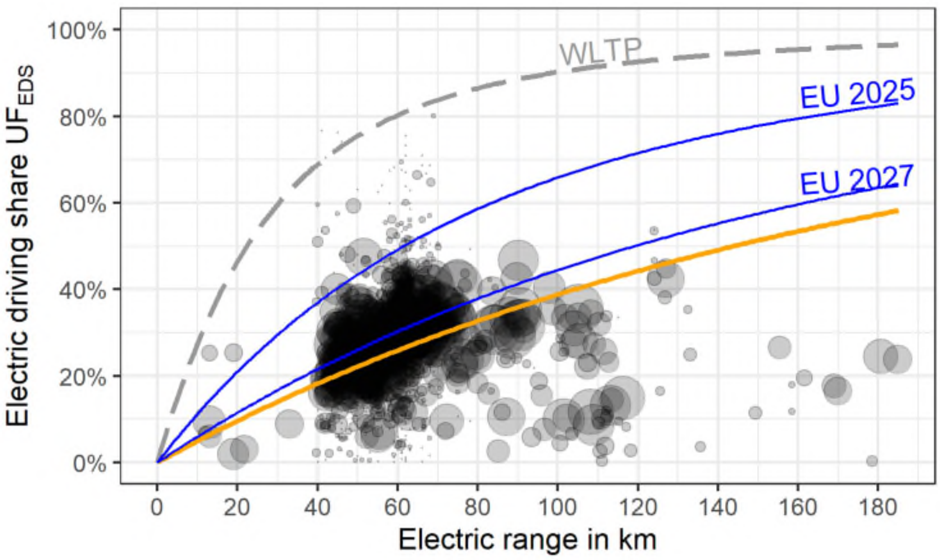

Figure 24: Electric driving share UF_{EDS} as a function of electric range.

Source: Own calculations

Calculation of the real-world fuel consumption gap according to different regulations

The real-world fuel consumption gap is calculated for the various regulatory levels (2024, 2025, 2027) based on a simplified methodology that considers the actual observed electric driving share based on electric energy consumption UF_{ener} (according to Plötz et al. 2022). In this methodology, PHEV usage is broken down into a purely electric and a purely combustion engine component. For the purely combustion engine component, the WLTP charge-sustaining consumption FC_{CS}^{wltp} is assumed to be 20% lower than the real CS consumption FC_{CS}^{real} as found directly in the OBCFM data, i.e. $FC_{CS}^{wltp} = FC_{CS}^{real} / 1{,}2$. Consumption in pure electric mode is set at 0 l/100 km, as no fuel is consumed in pure electric mode. The hypothetical regulatory WLTP consumption is then calculated as a weighted combination: $FC^{wltp} = \left(1 - UF_{regulation}\right) \cdot FC_{CS}^{wltp}$, where $UF_{regulation}$ is calculated using the utility factor function with regulation-specific scaling parametersd_n ($d_n = 800\text{ km}$ before 2025, $d_n = 2200\text{ km}$ from 2025 to 2026, and $d_n = 4260\text{ km}$ afterwards). The real-world fuel consumption gap is then determined from the actual measured real-world fuel consumption and the calculated WLTP consumption: $FCgap = (FC_{real} - FC^{wltp}) / FC^{wltp}$.

A numerical optimization was performed to determine an optimal scaling parameter d_n that achieves a weighted average real-world fuel consumption gap of 20%. The d_n value was systematically varied and the value at which the weighted average real-world fuel consumption gap, weighted by number of vehicles, reaches 20% was identified. The optimal d_n is $d_n = 7220\text{ km}$ and reflects real usage patterns in which the gap between type approval and real-world fuel consumption is balanced.

Figure 25 shows the average real-world fuel consumption gaps according to previous, current, future, and possible corrected regulations. It is clearly visible that the nearly one million PHEVs are on average approx. 300% above their nominal values. If the models had been approved under the 2025 or 2027 regulations, the deviation would still be approximately 100% or approximately 40%, i.e., still higher than the average deviation of approximately 20% for today's gasoline and diesel passenger cars. Only in an adjusted regulation (simulated here with $d_n = 7.220\ km$) the deviation would be comparable to combustion engine cars, at around 20% on average.

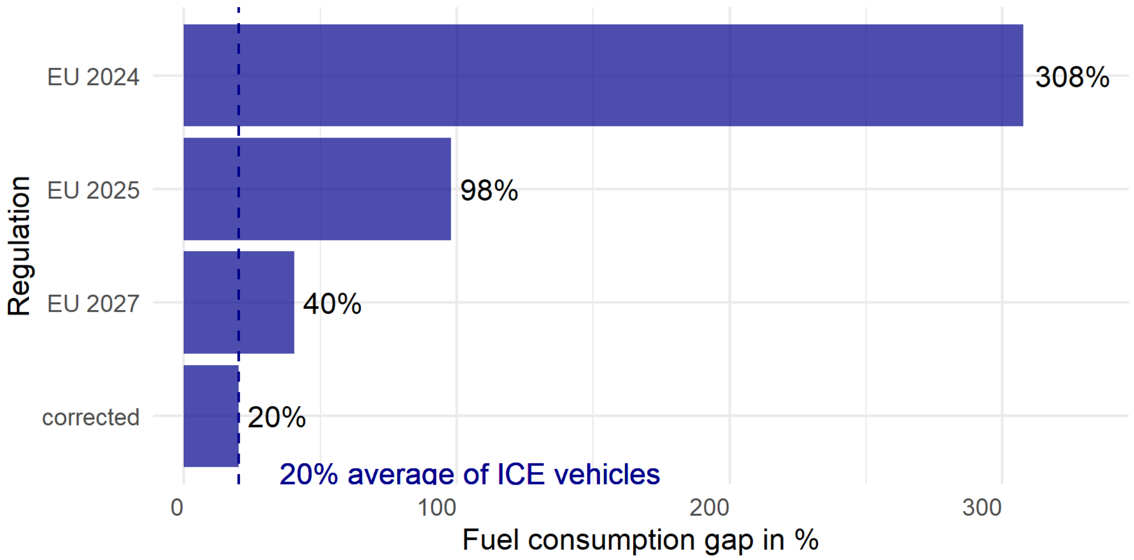

Figure 25 : **Difference between WLTP and real-world fuel consumption of PHEVs in Europe according to different regulations**

Source: Own calculations

Overall, the analyses in this section show that further tightening of the utility factor curves beyond the value planned for 2027 is empirically necessary, as all empirical approaches result in higher scaling parameters d_n than the value of 4260 km planned for 2027.

3.2.4. Discussion and sensitivity

The empirical analysis of electric driving shares and the real-world fuel consumption gap show the need to tighten PHEV regulations in Europe beyond the tightening planned for 2027. However, there are certain methodological uncertainties in the calculation of the real-world fuel consumption gap. We have followed the method of (Plötz et al. 2022), as it has been available for several years and has also been tested by various authors. However, there are other approaches to calculating a fuel consumption gap. This section discusses methodological uncertainties and other variants for calculating a real-world fuel consumption gap.

The method used here to calculate the real-world fuel consumption gap is based on the assumption that the functional relationship between the proportion of electric driving and electric range, i.e., UF_{ener}(EAER), is exactly the same as that between the proportion of km in CD mode used in the regulation and the CD mode range, i.e., $UF_{CD}(R_{CDC})$. However, Figure 20, in comparison to Figures 21, 22, and 24 above, including the scaling parameters obtained d_n , show that this assumption may be a good approximation but is not exactly accurate. Among other things, this means that calculating the real-world fuel consumption gap using this approach for the 2024 regulation, according to which all PHEVs in the data set were approved, resulting in a real-world fuel consumption gap of 440% instead of the observed 308%. Furthermore, there are uncertainties regarding the 20% difference between real and official CS mode consumption.

For comparison purposes, a further and new approach to determining the consumption gap was developed for this study. To this end, we calculate a new UF curve with a new UF_{corr} such that the type approval consumption and emissions calculated from it are only approx. 20% lower than the average real-world fuel consumption and emissions. Thus, this additional UF_{corr} is defined by the following equation: $FC^{real} = 1.2\left(UF_{corr} \cdot FC_{CD}^{wltp} + (1 - UF_{corr}) \cdot FC_{CS}^{wltp}\right)$. For the calculation, we need approximate values for the CS and CD mode consumption figures that are not available in the WLTP. This is done in several steps based on the model mean values:

1. The WLTP CS mode consumption FC_{CS}^{wltp} is assumed to be 20% lower than the real CS mode consumption and calculated from this, as vehicles in this mode almost exclusively run on combustion engines and the consumption of combustion engine cars is approx. 20% higher than the WLTP values, i.e. $FC_{CS}^{\mathrm{wltp}} = FC_{CS}^{\mathrm{real}}/1{,}2$.
2. The WLTP CD mode consumptionFC_{CD}^{wltp} is calculated from the known mixed WLTP consumption $FC_{mix}^{\mathrm{wltp}} = FC_{CD}^{\mathrm{wltp}} \cdot\ UF(R_{CDC}) + \left(1 - UF(R_{CDC})\right) \cdot FC_{CS}^{\mathrm{wltp}}$ by rearranging the equation to $FC_{CD}^{\mathrm{wltp}}\ = (FC_{mix}^{\mathrm{wltp}} - (1 - UF) \cdot FC_{CS}^{\mathrm{wltp}}\ )/UF$.
3. Using the values for , a new UF curve, e.g., the 2027 curve with$d_n = 4260\ \mathrm{km}$, can then be used to calculate a mixed WLTP consumption according to the amended regulation with the new $\widehat{UF}\ FC_{mix}^{\mathrm{wltp}} = FC_{CD}^{\mathrm{wltp}} \cdot\ \widehat{UF} + \left(1 - \widehat{UF}\right) \cdot FC_{CS}^{\mathrm{wltp}}$.
4. The gap between real and nominal consumption is then $\left(FC^{\mathrm{real}}\ -\ FC^{\mathrm{wltp}}\right)/FC^{\mathrm{wltp}}$.

This approach is very close to the official calculation of the mixed WLTP consumption, and for an example vehicle according to Dornoff (2021), the CD mode consumption obtained is very close to the actual consumption. However, the above approach neglects the fact that CD mode consumption cannot be calculated independently of a UF curve, because CD mode consumption is, strictly speaking, the UF-weighted average of WLTP phase consumption and not a variable independent of UF.[10] Nevertheless, this new approach was also applied here for comparison with the above approach, which is also subject to uncertainties.

This second approach results in similar real-world fuel consumption gaps for PHEVs as described above: With the modified utility factor curve for 2025, the consumption gap would be approximately 100% on average, and with the planned further adjustment from 2027 onwards, this would fall further to approximately 50% on average for vehicles. Finally, a new utility factor curve with an adjusted scaling parameter $d_n = 10.000\ \mathrm{km}$ was determined in such a way that the average consumption gap for PHEVs is approximately 20%. This alternative approach to calculating the real-world fuel consumption gap also reveals the empirical necessity of further tightening the UF curve beyond the 2027 value.

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[10] Thanks to Jan Dornoff (ICCT) for pointing this out and for the important discussion on this point.

The following methodological box summarizes the various UF approaches.

Methodological classification of the various utility factor approaches

The analysis uses several utility factor (UF) concepts that address different issues and are therefore not directly comparable with each other. Which utility factor answers which question?

1. UF_{CD} (regulatory): How are CD and CS phases formally weighted in the type approval process? Does not contain any statement about the proportion of electric driving.
2. UF approaches for measuring electric driving shares:
    a) UF_{real}: What proportion of CD mode kilometers are actually driven purely electrically?
    b) UF_{EDS}: How high is the real electric driving share measured in terms of actual consumption?
    c) UF_{ener}: What is the proportion of electrically supplied drive energy in relation to total drive energy?
3. Empirically corrected UF: Which UF parameter is required to close the real-world fuel consumption gap of the PHEV fleet in regulatory terms?

The UF_{CD}, which is anchored in European regulations, is based exclusively on the proportion of kilometers traveled in charge-depleting mode and is used for the formal weighting of CD and CS phases in the type approval process. It makes no explicit statement about the proportion of electric driving or energy and is primarily a regulatory calculation variable.

In contrast, there are empirical UF approaches such as UF_{EDS}, UF_{real}, and UF_{ener}, which evaluate real-world usage data from OBFCM and aim to describe the actual electric usage share of plug-in hybrid vehicles at the kilometer or energy level. These approaches provide consistent scaling parameters in the range of approximately 4,700 to 5,900 km and are suitable for analyzing real driving and charging behavior.

The empirically corrected utility factor pursues a different objective. It is not used to describe electric usage, but to calibrate the regulatory CO_2 assessment to real fuel consumption. The higher scaling parameter (≈ 10,000 km) derived from this is necessary to reduce the average fuel consumption gap of PHEVs to a level comparable to that of conventional vehicles. The different UF results are therefore not contradictory but reflect different analytical and regulatory objectives.

Finally, Figure 26 shows an additional sensitivity of the obtained scaling parameter d_n for three empirical UF considered here with respect to different minimum PHEV ranges. The reason for this is that newer PHEVs often have a higher range than many older models and may achieve different UF values or imply different UF curves. The results show that current long-range PHEVs drive even less electrically than all PHEVs and would also require a significant increase in the scaling parameter of the UF curve.

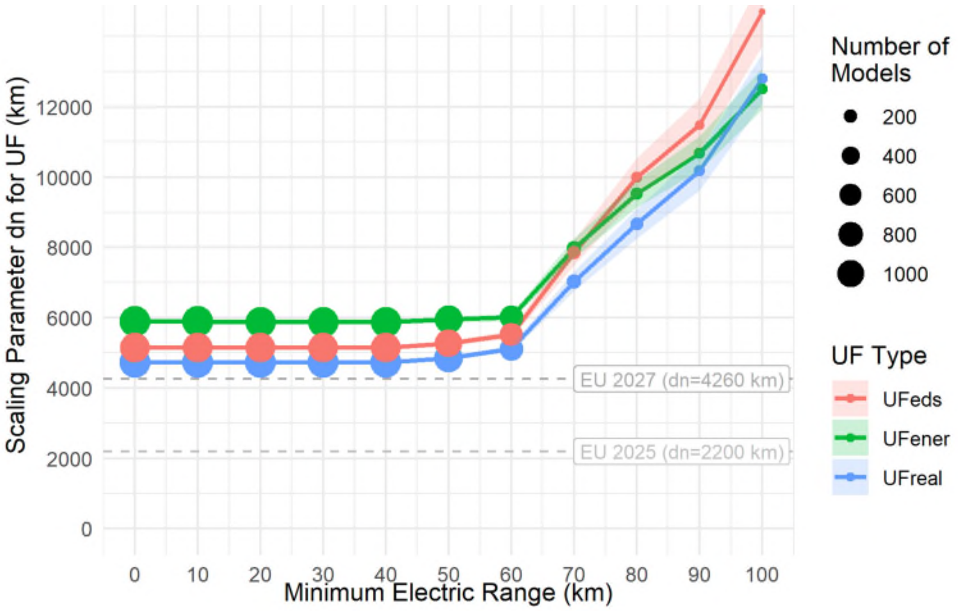

Figure 26 : **Sensitivity of the empirical scaling parameter to PHEV range**

Source: Own calculations

Overall, both the alternative approach for calculating the real-world fuel consumption gap and the sensitivity for PHEVs with a long range indicate a need to further tighten the UF curve beyond the 2027 value.

3.2.5. Conclusion

Due to the complexity of PHEV regulation and the different approaches in regulation and in the literature to calculating a utility factor using real data, there are a number of scaling factors and resulting consumption gaps for PHEVs. The table below summarizes the results regarding scaling parameters d_n and the resulting consumption gap for different approaches.

Table 2: **Results of scaling parametersd_n and consumption gap according to approaches**

Approach	y-axis	x-axis	d_n parameters [km]	Average consumption gap
EU regulation until 2024	UF_{CD}	R_{CDC}	800	308
EU regulation 2025–2026	UF_{CD}	R_{CDC}	2,200	100
EU regulation from 2027	UF_{CD}	R_{CDC}	4,260	40
Corrected regulation	UF_{ener}	Electric range	7,220	20
CD mode share	UF_{CD}	R_{CDC}	3,190 ± 70	59
Proportion of CD mode Combustion engine off	UF_{real}	Electric range	4,730 ± 110	35
Based on actual consumption	UF_{EDS}	Electric range	5,147 ± 135	31
Energy-based	UF_{ener}	Electric range	5,890 ± 150	26

Source: Own representation

3.3. Evaluation of VDA requirements at the individual vehicle level

3.3.1. VDA demands

In October 2025, the VDA published two brief papers on plug-in hybrid vehicles summarizing its demands on policymakers (VDA 2025a, VDA 2025b). Essentially, these two papers concern suspending the tightening of the utility factor calculation in (EC 2023) on the one hand and possible measures to increase the utility factor on the other. Section 3.1.2 discusses the VDA's arguments and outlines the consequences of a suspension. Section 3.1.3 evaluates the measures mentioned for increasing the utility factor in terms of their impact, feasibility, monitorability, and conflicting objectives, as well as their advantages and disadvantages.

3.3.2. Suspension of the adjustments

The VDA is calling for the UF tightening to be suspended as of January 1, 2026, and postponed until the CO_2 review has been completed. Various reasons are given, which are discussed below. All quotes are own translations from the original German.

"The [OBFCM] data collection to date is still insufficient, meaning that the [...] adjustment of the utility factor [...] is not feasible."

With one million PHEV data points from 2021-2023, there is a robust and statistically significant empirical basis. The sample thus covers around 30-40% of the European PHEV fleet in the European vehicle stock (3.2 million at the end of 2023 according to EAFO) and covers all relevant manufacturers and models. The data quality is high, as OBFCM systems are legally mandatory and collected in a standardized manner. The argument of an "insufficient database" is therefore not tenable from a scientific point of view. The available data is more comprehensive and representative than the original assumptions on which the previous UF curves were based.

"In view of the slowdown in the market ramp-up of battery electric vehicles [...] we are strongly committed to strengthening the future role of PHEVs [...] [as a transitional technology]."

This argument has been put forward for a long time and was certainly justifiable at a time when ranges were very limited. Today, however, PHEVs are often more expensive than pure electric vehicles with long ranges and, due to their very low electric driving ranges, cannot currently be seen as an improvement over combustion engines. With conventional fuel consumption averaging 2.7 l/100 km in CD mode, the mode in which the electric drive is used to its maximum, this is also more likely to be due to the fact that the majority of vehicles are designed as hybrid combustion vehicles with charging capability. In addition, PHEVs are sometimes regarded as a transitional technology on the way to purely electric vehicles, but there is not yet any empirical data to support this. Anecdotally, there are both cases: PHEV users who enjoy electric driving and subsequently use a BEV, but also PHEV users who are dissatisfied with driving neither entirely with a combustion engine nor entirely with electricity and subsequently switch back to a pure combustion engine (Hardman & Tal, 2021).

"Loss of incentive for range increase [of new PHEV models]"

Based on OBFCM data, there are higher UF values depending on the range, but these very clearly follow the regressions assumed in the regulation. Higher range cannot compensate for irregular charging. International markets such as China and the US also demand high electric ranges regardless of EU regulations, partly based on domestic regulations.

The VDA highlights the positive developments in PHEVs:

- Ranges of 100-130 km for new models
- Fast charging capability (DC up to 60 kW, AC up to 11 kW)
- Range extender concepts with electric-first logic

These developments are to be welcomed. However, OBFCM data show that even modern PHEVs with higher ranges do not increase the actual electric driving share to the extent expected. Plötz and Gnann (2025) point to a systematic deviation: PHEVs with a range of over 60 km tend to fall below the UF curve applicable from 2025, while shorter ranges tend to fall above it. This suggests that longer ranges alone do not sufficiently change usage behavior. Furthermore, it is unlikely that the low DC charging power of 60 kW compared to BEVs will be sufficient to make additional charging stops on long journeys. This would be more likely with a range extender vehicle with an electric range of over 200 km and charging power of over 100 kW.

"Regulatory threat to the further development of PHEVs" and "Technological developments [...] require regulatory planning security, however."

The economic challenges facing the automotive industry are real and must be taken seriously. However, it should be noted that the UF adjustments were already decided in 2023 and have been in force for new types since January 1, 2025. The industry therefore had sufficient preparation time. Furthermore, investments in PHEV technology can also be profitable under more realistic UF curves if the vehicles are actually driven predominantly electrically. A suspension would also favor manufacturers who rely on PHEVs with a low actual electric driving share over those who invest in pure BEVs. Furthermore, a regulation based on obviously outdated empirical data cannot be considered planning-secure.

Consequences of suspending the regulation

Suspending the tightening of UF would mean:

1. Continued systematic underestimation of CO_2 emissions in fleet regulation. The OBFCM data show that even the 2027 curve is still too optimistic.
2. Jeopardizing EU climate targets, as actual fleet emissions would be significantly higher than those recorded for regulatory purposes.
3. Misleading consumers with unrealistic claims regarding fuel consumption and CO_2 emissions.
4. Unjustified preference for PHEVs over efficient combustion engines or BEVs
5. Misguided incentives for manufacturers, as low official CO_2 values remain achievable even with a low actual proportion of electric driving

In the authors' opinion, the planned UF adjustment for 2027 should be implemented as planned. It is within the empirically determined reasonable range. Further delay would slow down the transition to zero-emission mobility and undermine the credibility of EU climate policy.

3.3.3. Measures to increase the utility factor

The VDA proposes additional measures to increase the proportion of electric driving:

1. **Inducement (charging obligation):** Inducement would require charging after a certain mileage (e.g., every 500 kilometers). After warnings and the expiration of a time window, a reduction in system performance would also be conceivable.
2. **Geofencing:** Here, electric driving mode is automatically activated in predefined zones (e.g., low emission zones and city centers). This is based on GPS information and would be mandatory for all new PHEVs.
3. **Display transparency:** The electric driving share should be displayed on the on-board menu, and a statistical comparison with other users should also be possible. Tips for improving electric use are also conceivable.

These three measures are discussed in the following.

Inducement

Feasibility & monitorability: The vehicle software can monitor charging processes and mileage and limit performance accordingly. Similar systems already exist in emission control systems.

Challenges

- The definition of appropriate mileage limits that consider user heterogeneity (differences between urban/rural, frequent/infrequent drivers, private/company car users)
- How are exceptional cases, such as emergencies, lack of charging infrastructure, or technical defects, handled?
- The system only works if charging is possible and affordable everywhere.

Advantages

- Enforces regular charging even for users that never chargers
- Works independently of driving profile
- Psychological effect: users get used to charging rituals

Disadvantages

- Highly dependent on electricity prices: if public charging is more expensive than refueling, acceptance will be low
- Inducement carries a high risk of user dissatisfaction and negative public perception
- Minimal charging could meet requirements without any real change in usage
- Households without private charging facilities would be disproportionately affected, which could lead to a debate about fairness.

Possible effects: Forced charging after a certain distance, as suggested by the VDA, would only have a significant effect if the charging interval is sufficiently short. The theoretical utility factors are shown in simplified form in Figure 27 (upper panel) as a function of different ranges. Here, it is clear that even at a charging interval of 200 km, the utility factor is already only 50% (for electric ranges of 100 km) or less (lower electric ranges). For future long electric ranges of 200 km, high UFs can also be achieved with short charging intervals. For charging every 1000 km, PHEVs with a range of 200 km would have a UF of 20%, with lower ranges correspondingly lower. While an UF of 90% is assumed for an electric range of 80 km in the WLTP, even an inducement every 100 km would not be sufficient to achieve this UF in reality.

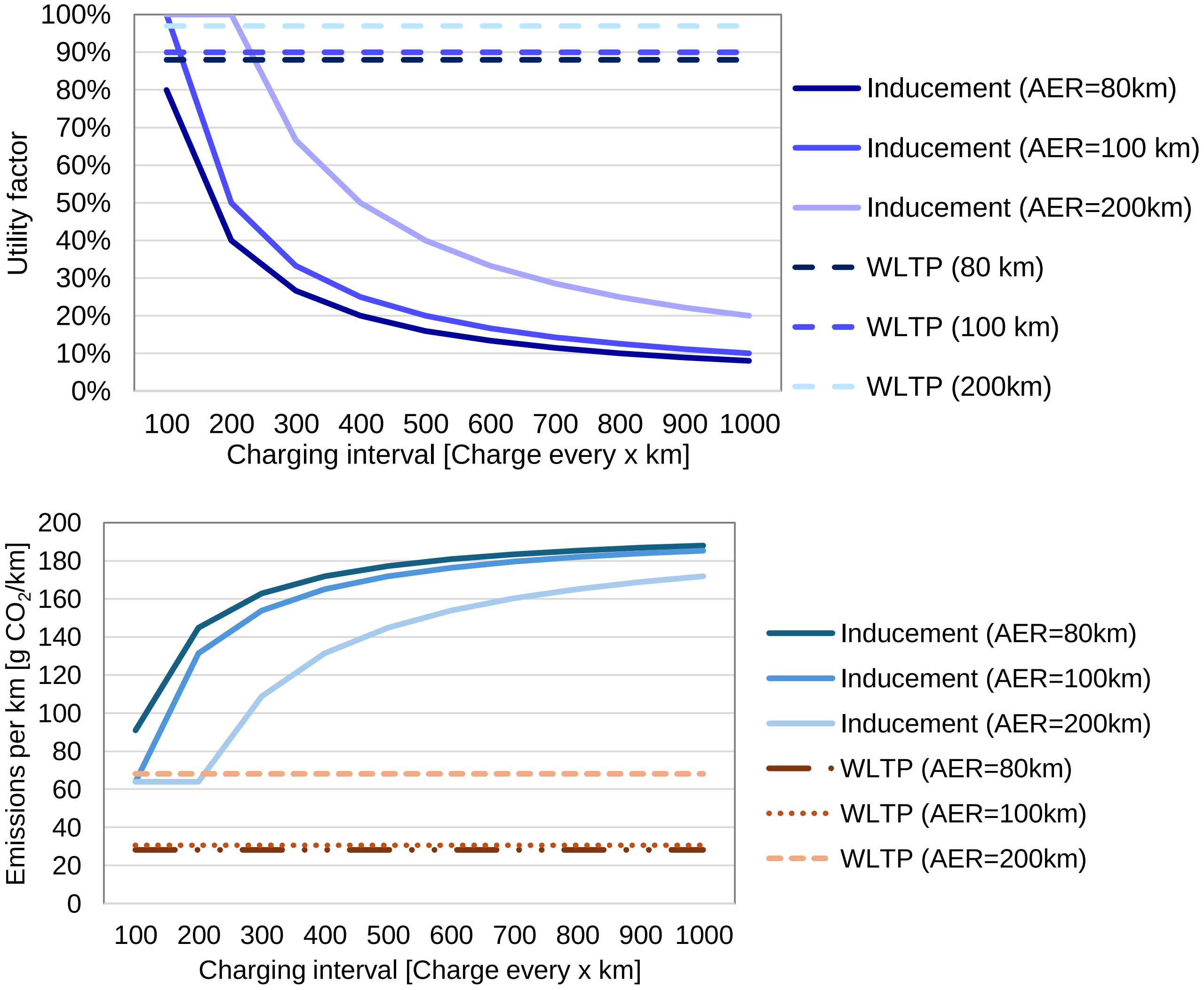

Figure 27: Theoretical utility factor and CO_2 emissions with specified charging intervals and different electric ranges

Source: Own calculations

For comparison, both figures also show the utility factor and emissions according to WLTP. In order to see UFs according to WLTP in reality and adjust the regulation accordingly, recharging would have to be enforced at the intersections of the respective ranges. Or, to put it simply, the vehicle would always have to be recharged when it is below the UF according to WLTP. These intersections would be at 88 km charging interval for 80 km range, 111 km charging interval for 100 km range, and 206 km charging interval for 200 km range to achieve UF values of 88%, 90%, and 97%.[11]

The resulting emissions for different charging intervals are shown in the lower panel of Figure 27. Here, PHEV with 100% UF emit 64 g CO_2/km based on OBFCM data (average consumption 2.7 l gasoline) (T&E 2025, Plötz and Gnann 2025 and above). Thus, even with high ranges, very high emission values result at lower UFs (100 g CO_2/km at a range of 200 km and a charging interval of

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[11] This charging interval, which is necessary for the WLTP-UF, can be obtained as charging interval = range / WLTP-UF.

~250 km). The nominal WLTP emissions can only be achieved with electric ranges of 200 km and almost exclusive driving in CD mode.[12]

However, this is only a theoretical consideration, as it assumes that the same distance is driven every day or that the battery is always recharged after x kilometers. This contradicts the intended concept of PHEVs, which use the combustion engine instead of the electric drive for long distances when the battery is empty. These long journeys are rare, but account for a significant proportion of annual mileage (Plötz 2014, Plötz et al. 2017). In reality, private users drive around 32.5 km on average each day, but on around 24 days a year they drive distances of over 100 km (an average of 163 km on these days), accounting for 27% of their annual mileage (calculations based on (Plötz 2014, Plötz et al. 2017, Gnann et al. 2018, Gnann 2015)). The annual mileage is around 14,000 km. Company car users, on the other hand, drive 38.6 km on average days and around 25,000 km per year. On around 65 days a year, they exceed the 100 km daily distance (averaging 226 km) with 58% of the annual mileage (calculations based on MOP 2010, Gnann et al. 2018).

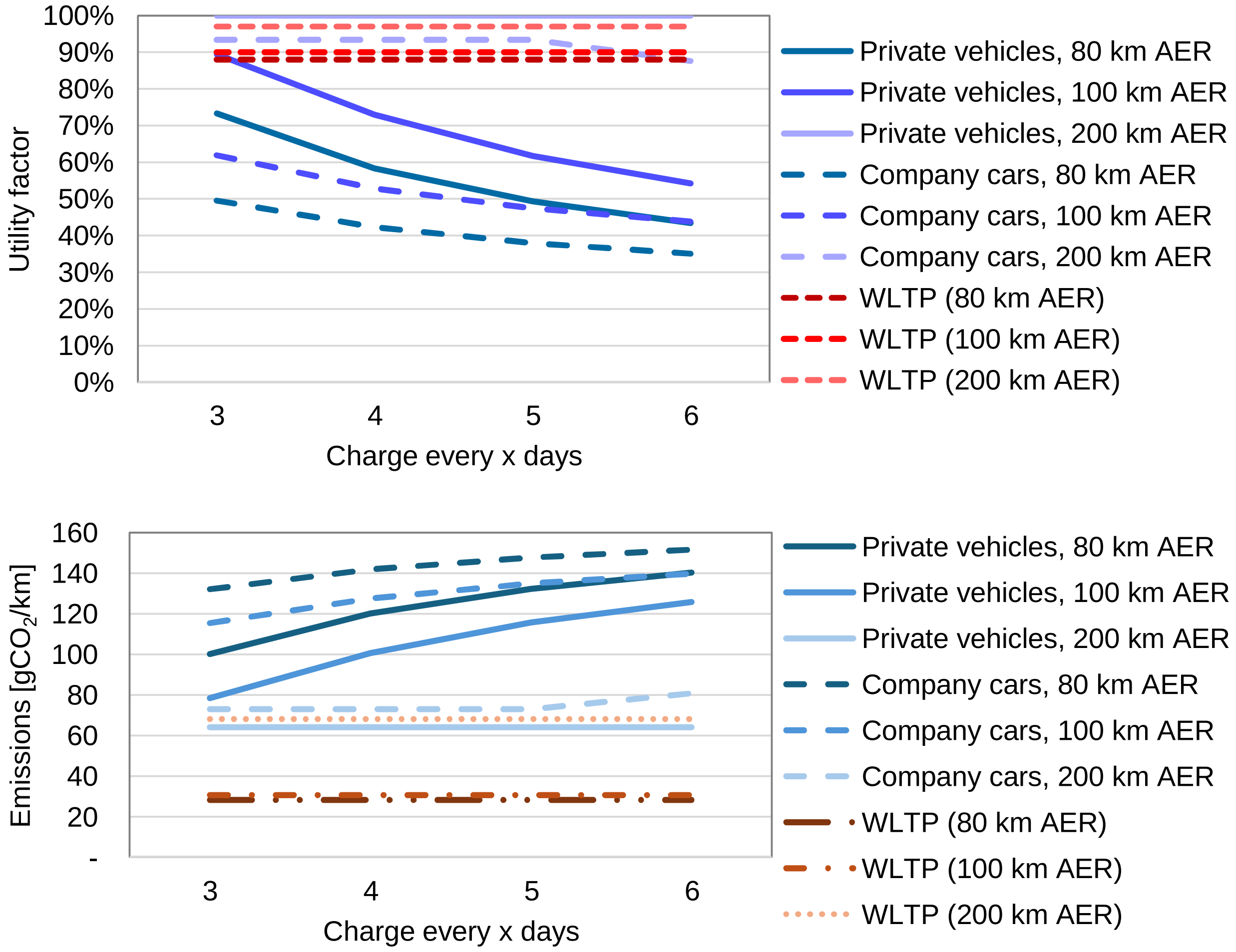

Figure 28: Empirical UF and CO_2 emissions with different electric ranges and charging

Source: Own calculations

If charging every 100 or 200 km were to be used as a basis and it were assumed that long journeys would not be interrupted by charging breaks, private cars would have to be recharged every three

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[12] The WLTP emissions are based on the OBFCM data and are averages of the vehicle models included therein in a range of 80, 100, 200 km +/- 10 km. For a range of 80 km, this includes 81 models and 132,161 vehicles; for 100 km, 33 models with 69,092 vehicles; and for a range of 200 km, 12 models with 457 vehicles.

or six days and company cars every three or five days. If we also consider the long journeys mentioned above, the average utility factor and CO_2 emissions change as shown in Figure 28.

A private vehicle with an electric range of 100 km and charging every 5 days would obtain a UF of 54%, while company cars with charging every 3 days would result in a UF of around 47%. Since company cars in particular account for a large proportion of today's PHEVs, the effect is even smaller than estimated in the simplified representation in Figure 27. Accordingly, fuel consumption and emissions are also higher.

However, increasing the charging frequency could bring about significant improvement. With daily charging, UF values of 80% for private vehicles and up to 60% for company cars are conceivable, even with small ranges.

Geofencing

Feasibility: All new vehicles have GPS navigation and the technical requirements for geofencing. The technology is already being used in pilot projects (e.g., in London and Paris for ultra-low emission zones).

Monitorability: Vehicle tracking can be done purely technically. Verification is conceivable, for example, when reading OBFCM data, but requires a high level of data and information.

Challenges

- A uniform EU-wide definition of geofencing zones in which only electric vehicles are permitted is then necessary.
- Continuous updates of the zone definitions are required.
- Legal issues must be clarified in the event of failures or incorrect zone recognition.
- The tracking of vehicle movements raises data protection issues.
- Liability issues in the event of technical failure of the system must be clarified.
- Geofencing can reduce local emissions but does not necessarily lead to an increase in driving in CD mode. It is therefore not a clear-cut option for reducing CO_2 emissions.

Advantages

- Electric driving is enforced in urban zones
- Studies from London show compliance rates of >90% with technical enforcement
- Effect particularly large for frequent urban drivers (taxis, delivery services)

Disadvantages

- Only effective for journeys in defined zones (commuting distances, long journeys are not considered)
- Many PHEVs have a special charge-increasing mode that allows users to recharge the battery with the combustion engine before entering zero-emission zones. Thus, additional charging of the vehicle at a power outlet is not guaranteed by geo-fencing, and company cars in

particular, which have to pay for electricity but not for gasoline, could take advantage of this. This could therefore also lead to an increase in fuel consumption and emissions.

- No effect outside the zones
- Users could strategically adjust routes to bypass zones
- Battery capacity must be sufficient for crossing zones (otherwise combustion engine start necessary)

Possible effects: It is difficult to make a direct assessment here, but the effect on fuel consumption may even be negative due to the need to reserve electric driving performance for city driving and to bypass geofencing, even if local (pollutant) emissions can be reduced. CO_2 emissions savings are therefore not to be expected.

Display transparency

Feasibility/monitorability: A software update is sufficient for most systems, and no hardware changes are necessary. Some manufacturers already offer such features.

Challenges

- Behavioral research shows that information alone is not very effective. Behavioral psychology studies show that information alone, without financial incentives or obligations, only brings about marginal changes in behavior. Meta-analyses on energy feedback show average savings of 5-10% in households (Agarwal et al. 2023) and 3-5% in the mobility sector (Tulusan et al. 2012, Stillwater et al. 2017).
- Furthermore, uniform metrics and representations across the EU would be useful but require long coordination.
- Comparisons with other users require aggregated data processing to protect personal rights.

Advantages

- Very easy to implement
- Learning effects and behavioral adjustments are possible

Disadvantages

- The impact of purely informational measures is very limited
- Difficult to achieve uniform presentation across manufacturers
- No way to verify the effectiveness of the measure

Possible effects

Introducing this measure could potentially help raise user awareness, but it would by no means be sufficient on its own.

Conclusion on measures to increase the utility factor

The proposed measures are generally useful as supplementary instruments, but in the authors' point of view, they cannot replace a realistic representation of the utility factor in regulation. Most of the proposed measures also face several hurdles.

In the case of geofencing, these mainly relate to the regulatory complexity and the timeliness of geofencing zones. Unless the vehicles are predominantly driven in the city, the effect of this measure is inevitably limited or even negative overall. Savings are therefore not to be expected.

The inducement is heavily dependent on infrastructure expansion and charging prices, but also on the selected recharging distance. If this is set too high, the effect is very limited; if it is set too low, long journeys are hardly feasible, which is what PHEVs were originally designed for. It would make more sense to focus on increased charging frequency (daily or every two days).

Display transparency is a no-regret option that could be easily implemented via a software update. However, based on studies on informational measures, their effect is likely to be very modest (maximum 3-5% improvement) and only meaningful in combination with other measures.

In Figure 29, we compare these emissions from the individual calculations once again. On average, PHEVs emitted 147 g CO_2 /km according to real-world measurements (EEA 2023). This is about five times higher than the emissions according to WLTP, which are around 30 g CO_2/km. The adjustments to the regulation are intended to close this gap, so that emissions would then be 53 g CO_2/km (from 2025) and 73 g CO_2/km (from 2027) (with average electric ranges of 100 km). Even then, we are still a factor of 2 away from real emissions. Even if the differences in real and nominal consumption were taken into account, the discrepancy would be striking.

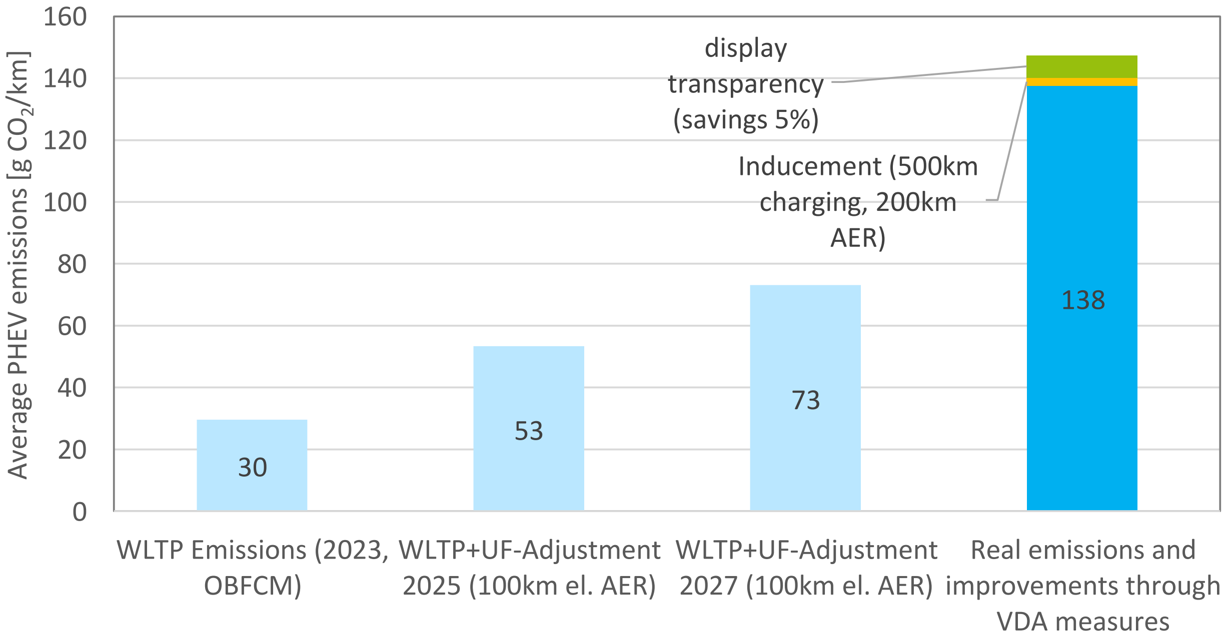

Figure 27: **Comparison of average emissions from PHEVs according to regulations, real-world emissions, and options for reduction by the VDA**

Source: Own calculations

Even the VDA's proposals (in green and red) could only change this to a limited extent. With forced charging every 500 km, emissions would be around 2-3 g CO_2/km below current emissions. The savings achieved through display transparency are also negligible at 3-5%. It should be noted once again that, due to the average CD mode consumption of 2.7 liters of fuel per 100 kilometers, only a very high proportion of journeys in CD mode would allow for values close to the adapted proposal for 2027.[13]

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[13] With UFs of 88% for 200 km electric range, 90% for 100 km, and 97% for 80 km electric range, the vehicles would have to be recharged after almost every complete discharge in order to comply with the 2027 regulation.

3.4. Scenario modeling of CO_2 emission effects

3.4.1. Scenario design

The scenarios for different assumptions of real and WLTP consumption of PHEVs are modeled using the TEMPS (Transport Emissions and Policy Scenarios) model.[14] The scenarios, including framework data and instruments, are based on the 2025 projection report (Förster et al. 2025) with slight adjustments: an update of the new registration figures for 2024, an adjustment of the fleet target values to the level at the beginning of 2025 (averaging 2025-2027), and an update of the real utility factor and real energy consumption for plug-in hybrids based on the analyses in (Plötz & Gnann 2025).

In TEMPS, a utility factor for regulation (UF_{reg}) and one for real-world fuel consumption (UF_{real}) are defined for PHEVs in line with previous analyses. For all scenarios, the real utility factor is derived based on ICCT (2022) and Plötz et al. (2022) as well as the energy consumption from (Plötz & Gnann 2025); the utility factor considered for regulation differs in the scenarios listed below according to the respective scenario definition. In the modeling, a distinction is also made between private and commercial vehicles in terms of real vehicle use and real charging behavior. The battery range of PHEVs is updated based on evaluations of EU monitoring data for historical data up to 2024. By 2030, it is also assumed that battery ranges will increase to 80 km (2024: 63 km) for small vehicles, 90 km (2024: 67 km) for medium-sized vehicles, and 100 km (2024: 82 km) for large vehicles. The scenarios are parameterized as described in Table 7.

Table 7: Description and parameterization of scenarios for determining the CO_2 emission impact of various design options for handling PHEVs

Scenario	Description	Parameterization
Scenario 0 (reference – S0)	Implementation of planned UF adjustments (from 2025: d_n = 2,200 km, from 2027: d_n = 4,260 km)	UF_{reg} for all new PHEVs in the model in accordance with the adjustments in 2025 and 2027
Scenario 1a (S1a)	Suspension of UF adjustments for 2025 and 2027	UF_{reg} in the model in line with the structure prior to 2025 (d_n=800 km)
Scenario 1b (S1b)	Suspension of UF adjustments for 2025 & 2027 and mapping of the effect of geofencing and inducement from 2027 onwards	UF_{reg} in the model according to the design prior to 2025 (d_n=800 km) In line with the analyses in the previous chapters, a 5% improvement in real-world fuel consumption compared to scenario S1a is assumed for the effect of further measures such as geofencing and inducement from 2027 onwards.
Scenario 2 (S2)	Suspension of UF adjustments in 2027 (from 2025: d_n = 2,220 km)	UF_{reg} for all new PHEVs in the model in line with the adjustments in 2025

Source: Own assumptions for the design

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[14] Cf. https://thg-projektionen2025-daten-modell-dokumentation-788cd5.usercontent.opencode.de/Modell/temps/

3.4.2. Results

The key results of the modeling are the new registration structure for passenger cars and the effect on GHG emissions in road traffic.

When comparing the scenarios, the share of new PHEV registrations in the reference scenario S0 is consistently the highest (around 10%) until 2030, and the share of purely battery electric passenger cars (BEVs) is also comparatively high (see Figure 30). In scenario S2, it is assumed that the utility factor will only be adjusted in 2025 and will be suspended for 2027. Accordingly, deviations from the S0 reference only occur from 2027 onwards. Compared to the S0 reference, the share of new PHEV registrations is slightly lower until 2030. This is offset by a minimally higher share of new BEV registrations, but above all by a higher percentage of new ICEV registrations. The differences in the new registration structure result from the model logic of TEMPS, in which cost optimization is carried out from the perspective of vehicle manufacturers to comply with fleet target values based on the stored cost curves. From 2027 onwards, PHEVs in scenario S2 will have lower specific CO_2 emissions in the regulation, so that with more PHEVs, for example at the expense of BEVs, the fleet target values can be met. However, the cost optimization of the modeling, in conjunction with the demand elements of TEMPS, selects more ICEVs and BEVs for meeting the fleet target values, as they lead to lower overall production costs compared to PHEVs.

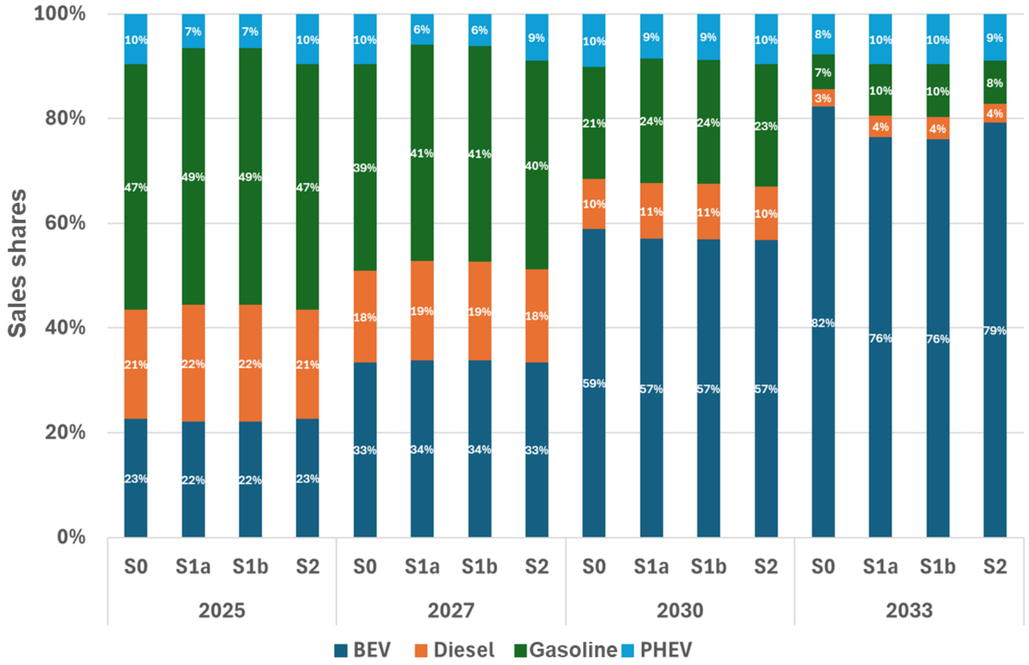

Figure 30: Comparison of the structure of new car registrations for selected years

Source: Own calculations

In scenarios S1a and S1b, an even greater decline in new PHEV registrations can be observed by 2030. The absence of the two adjustment steps for the utility factor in 2025 and 2027 means that PHEVs with significantly lower WLTP emissions are included in the fleet target values than in S0, and as a result, the CO_2 emission standards are met with a significantly higher ICEV share. In addition to PHEVs, the share of new BEV registrations also declines in scenarios 1a and 1b. There are only minimal differences between scenarios 1a and 1b in the modeling due to the small differences in real-world fuel consumption and the resulting very small differences in the usage costs of PHEVs. In these scenarios, too, the modeling logic of cost optimization from the manufacturers' perspective is the reason for the effects and the lower share of new PHEV registrations.

After 2030, the effects between the scenarios change due to the different regulatory treatment of PHEVs. This is related to the minimum development of average CO_2 emissions from new registrations assumed for the CO_2 emission standards in the modeling and the resulting continuously increasing level of ambition for CO_2 emission reduction in new registrations[15]. Since PHEVs have higher WLTP emissions in the reference scenario S0 compared to scenarios 1a, 1b, and 2, more BEVs are needed to meet the fleet target values than in the other scenarios, given the continuously increasing level of ambition of the regulation assumed for 2030. Accordingly, scenario S0 has the highest share of new BEV registrations, while scenarios 1a and 1b have the highest share of new PHEV registrations. As in the period up to 2030, scenario S2 lies in the middle of these scenarios.

Figure 31 shows the cumulative additional emissions of scenarios S1a, S1b, and S2 compared to the reference S0. S1a and S1b show the highest additional emissions over the entire period up to and including 2034 due to the lack of adjustment steps for the utility factor and the associated higher new registration shares of higher-emission passenger cars. By 2050, the additional emissions will accumulate to 23.1 (S1b) and 25.2 (S1a) Mt CO_2eq. The difference between these two scenarios is mainly because of the different real emissions of PHEVs, which are slightly lower in scenario 1b than in scenario 1a due to the assumed effect of geofencing and inducements. Scenario 2, which considers the suspension of the utility factor adjustment in 2027, shows a lower increase in GHG emissions compared to the S0 reference. By 2050, cumulative GHG emissions are 7 Mt CO_2eq. higher than in the S0 reference. In this case, the additional emissions are mainly due to the different new registration structure between scenario 2 and scenario S0 in the period after 2030.

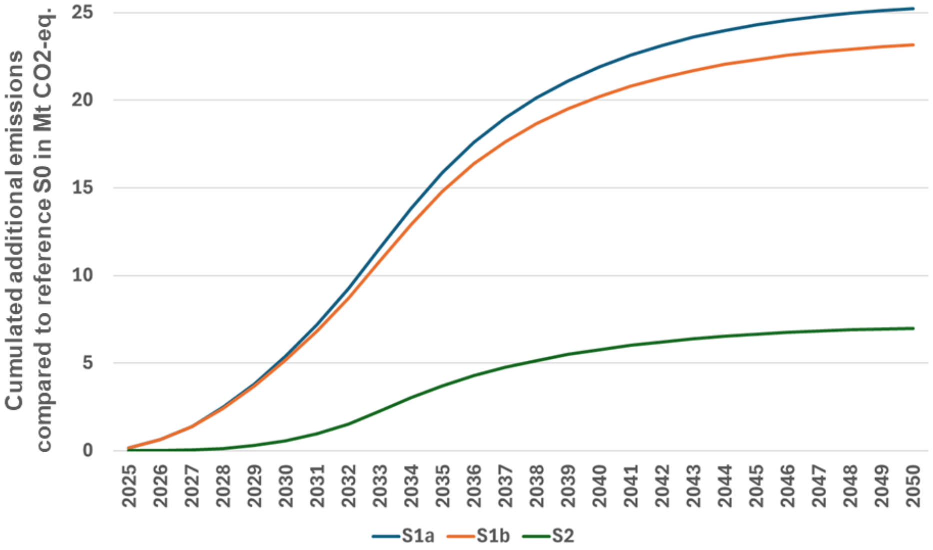

Figure 31: **Cumulative additional GHG emissions compared to reference S0**

Source: Own calculations

Regarding GHG emissions, it should be noted that the TEMPS model is based on the valid CO_2 fleet targets for passenger cars at the time of writing, meaning that from 2035 onwards, "only" zero-emission new passenger cars will be registered. The additional GHG emissions compared to the S0 reference scenario would correspond to adjusted CO_2 fleet target values as proposed by the EU Commission in the "Automotive Package" of December 16, 2025.

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[15] The 2025 projections are modeled on the assumption that the maximum specific average CO_2 emissions of new registrations will decline continuously and linearly between 2030 and 2035.

3.5. Regulatory requirements for low-emission PHEVs

3.5.1. Initial situation and problem definition

Plug-in hybrid vehicles (PHEVs) are sometimes treated as a bridging technology and benefit from favorable credits toward CO_2 fleet targets in European regulations. Type-approval is based on assumptions about high electric driving shares, which are not confirmed in practice. Current OBFCM data show that the real fuel consumption of PHEVs averages around 5.8–6.1 l/100 km, which corresponds to CO_2 emissions of around 140 g CO_2/km. Even under optimal charging conditions (= driving exclusively in charge-depleting mode), today's PHEVs do not achieve truly low emissions: the models average around 2.8 l/100 km or 68 gCO_2/km – far above climate-neutral mobility.

From a climate policy perspective, there are considerable concerns about allowing PHEVs to be registered beyond 2035. PHEVs registered after 2035 will remain in the vehicle fleet for around 12 years and emit significant cumulative amounts of CO_2 over this period. With current real-world emissions of around 140 gCO_2/km, this corresponds to around 17 tons of CO_2 per vehicle over its lifetime. The EU has committed to climate neutrality by 2050, and PHEVs registered after 2035 would still be in the fleet in 2050, assuming a vehicle lifetime of 15 years. They would continue to cause fossil CO_2 e missions and jeopardize the climate neutrality goal.

Comparing the 2035 target with the GHG emission budgets for the transport sector compatible with the Paris Agreement also shows that the phase-out of combustion engines would have to take place sooner rather than later (see Plötz et al. 2023). A softening of the 2035 target would make it even more difficult to achieve. Nevertheless, various approaches are being pursued internationally that envisage a limited role for highly efficient PHEVs. These approaches are used below as a basis for the development of possible regulatory elements.

Basically, the calculation of type-approval consumption figures for PHEVs serves at least two purposes. On the one hand, it provides typical consumption values after homologation as information for buyers, for example within the framework of the Car Labeling Directive and its national implementations. Secondly, the mixed consumption figures for PHEVs are included as CO_2 emissions per km in the calculation of the average fleet emissions for each manufacturer. The following equation therefore applies approximately to both type-approval values and real values for fuel consumption and CO_2 emissions:[16]

$$\text{Consumption}_{\text{mixed}} = \text{Consumption}_{\text{CD-mode}} * \text{UF} + \text{Consumption}_{\text{CS-mode}} * (1 - \text{UF}) \qquad (1)$$

The mixed consumption and mixed emissions per km in the type-approval and in real terms are the UF-weighted mixture of charge-depleting mode and charge-sustaining mode consumption. Originally, it was probably assumed that CD mode would be almost entirely electric, and UF was therefore often interpreted as the proportion of electric driving. The actual electric driving share of the nearly one million PHEVs in the OBFCM data is 42% (total CD mode) and 31% (CD mode with engine off), respectively, and on average across vehicle models, the combustion engine accounts for only 63% of CD mode km, meaning that over a third of CD mode km are driven with the combustion engine.

There are several options for realistic official values. Many studies and the OBFCM data have now shown a significant discrepancy between official and actual mixed consumption (left side of the equation in each case). Furthermore, the real-world OBFCM data has shown that all three variables on the right side of the equation deviate significantly from the official type-approval values. Depending

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[16] UF is actually applied to the individual phases, but essentially the calculation boils down to the logic shown here. The equation is a strong simplification and primarily used here for explanatory purposes; the exact procedure for regulation is described in section 1.2.

on the manufacturer, CD mode has a very high proportion of driving with the combustion engine and thus deviates substantially from purely electric operation on average. The extent of the deviation varies greatly between manufacturers, but on average, CD mode shows a fuel consumption of 2.7 l/100km or approx. 70 gCO_2/km.

To close the gap between official and real values, each individual variable on the right-hand side of the equation can be adjusted, or just the UF. This means that the determination of consumption in CD and CS mode and/or the UF could be corrected. Adjusting the test procedures and definitions of CD and CS modes would be costly and would require significant changes to international regulations on measuring vehicle fuel consumption. Therefore, adjustment efforts have so far focused on the UF: changing a number in the UF formula can reduce the gap between real and nominal emissions.

Since PHEVs officially emit only about 30 gCO_2/km on average, the above formula shows that an adjustment alone can reduce but never close the gap between real and nominal emissions. Since the smallest possible UF = 0, the smallest possible nominal consumption would be equal to the CD mode consumption.

3.5.2. Range extenders and international examples of regulation

Range extender concepts differ fundamentally from conventional PHEVs. They have a primarily electric drive with a large battery, typically with over 20 kWh of usable capacity (e.g., Opel Ampera, BMW i3 REX, Leapmotor C10 REEV). The combustion engine serves exclusively as a generator for charging the battery and not as the primary drive. The vehicle is optimized for a very high electric driving range of over 90%, and the combustion engine is smaller in size. Driving in mainly combustion mode (CS mode) is therefore significantly limited in terms of achievable dynamics, and CS mode is therefore only intended for rare long-distance journeys. The electric-first logic is technically implemented, e.g. by starting the internal combustion engine only with empty battery.

Regulation with upper limits on real-world emissions of, for example, 10 g CO_2/km is therefore effectively aimed at range extender vehicles and not at conventional PHEVs. Such low emission values can only be achieved with fundamentally different vehicle concepts with very high electric driving ranges. This has far-reaching implications for manufacturers' technological development and investment planning.

California allows PHEVs as "Transitional Zero Emission Vehicles" (TZEV) under the ZEV mandate, with a limit of 10% of the ZEV compliance obligation. The minimum requirement is 50 miles (approximately 80 km) of electric range, with requirements gradually becoming more stringent and the permissible share being reduced. The trend is clearly moving toward complete replacement by BEVs.

China allows Extended Range Electric Vehicles (EREVs) under the New Energy Vehicle (NEV) regulation. These are characterized by very high electric ranges, typically over 100 km and often over 150 km. Chinese regulations use a more conservative utility factor curve that saturates at 87.6% rather than 100% as in Europe. The market for EREVs is growing strongly, with over one million sales expected in 2024. Technologically, these vehicles are often designed as range extender concepts with electric-first logic.

3.5.3. Elements of a possible regulatory framework

Based on international experience and considering empirical OBFCM data, key elements for a possible regulatory framework are developed below. This could allow the new registration of PHEVs under clear conditions for a limited period even after 2035. The specific numerical values are to be understood as a guide and are subject to political consideration.

1. Limited market share

   To prevent PHEVs from delaying the transition to zero-emission mobility and to avoid jeopardizing the 2050 climate neutrality target, the registration of PHEVs after 2035 should be strictly limited and regulated in a separate system beyond the existing fleet target values. A maximum share of 5 to 10% of the manufacturer's fleet of new registrations with a time limit until the end of the 2030s (2038 to 2040) appears appropriate. The design should be degressive, for example with 10% in 2036, 7% in 2037, 5% in 2038, 2% in 2039, and 0% from 2040 onwards. This scale allows flexibility for specific user groups, such as those without charging facilities or with extreme long-distance requirements, is based on the California ZEV mandate with a maximum share of 10% and signals a clear transition phase without a permanent alternative to zero-emission vehicles through the degression. The time limit also ensures compatibility with the EU's 2050 climate neutrality target.

2. Minimum technical requirements

   Only vehicles that operate predominantly on electricity should be approved. A minimum electric range of at least 150 km according to WLTP is necessary, as this range covers approximately 80 to 90% of daily journeys. The vehicle must be able to reach at least 130 km/h in pure electric mode to ensure highway capability in electric mode and prevent frequent engine starts on long journeys. An electric-first logic must be technically implemented so that the combustion engine only starts when explicitly necessary, such as when high power is required or the battery is empty. These requirements effectively lead to range extender concepts, as conventional PHEVs cannot achieve this combination of range, performance, and emissions. They ensure that only vehicles that are structurally designed for very high electric driving shares are approved.

3. Upper limit for real-world emissions

   An important element of an effective regulatory framework could be a cap on real-world emissions (see Plötz & Tal 2025). The decisive factor is not the technical design alone, but the actual emission reduction achieved in real-world operation. A cap based on OBFCM data closes the gap between the laboratory and reality and represents a paradigm shift in vehicle regulation. A maximum value of, for example, 10 g CO_2/km in real driving conditions seems ambitious but achievable under optimal conditions and would be in line with range extender concepts. The measurement should be based on OBFCM data. Compliance assessment could take place after approximately two years and be calculated as the arithmetic mean of all post-2035 PHEVs sold by the manufacturer.

   A value of 10 gCO_2/km corresponds to approximately 0.4 liters of fuel per 100 km. With typical CS consumption of 7 l/100 km, this requires an electric driving share of approximately 97%. Alternative caps under discussion would be 20 gCO_2/km (required UF approx. 94%, significant improvement but possibly not ambitious enough) or 50 gCO_2/km (required UF approx. 85%, hardly any improvement compared to the status quo and insufficient in terms of climate policy). The value of 10 gCO_2/km represents an appropriate compromise between the level of ambition and technical feasibility under optimal conditions.

4. Review and revision

   Continuous review and public transparency are central to the credibility and adaptability of the regulation. Aggregated OBFCM data should be published annually for each brand and model, with metrics such as real-world CO_2 emissions, electric driving share, and charging frequency. The data should continue to be made publicly available via the EEA database in a machine-readable format. An initial evaluation of effectiveness should be carried out after approximately two years. The evaluation criteria should include whether the 10 gCO_2/km cap is being achieved on average, how the PHEV market share is developing, which models and concepts are successful, and whether any undesirable side effects or circumvention strategies are occurring.

Conclusion

The development of a regulatory framework for low-emission PHEVs shows that a technically and climatically sensible design is possible, but that it poses considerable challenges. The five core elements developed, consisting of limited market share, minimum technical requirements, real-world emission caps, transparency, and monitoring, form a coherent system. This system is based on international models and uses the availability of OBFCM data for a paradigm shift toward real-world emission-based regulation. However, the analysis makes it clear that such regulation is in fact aimed at range extender concepts and not at conventional PHEVs. Current PHEV technology cannot structurally achieve the required low real-world emissions. This requires a fundamental redesign of vehicles by manufacturers, with corresponding investment requirements.

The primary recommendation is therefore to adhere to the consistent implementation of the 2035 target without exception. If a temporary and limited exemption for PHEVs appears unavoidable, the elements developed here provide a framework that ensures that only vehicles with demonstrably very low real-world emissions are approved. However, the design must then be consistent, with ambitious real-world emission caps, effective sanctions, and a clear time limit until the end of the 2030s at the latest. It is crucial that any exemption is not misunderstood as a permanent alternative to zero-emission mobility, but rather as a narrowly defined transitional option that does not jeopardize the fundamental transformation path to climate neutrality by 2050. The regulatory elements must be designed in such a way that they promote innovation towards maximum efficiency, but at the same time prevent them from delaying the necessary complete electrification.

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Appendix

Table 8: Detailed comparison of the structure of new passenger car registrations between the scenarios – all numbers in %.

Year	Scenario	BEV	PHEV	Diesel	Gasoline	Other
2025	S0	22.7	9.6	20.8	46.7	0.2
	S1a	22.1	6.5	22.3	48.9	0.2
	S1b	22.1	6.5	22.3	48.9	0.2
	S2	22.7	9.6	20.8	46.7	0.2
2026	S0	26.9	9.0	19.8	44.1	0.2
	S1a	27.1	5.8	21.0	45.9	0.2
	S1b	27.1	5.8	21.0	45.9	0.2
	S2	26.9	9.0	19.8	44.1	0.2
2027	S0	33.3	9.6	17.5	39.4	0.1
	S1a	33.8	5.8	18.9	41.3	0.2
	S1b	33.8	6.1	18.8	41.2	0.2
	S2	33.4	9.0	17.8	39.7	0.1
2028	S0	41.2	9.6	15.2	33.9	0.1
	S1a	41.7	5.8	16.6	35.8	0.1
	S1b	41.6	6.0	16.5	35.7	0.1
	S2	41.3	8.9	15.5	34.3	0.1
2029	S0	49.0	9.5	12.8	28.5	0.1
	S1a	49.5	6.0	14.1	30.3	0.1
	S1b	49.5	6.2	14.0	30.2	0.1
	S2	49.1	8.9	13.1	28.9	0.1
2030	S0	58.9	10.1	9.5	21.4	0.1
	S1a	56.9	8.5	10.6	23.8	0.1
	S1b	56.9	8.8	10.5	23.7	0.1
	S2	56.7	9.7	10.3	23.3	0.1
2031	S0	66.7	9.0	7.7	16.5	0.1
	S1a	62.2	8.9	8.9	20.0	0.1
	S1b	61.8	8.9	9.0	20.2	0.1
	S2	64.0	9.6	8.2	18.1	0.1
2032	S0	74.5	8.4	5.5	11.5	0.1
	S1a	69.0	9.3	6.6	15.1	0.1
	S1b	68.7	9.4	6.6	15.2	0.1
	S2	71.5	9.4	5.9	13.1	0.1
2033	S0	82.2	7.7	3.3	6.7	0.1
	S1a	76.4	9.6%	4.2	9.8	0.1
	S1b	76.0	9.7	4.3	10.1	0.1
	S2	79.2	9.0	3.7	8.1	0.1
2034	S0	91.5	1.2	1.7	5.5	0.0
	S1a	89.6	2.6	1.8	6.0	0.0
	S1b	89.5	2.6	1.8	6.0	0.0
	S2	91.0	1.8	1.7	5.5	0.0

Source: Own calculations