Plug-in hybrids 2.0:

Still not a solution for the climate

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Author: Anna Krajinska
Modelling: Yoann Gimbert
Expert group: Julia Poliscanova, Thomas Earl

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Further information

Anna Krajinska
Transport & Environment
anna.krajinska@transportenvironment.org
Mobile: +447761536337
www.transportenvironment.org | @transenv | fb: Transport & Environment

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1. Introduction

Since the publication in November 2020 of T&E's first report on the real world performance of plug-in hybrid cars (PHEVs)[1], sales of PHEVs in the European Union have continued to skyrocket as carmakers expand their line up and push sales to meet their CO_2 targets. Covid has not dampened carmakers' commitment to the technology which has been supported further by generous purchase incentives in many Member States. PHEVs share of total vehicle sales increased from 5.1% in 2020 to 8.9% in 2021[2], increasing to 9.4% in 2022 just behind battery electric cars (BEVs) at 12.1%. There are now 87 PHEV models available to buy in the EU compared to 57 in 2020 and 877,00 PHEVs were sold in 2022[3]. By the end of the decade it is expected that there will be about 11 million PHEVs in the EU vehicle fleet[1].

Yet, while the climate benefits of 100% electric vehicles cannot be doubted, the widely advertised climate benefits of PHEVs cannot be guaranteed. Officially, PHEVs boast very low tailpipe CO_2 emissions; the majority of EU PHEVs emit less than 50 gCO_2/km on paper with some boasting CO_2 as low as 16 gCO_2/km. However, while the average official CO_2 of PHEV models decreased in the first half of 2022 by 6.5% compared to 2021[4], real drive data shows that PHEVs do not deliver the expected CO_2 savings on the road with PHEVs actually emitting 3-5 times more CO_2 than official figures[5]. This means that the average PHEV sold last year emits between 114-190 gCO_2/km instead of the official 38 gCO_2/km.[2] The large gap in emissions means that carmakers benefit significantly from PHEV sales when it comes to CO_2 compliance while the climate benefits are not realised on the road. This both undermines the EU car CO_2 targets and as PHEV fleet penetration increases will make it harder for Member States to meet their climate obligations when it comes to transport emissions.

The large gap between official and real world PHEV CO_2 emissions arises because of overly optimistic regulatory assumptions on the share of electric kilometres driven by PHEVs known as utility factors. Battery electric vehicles (BEVs) can only be driven using the electric motor and battery and therefore their tailpipe CO_2 and pollutant emissions are guaranteed to be zero. PHEVs on the other hand are fitted with both an electric drivetrain and an internal combustion engine (ICE). This means that the share of electric driving and therefore the PHEV's CO_2 and pollutant emissions are determined by the design of each PHEV model (e.g. the power of the internal combustion engine vs. electric motor and how these are programmed to interact, electric range i.e. battery size and charging speed) as well as how often the PHEVs is charged, the trip distances driven, ambient conditions and the driving modes used. This means that PHEV design and use are critical determinants of the CO_2 and pollutant emissions savings that the technology can achieve.

In 2020 T&E undertook testing on 3 SUV PHEVs: a BMW X5, Volvo XC60 and Mitsubishi Outlander which showed that the PHEVs tested were much closer in design to traditional ICE cars than BEVs[6]. Large CO_2 emissions when the PHEVs were driving using the internal combustion engine only, an electric drive

[1] Based on 2021 PHEV in the fleet data from the European Alternative Fuels Observatory and LMC Automotive Global hybrid & Electric Vehicle Forecast (Q2 2022).

[2] Based on the real world UF for company and private cars published in ICCT. (2022) Real-world usage of plug-in hybrid vehicles in Europe and T&E's methodology for calculating PHEV CO_2 emissions outlined in T&E. (2022) Update- T&E'S analysis of electric car lifecycle CO2 emissions.

which only had sufficient power for zero emission driving under a narrow range of on-road conditions and lack of fast charging combine to make it hard to achieve the officially very low CO_2 emissions in the real world. The small PHEV battery sizes which constrain the electric range and weak electric motors seen across much of the EU PHEV fleet further indicated that PHEVs were being sold as compliance tools to help carmakers meet their car CO_2 standards rather than to deliver the expected CO_2 savings on the road. Research conducted since has shown PHEVs are drifting further away from BEVs with real world fuel consumption increasing by 6-8% per year[5].

While the European Commission took action earlier this year to update utility factors based on real world data[3], the gap between official and real world CO_2 emissions will not be fully closed until 2027. As regulation has been a strong driver of PHEV design it is unlikely that significant improvement to PHEVs will be made prior to 2025, when the first adjustment to the utility factor and thereby PHEV CO_2 emissions takes place. Yet, despite knowing the large gap between official and real world PHEV CO_2 emissions and arguing against substantial improvements to regulation[7][4], the EU's carmakers have been advertising PHEVs as a good driver choice for the environment. Skoda goes as far as to advertise that the PHEVs are 'great for the environment'[5]. Carmakers have also been claiming that PHEVs are the 'perfect' city car[6] which allows owners to drive zero emission in cities while the internal combustion engine is a back up for longer trips[7]. BMW has even voluntarily introduced geo-fencing technology-- so called 'eDrive zones' which it claims automatically place their PHEVs in zero emission mode when driving in 138 European cities thus providing air quality and emissions benefits[8].

Since T&E's last PHEV testing, carmakers have increased their offering of small and medium sized PHEVs. To check how these smaller PHEVs perform, T&E commissioned TU Graz to independently undertake testing of three popular compact PHEV passenger cars, the BMW 3 Series, the Peugeot 308 and the Renault Megane. The PHEVs were tested during city and commuter use, which is often touted by carmakers as the ideal use case for PHEVs[9]. T&E also tested the effectiveness of BMW's flagship eDrive zones geofencing technology. This report presents the results of the on road tests as well as an analysis of the use of PHEVs by the three carmakers as a CO_2 compliance mechanism.

2. Methodology

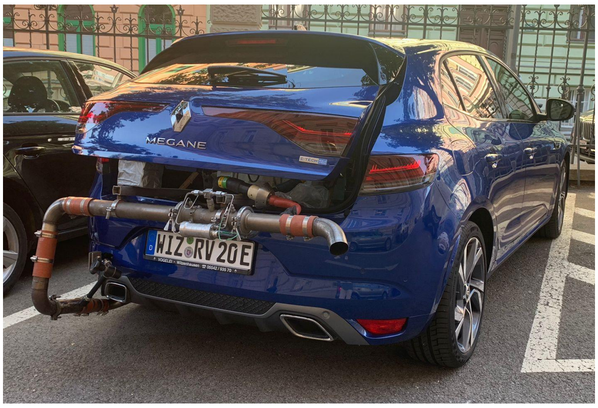
In the summer of 2022 T&E commissioned TU Graz based in Graz, Austria to undertake testing of PHEVs under real world city and commuter driving conditions to investigate the vehicles' real world electric range, fuel consumption, CO_2 and pollutant emissions.

[3] https://ec.europa.eu/transparency/comitology-register/screen/documents/082562/1/consult?lang=en
[4] T&E. (2021) How to fix the PHEV loophole.
[5] https://www.skoda.co.uk/electric-hybrid-cars/phev-technology. Accessed 20th November 2022.
[6] https://www.bmw.co.uk/en/all-models/phev.html. Accessed 10th September 2022.
[7] https://www.renault.co.uk/engines-innovation/plugin-hybrid-technology.html Accessed 10th September 2022.
[8] https://www.press.bmwgroup.com/global/article/detail/T0361792EN/emission-free-city-centres:-bmw-edrive-zones-now-available-in-138-european-cities?language=en Accessed 10th September 2022.
[9] https://discover.bmw.co.uk/article/bmw-edrive-zones-in-the-uk Accessed 10th September 2022

2.1. The cars

Three PHEVs were chosen by T&E for the testing: a BMW 3 xDrive series, a Peugeot 308 and a Renault Megane. Smaller non-SUV PHEV models were chosen on this occasion to complement the SUV PHEV testing undertaken by T&E in 2020[6], thereby providing a wider overview of the performance of PHEVs across different car segments and top EU car brands. A BMW PHEV was chosen specifically to test its 'eDrive zone' geo-fencing technology, which is advertised to automatically put the PHEV into zero emission driving mode in 138 European cities,[10] and anticipatory hybrid technology (which uses the sat-nav to optimise battery and engine use). These have been widely advertised by BMW as a 'success story' for inner city emissions, and for drivers due to lower fuel costs[11]. The BMW 3 series was chosen for the testing since it is the second best selling PHEV in Western Europe in 2022[8]. The other two PHEVs were chosen because they are compact PHEVs sold by two well known European carmakers.

All three cars were of the Euro 6d emission standards approved under the WLTP regulation and were sourced independently of T&E by TU Graz. Further details of the tested vehicles are available in Annex 7.1.



[10] https://www.press.bmwgroup.com/global/article/detail/T0361792EN/emission-free-city-centres:-bmw-edrive-zones-now-available-in-138-european-cities?language=en Accessed 10th September 2022.

[11] https://www.press.bmwgroup.com/global/article/detail/T0361792EN/emission-free-city-centres:-bmw-edrive-zones-now-available-in-138-european-cities?language=en

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Fig. 1: The three PHEVs testest by TU Graz: BMW 3 xDrive series, Peugeot 308 and the Renault Megane with installed Portable Emission Measurement System.

2.2 The routes

Three different on-road test routes were developed by TU Graz to represent driving routes and styles which can be considered to be representative of typical PHEV use including city and commuter driving.

1. City driving route

The city driving route was designed to test the PHEV's performance and emissions when driving within a town or city. This route starts and finishes at the test centre at the Inffeld Campus of TU Graz and is driven on roads within the inner city of Graz. The full test route involves driving the full loop (as shown in fig. 2) counterclockwise twice with a total test distance of 66 km. The average speed on this test was between 20-30 km/h with 97-99% of driving conducted at speeds of less than 60 km/h as per the EU Real Driving Emissions (RDE) urban driving boundary.

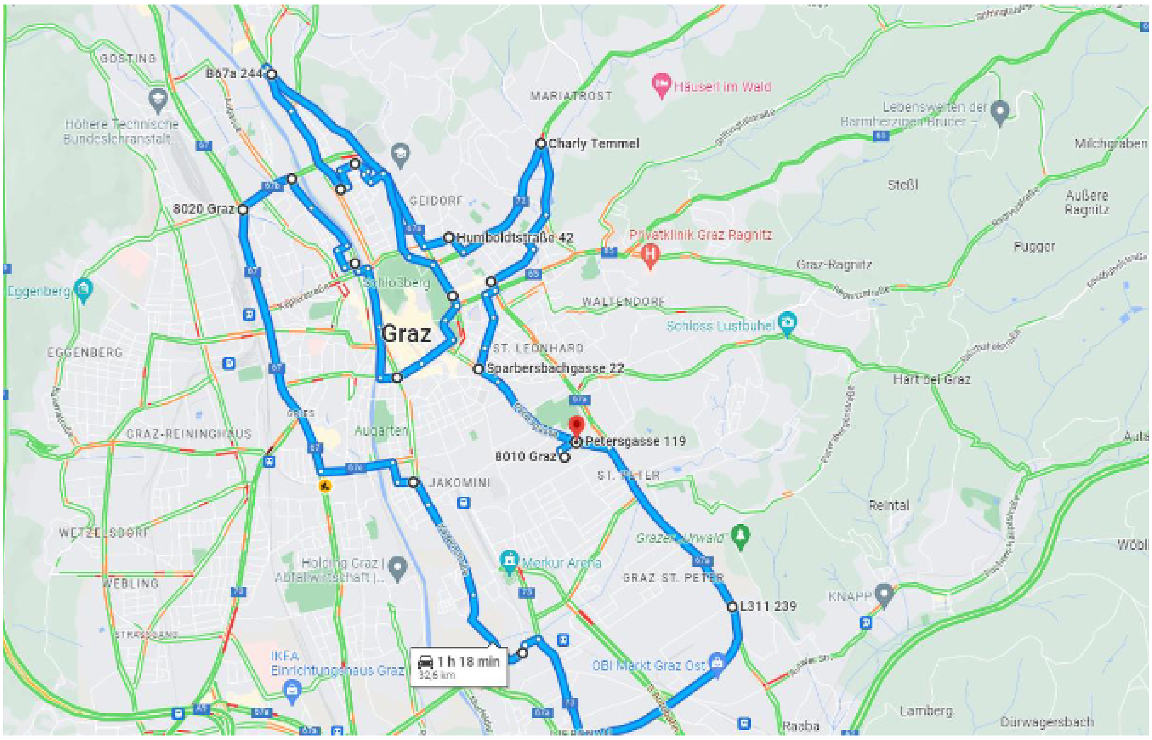

Fig. 2: The city driving route around the city of Graz, Austria. Map source: Google maps

2. Commuter route

This route was designed to test the PHEV's performance when commuting into a town or city. The route starts 20km from Graz in a small town called Gleisdorf which is a popular commuter town for Graz. The A2 highway is taken into the inner city of Graz and a brief 20 minute stop took place in the centre of town at the old campus of TU Graz University. The stop was included to represent an event such as shopping,

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drop off or attending work. The length of the stop was limited by the capacity of the emission measurement equipment battery, however it is not expected that a longer stop would have a significant impact on the performance of the vehicle outside of the cold start period. After the stop, with the exception of several one way streets, the same route was driven back. The total test is 55 km long, the majority of driving by distance (73%) occurred at speeds of above 90 km/h, city driving at speeds of less than 60 km/h accounted for 18% of the trip and the remaining 9% encompassed speeds typical of rural driving with speeds of between 60-90 km/h.

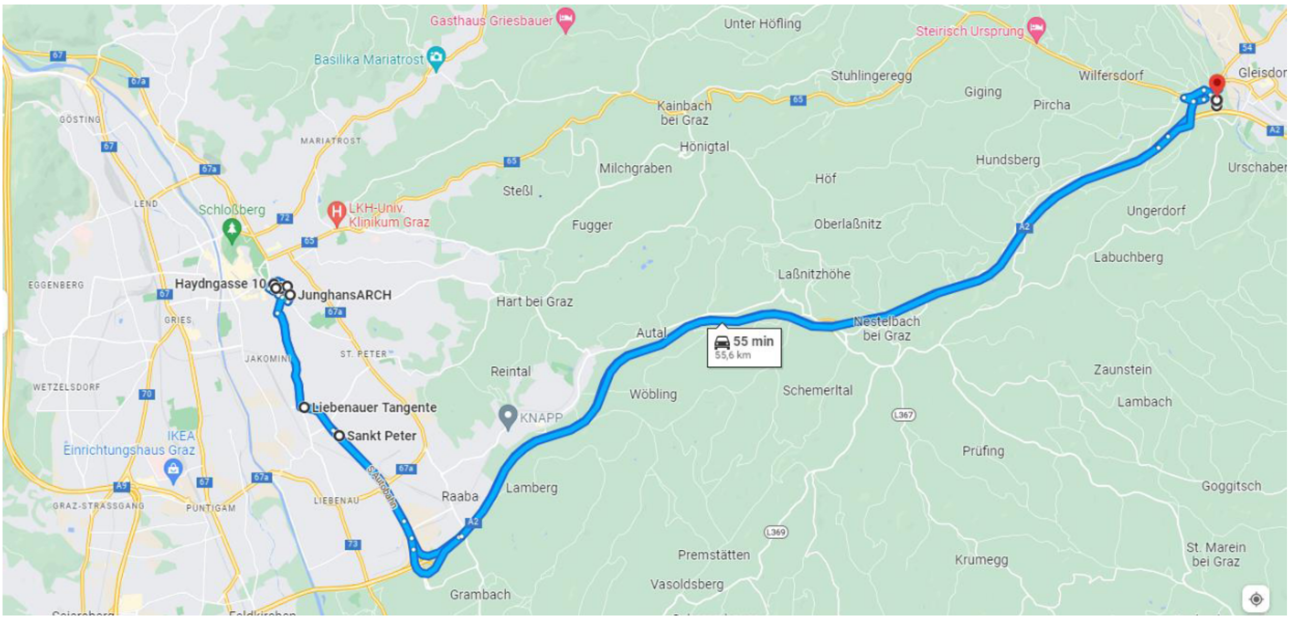

Fig. 3: The commuter route used for testing of hybrid emissions. Map source: Google maps

3. Extended commuter route

This route was designed to test the PHEVs performance on a commute where the engine is used to charge the battery for later zero emission use by using the driver selectable charge increasing mode. The route starts at the Inffeld campus in the centre of Graz and the A2 highway is taken to Ilz 48 km away with the same route driven back. This route was longer than the commuter route to allow sufficient time for the battery to charge so that the emission impact of charging could be assessed. The majority of driving (>80 %) occurred at speeds of above 90km/h, city driving accounted for 8% of the trip and the remainder was driven at 60-90km/h.

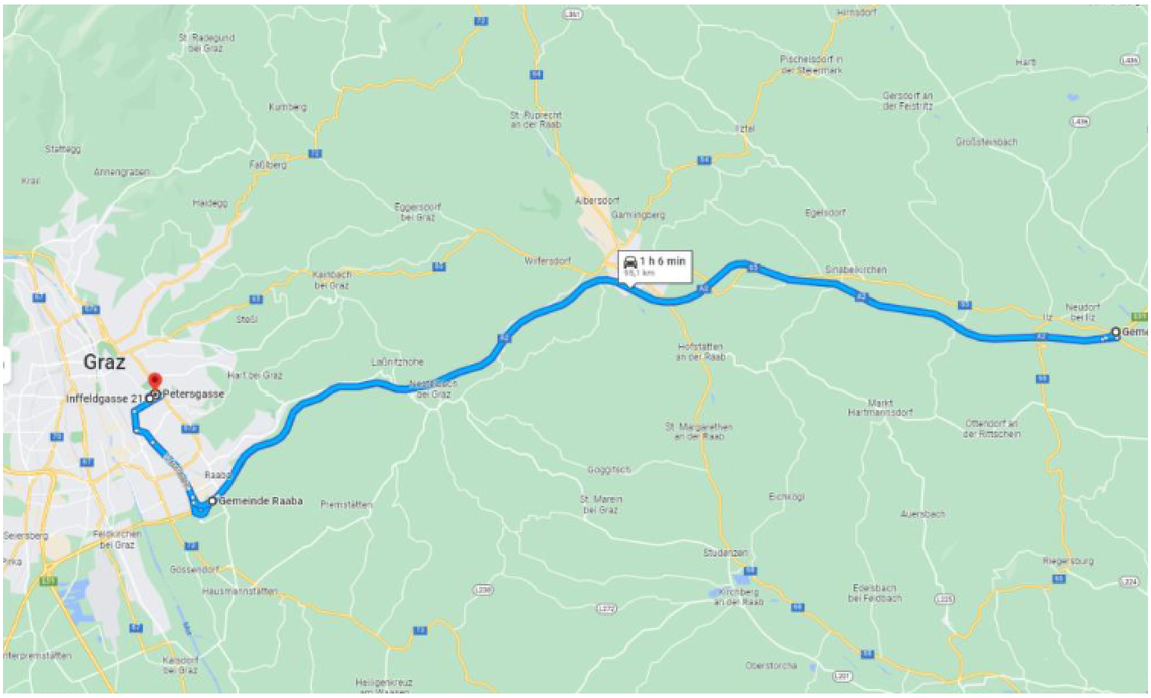

Fig. 4: The extended commuter route used for testing of the charge increasing mode. Map source: Google maps

It should be noted that the routes used for this testing programme are not compliant with RDE (RDE) regulation for on-road testing due to the stringent criteria surrounding the length, order and share of urban, rural and motorway driving which must take place during the RDE test and the maximum stop time allowable. However they cover driving conditions which can be reasonably expected to be driven by a PHEV under normal conditions of use. Full technical details of the test routes are available in Annex 7.2.

2.3 The tests

The following tests were carried out on the routes described in Section 2.2. During all tests the air conditioning was set on automatic mode at 22 ^{0}C. Infotainment and lights were set on the default automatic mode selected by the PHEV. The same load was used for all vehicles of around 275kg which comprised the driver, co-driver and the PEMS system. During all tests the vehicles' pollutant (NO_2, NO, CO, PN) and CO_2 emissions were measured continuously at the tailpipe at a frequency of 1Hz using an AVL M.O.V.E. Portable Emissions Measurement System (PEMS). On-board diagnostic channels were monitored using a CAN connection, however it should be noted that no channels relating to the operation of the PHEV's high voltage battery were available on any of the three cars tested.

1. **City electric range test (BMW, Peugeot, Renault):**

City driving is often advertised by carmakers as the ideal use case for PHEVs, therefore to determine if the official electric range could be replicated during real world city driving the electric range of the three PHEVs was tested on the city driving route. All three PHEVs started the test with a fully charged battery

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and the electric charge depleting mode was activated at the start of the test. For all three PHEVs this was a cold start test i.e. all three cars were left with their engine off for more than twelve hours. The end of the test corresponded to the point at which the battery was fully depleted. None of the PHEVs tested provided data on the state of charge (SoC) of the battery via the data-logger connected to the on-board diagnostic port, therefore the dashboard display on the state of charge was used. As this is the only source of information on the battery SoC provided to the driver (i.e. the consumer) it is an acceptable method for monitoring SoC during real world testing where the aim is to replicate realistic on road driving conditions experienced by a typical PHEV driver. Due to the low power needed on this test route, the ICE was not started on any of the PHEVs to support the electric motor and the ICE was only started when the PHEV battery was empty, which defined the real world electric range.

2. **Charge sustaining CO_2 test (BMW, Peugeot, Renault) :**

The test to determine CO_2 emissions when the battery is empty and the car is running using the ICE only (so called 'charge sustaining' mode) was also conducted on the city driving route to determine the real world city emissions that occur when PHEVs are not charged. The test was conducted on the same day as the city electric range test with a break between tests and as such constitutes a 'hot test' i.e the engine was not fully cold at the start of each test. Each vehicle started the test with an empty battery as determined from the dashboard display and the test was conducted in the default driving mode selected by the PHEV at the start of the test. During the test two laps of the city driving route were driven per vehicle. A 10 minute stop occurred after the first loop of the test to change the PEMS batteries.

3. **Hybrid 'Default mode' test (BMW, Peugeot, Renault) :**

Not all PHEV users will choose the driving mode for the PHEV and will rely on the vehicle to make the choice. To test what each vehicle would do and the associated CO_2 emissions when the car is fully charged, used for commuting and driven in the default mode selected by the PHEV were tested on the commuter route. On the BMW the eDrive zones geo-fencing technology was active by default and this test was also used to assess the effectiveness of the technology once the car enters the city centre. This was a hot start test for all three PHEVs as they were first driven to the start of the test route at Gleisdorf.

4. **Anticipatory hybrid test (BMW):**

The BMW is fitted with adaptive hybrid technology which is advertised to use the satellite navigation in the car to optimise the use of the internal combustion engine and the battery for efficient driving. To test how this affects the BMW's performance and CO_2 emissions and if it has any impact on the eDrive zone geo-fencing technology the car was driven once again on the commuter route with a fully charged battery. To activate the adaptive hybrid technology the route was programmed into the sat-nav prior to the start of the test. This was a hot start test.

5. **Charge increasing CO_2 test (BMW):**

Only the BMW was equipped with a battery charging (charge increasing) mode therefore only the BMW was subject to the charge increasing test. The test to measure CO_2 emissions when the internal combustion engine is used to power the car and charge the battery (so called 'charge increasing' emissions) was conducted on the extended commuter route. This route was chosen as this is representative of what the carmakers often claim is the ideal use case for this mode i.e. the battery is charged during high speed motorway driving during travel to a town or city which then allows zero emission in the town or city. This was a cold start test.

6. **50% hybrid test (Peugeot, Renault):**

Since neither the Peugeot nor the Renault were equipped with a charge increasing mode like the BMW it was decided to instead test the two PHEVs on the extended commuter route in hybrid mode starting the test with a 50% charged battery to check how this would affect their performance.

3. Results

This section presents the electric range and CO_2 emissions results of the three tested PHEVs as well as an assessment of the performance of BMW's geo-fencing (eDrive Zones) and adaptive driving modes.

While on-road pollutant emissions were not the main focus of this project, pollutant emissions were measured on all tests and all PHEVs complied with the applicable Euro 6d on-road emission limits[12] for particle number (PN) and nitrogen oxides (NO_x). The Euro 6 limit for carbon monoxide (CO) was also met by all three PHEVs.

3.1 Real world electric range

The electric and in particular the zero emission electric range of a PHEV is a critical determinant of the CO2 emission savings that PHEV technology can deliver. The greater the electric range of a PHEV, the greater, on average, the share of electric kilometres driven and therefore the greater the associated CO_2 reduction[5]. As such, it is important that the official type-approval electric range determined on the WLTP test and used both for the calculation of PHEV CO_2 emissions and for advertising, reflects the vehicle's real world performance. This is important for consumers so that they are not misled into buying cars which are not capable of achieving the electric range expected of them, especially since city driving is often advertised as the optimal use case for PHEVs.

[12] Euro 6 limits combined with the applicable 6d conformity factor.

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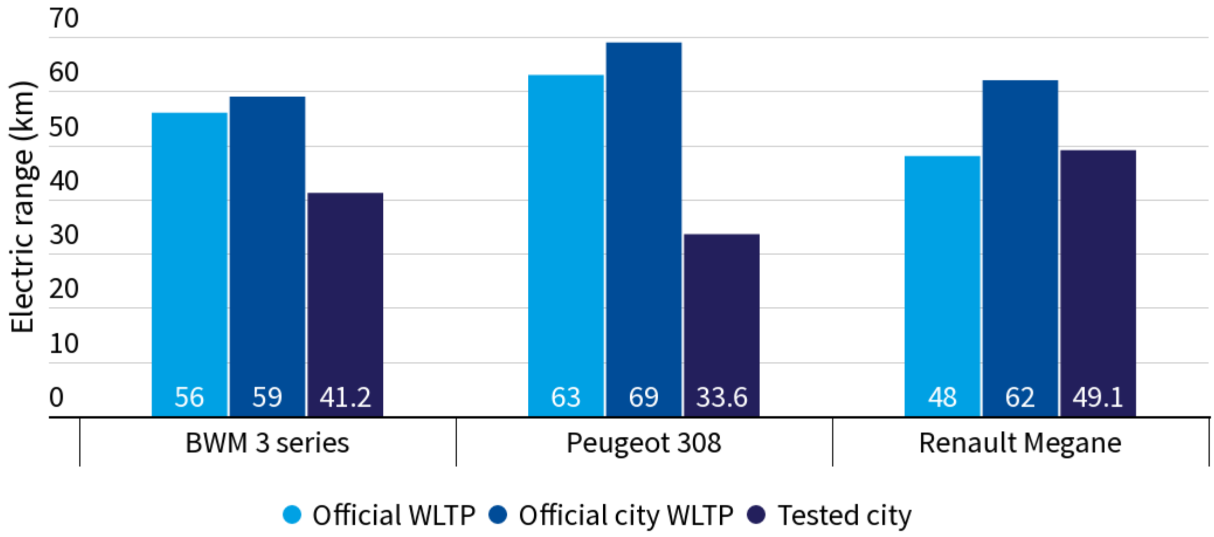

Fig. 5. The tested and official WLTP electric range of the BMW, Peugeot and Renault PHEVs[13]. All three PHEVs had a shorter real world electric range than expected from real world values.

Fig 5. shows the results of the electric range of the vehicles tested on the city driving route, compared to their official WLTP ranges. Despite the mild driving conditions experienced during this test, the electric range of both the BMW and Peugeot were significantly lower than the Equivalent All Electric Range, EAER stated on the PHEV's Certificate of Conformity (CoC).

-The BMW's tested electric range was 26% lower
-the Peugeot's was almost half the advertised range (47%)
-Only the Renault managed to achieve a greater electric range by 2%

The gap further increased when compared to the WLTP electric range determined specifically for city driving, (known as the Equivalent All Electric Range City, $EAER_{CITY}$):

- BMW's range was 30% lower
- Peugeot's range was 51% lower
- Renault Range was 21% lower

City driving often results in an increased electric range compared to the EAER, as evidenced by the longer WLTP electric range of the PHEVS for city driving ($EAER_{CITY}$) compared to that reported for the whole test which is a combination of city, rural and motorway driving . This is partly due to the lower speeds in city driving consuming less energy and more opportunity for regenerative braking.

[13] The official electric range refers to the Equivalent All Electric Range (EAER)and the official city electric range refers to the City Equivalent All Electric Range ($EAER_{CITY}$).

Some of the gap in electric range may be due to differences in how the WLTP electric range and the on-road electric range are determined. The EAER is determined by calculating, from the point at which the battery is fully depleted, how much of the total distance driven can be attributed to electrical energy. This method allows driving with the internal combustion engine prior to the full depletion of the battery and as such does not exclusively cover EV only (zero emission) driving. The method used for the determination of real world EV range during on road testing was based on the first ignition of the internal combustion engine which for all three PHEVs also corresponded to an empty battery state of charge on the driver's dashboard. The main reason for the variation in on road and WLTP values is likely to be due to differences in the on road and the laboratory based WLTP test procedures including differences such as payload, ambient conditions and driving style.

3.2 CO_2 emissions

3.2.1. Emissions when not charged

Driving without a charge battery, using the engine only, is known as driving in charge sustaining mode. Real world data on the use of PHEVs indicates that a significant proportion of the PHEV fleet is rarely, if ever, charged despite the assumption in WLTP Regulation that PHEVs are charged daily. This is particularly a problem for company cars; data from Belgium indicates that only 8% of PHEVs[6] are charged once a week. Considering that the electric range of most PHEVs is rather limited - the average official WLTP electric range is 58 km[14]- especially compared to BEVs which have an average official WLTP range of around 400 km[15], infrequent charging means that the PHEV is likely to drive predominantly using the internal combustion engine only. As such, it is important to determine PHEV's real world CO_2 emissions when the PHEVs battery has not been charged as for many cars, especially company, this will be the mode in which they are driven most frequently. The three PHEVs CO_2 charge sustaining emissions were determined during the city charge sustaining test.

[14] Equivalent All Electric Range, based on T&E's weighted analysis of 2021 EU sales.
[15] Based on T&E's weighted analysis of 2021 EU sales.

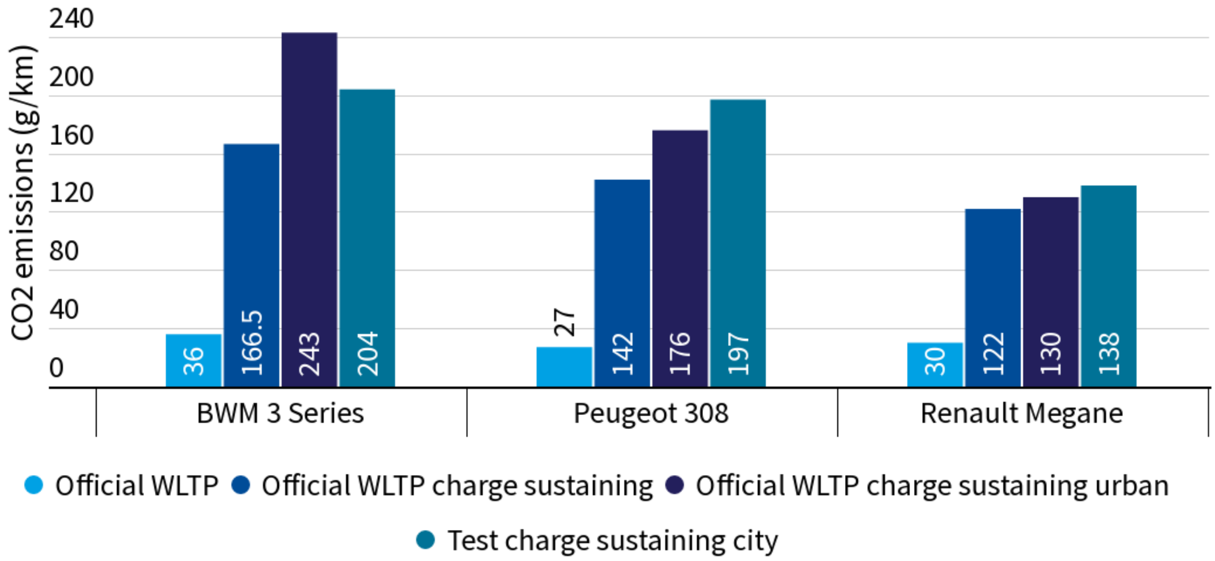

Fig. 6. Official WLTP CO_2 and that measured during city driving in charge sustaining (engine only) mode. Emissions when the engine is running are 5-7 times the official values used for CO_2 compliance and advertising.

On-road city CO_2 vs. official urban charge sustaining WLTP CO_2

Fig 6. Shows the results of the charge sustaining test driven on the city route. On this test the Peugeot and the Renault PHEV emitted more CO_2 than the comparable low urban phase of the WLTP test as reported on the CoC. This part of the WLTP test replicates city and rural driving with speeds up to 77 km/h, frequent stops and accelerations therefore covering similar driving conditions to the city driving route on which the PHEVs were driven for this test, albeit with some faster rural driving. On the road, the Peugeot emitted 12% and the Renault 6% more than the official WLTP urban phase. This is broadly in line with the CO_2 gap reported of 14% between the WLTP test and on-road driving[9].

The BMW emitted 16% less than reported for the WLTP urban phase. This may be due to the high contribution of cold start emissions to the urban phase of the WLTP test for this PHEV. As this test was not a cold start, the magnitude of the initial increase in CO_2 when the engine is first started may have been reduced compared to the WLTP test which is a cold start. The warmer ambient temperature during the on-road testing may also have played a part. Additionally, the city driving test is much longer than the urban phase of the WLTP tests, 65.2 km vs. 3.1 km. High CO_2 from when the engine is first started are averaged over more kilometres resulting in lower average emissions. It is also possible that despite the dashboard displaying an empty battery, there was some residual charge left in the battery which assisted the ICE and reduced CO_2 emissions on this test.

On-road city CO_2 vs. official whole test charge sustaining WLTP CO_2

Official whole test (combined) charge sustaining WLTP emissions[16] were significantly lower than emissions reported for urban low speed phase of the WLTP test for the BWM and the Peugeot. Therefore it could be expected that, particularly for these vehicles, there would be a larger gap between official charge sustaining WLTP CO2 and CO2 measured on the city driving route. The gap between official WLTP and on road CO2 was:

-22% for the BMW
- 39% for the Peugeot
- 13% for the Renault

On-road city CO2 vs. official combined WLTP CO2

Compared with the official weighted WLTP values that are used for CO2 compliance[17] which include assumptions on the share of electric kilometres driven by PHEVs i.e utility factors, on road city CO2 emissions were:

- 5.7 times the emissions for the BMW
-7.3 times for the Peugeot
-4.6 times for the Renault

Overall, the CO2 emissions of the BMW and Peugeot are high when the PHEV is not charged. They are more than double the EU CO2 fleet average target of 95g /km. While Renault's CO2 emissions were lower, with a smaller gap between official and real world values, they were still 32% higher than the EU CO2 fleet average target.

3.2.2 Charge increasing emissions

The charge increasing (CI) mode on PHEVs uses the internal combustion engine to charge the PHEV's battery as the PHEV is driven. Of the three PHEVs tested only the BMW was equipped with this driving mode.

[16] As reported on the Certificate of Conformity
[17] As reported on the Certificate of Conformity

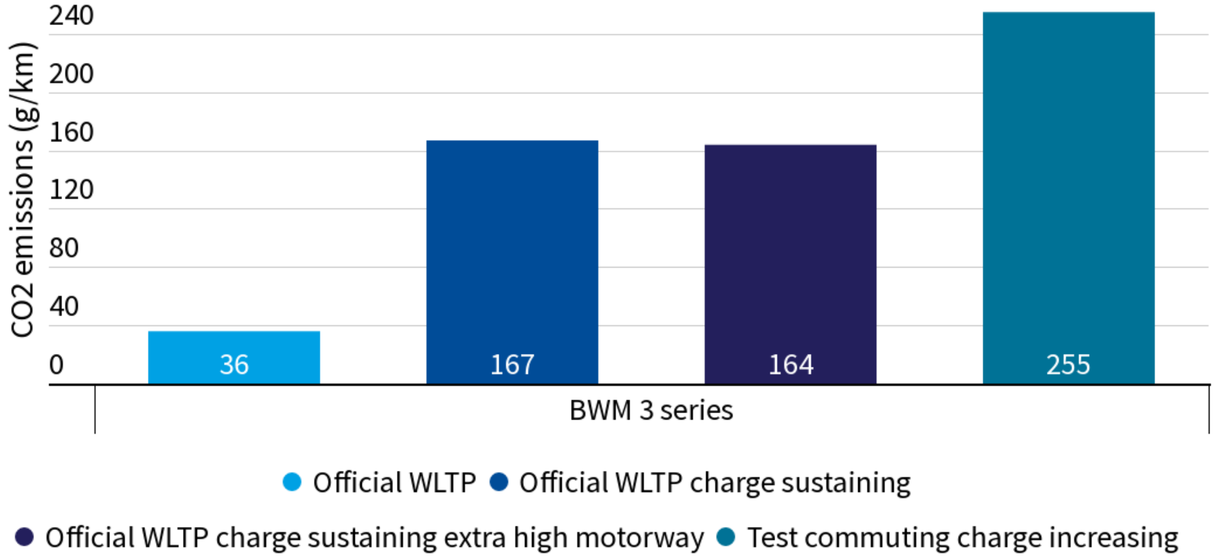

Fig. 7. Official BMW WLTP CO_2 and that measured on the extended commuter route in charge increasing (battery charging) mode. Charging the PHEV battery in this mode causes a large increase in CO_2. Emissions in this mode are over 50% higher than those measured on the WLTP charge sustaining (engine only).

During the charge increasing tests undertaken on the extended commuter route the battery state of charge increased from 0% to almost 100% as indicated by the driver display. This means that the 12.4 kWh battery was almost fully charged during the 97 km test. The BMW's CO_2 emissions in the charge increasing mode were much higher than official figures from the WLTP charge sustaining test. Compared with the motorway[18] phase of the WLTP test which covers high speed motorway driving (as undertaken during 86% of this on road test) CO_2 was 55% higher on the road in charge increasing mode. As there is little difference between the whole test WLTP CS CO_2 and the high speed phase (3 gCO_2/km) the difference between road and the whole test WLTP CS CO_2 was only slightly smaller at 52%. On- road charge increasing emissions were 7 times the official WLTP CO_2 used for calculating fleet CO_2 and advertising[19].

The increase in CO2 emissions due to use of the charge increasing mode is in line with results previously reported by the International Council on Clean Transportation[10] for the BMW X1 which reported a 60% increase in WLTP CO_2 and T&E's previous on road testing of the BMW X5 for which CO_2 increased by over 50%[6]. For this test, the increase in CO_2 due to battery charging could be equivalent to up to 87 g/km. Over the 97 km test distance that would equate to 8.4 kg of CO_2 to deliver a maximum 41 km of zero emission driving in the city (as determined during this testing and described in Section 3.1). This in turn would equate to 206 gCO_2 per electric kilometre driven. This is comparable to the CO_2 measured for this car when driving using the ICE only (charge sustaining mode) in the city (as described in Section 3.2) suggesting there is no CO_2 benefit to charging the battery using the ICE for later zero emission use.

[18] Extra high phase
[19] Weighted, combined WLTP CO2

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In contrast charging from the mains[20] would results in emissions of 88 gCO_2/km[21], meaning that using the engine to charge the battery is 2.3 times more energy intensive then using the grid. While there is significant uncertainty regarding some of the parameters in this calculation[22], it does suggest that on average in the EU charging from the mains is more efficient than using the ICE. This aligns with findings from ICCT which reported 2.5-2.8 higher CO_2 from use of the charge increasing mode compared to charging from the mains .

3.2.3 Hybrid emissions

The hybrid mode on PHEVs uses both the battery and the internal combustion engine to power the PHEV. Two different hybrid tests were undertaken during this testing programme: the hybrid 'default mode' test and the 'Hybrid test with 50% charged battery'.

Hybrid 'default mode' test

Not all PHEV users will choose a driving mode but rather rely on the PHEV to make the choice. To test how each PHEV default mode performs when the car is fully charged, all three PHEVs were tested on the commuter route starting with a fully charged battery and driven in the default mode selected by the PHEV. Fig. 8 shows the results of this test.

[20] A 2022 EU grid carbon intensity of 244.6g/kWh is applied as reported in T&E. (2022) Update- T&E's analysis of electric car lifecycle CO2 emissions. 6.4% electricity grid losses and 9.8% charging losses are applied.
[21] This is a highly conservative estimate as it assumes that the whole 12.4kW battery is charged during the drive. However, usually a minimum state of charge is always maintained within the battery for durability reasons so the full 12.4kW will not be charged. Therefore the CO2 emissions associated with grid charging may actually be lower.
[22] For example due to the battery not being fully charged, or because there is likely to have been residual battery charge at the end of the city electric range test.

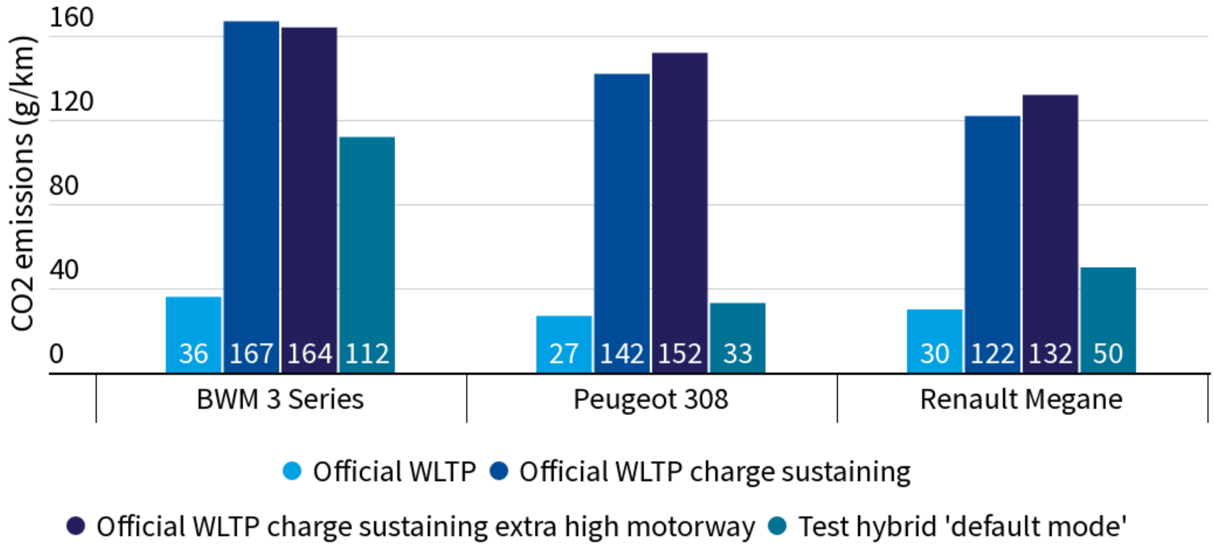

Fig. 8. Official WLTP CO_2 and that measured on the commuter route starting with a fully charged battery in the default mode selected by the PHEV. This resulted in a significant reduction in CO_2 for the Peugeot and Renault compared to using the ICE but only a small 33% reduction for the BMW vs. WLTP.

The BMW had the highest CO_2 on this test, more than double the CO_2 of the Peugeot or the Renault. Compared to the WLTP extra high motorway phase (motorway driving accounted for the majority of the test km's) the default hybrid mode selected by the BMW reduced CO_2 by only 32%. In contrast the Peugeot reduced CO_2 by 78% and the Renault by 62%. Compared to WLTP whole test charge sustaining CO_2, the BMW reduced CO_2 by 33%, the Peugeot by 77% and the Renault by 59%. Compared to official WLTP figures [23] for the three PHEVs, CO_2 emissions on the test were:

-3.1 times the official values for the BMW,
-1.2 times for the Peugeot's
- 1.7 times for the Renault

.

The large difference in CO_2 savings between the three PHEVs appears to be predominantly down to differences in the operating strategy of the three PHEVs. From the drive data it appears that both the BMW and Peugeot selected a hybrid driving mode to operate in during this test with the ICE coming on after around 0.6km of driving during the first acceleration onto the motorway. In contrast, the Renault operated zero emissions until 36 km into the 55 km test after which the internal combustion engine stayed on for most of the rest of the test.

[23] Weighted, combined

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Both the Peugeot and Renault maximised the use of the battery and electric motor, finishing the test with fully depleted batteries. The BMW on the other hand only used between 25-50% of the battery, finishing with between 50-75% of the battery SoC left. This meant that the BMW had to use the ICE more. Based on an analysis of engine data the BMW used the ICE two and a half times more than the other two PHEVs[24] on this test, resulting in much higher fuel consumption and CO_2 emissions on this test.

Hybrid test with 50% charged battery

Neither the Peugeot or the Renault were equipped with a charge increasing mode like the BMW. Therefore it was decided to instead test the two PHEVs on the extended commuter route in the default mode selected by the car, this time starting the test with a 50% charged battery to check how this would affect their performance.

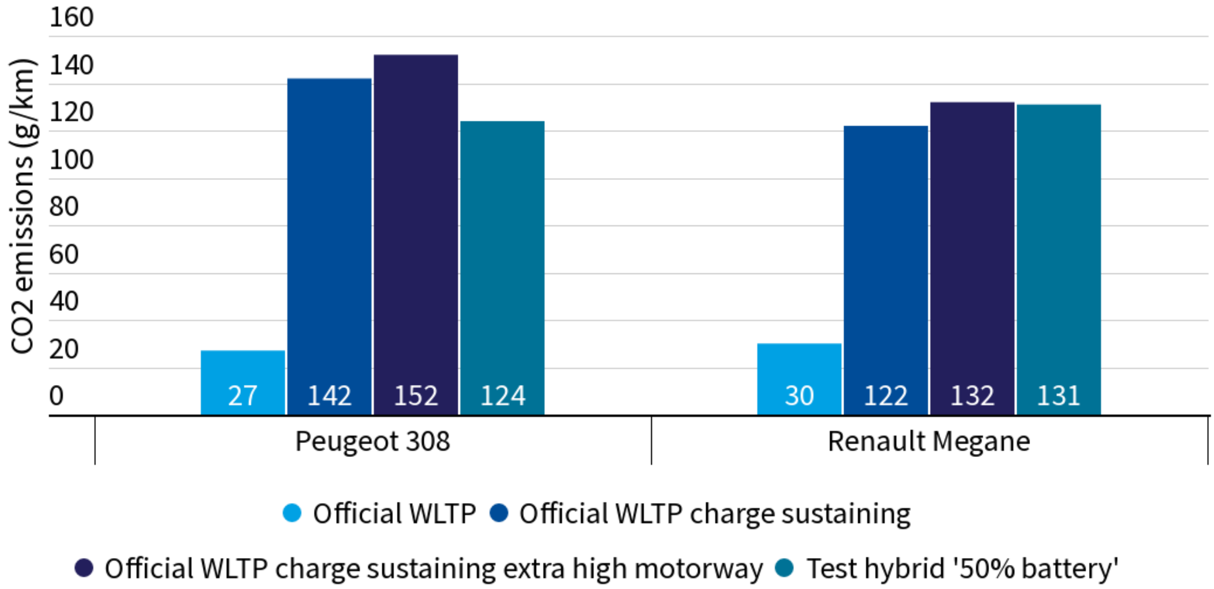

Fig. 9. Official WLTP CO_2 and that measured on the extended commuter route starting with a 50% charged battery in the default mode selected by the PHEV. This resulted in only a minimal CO_2 reduction for both the Peugeot and the Renault compared to driving using the ICE based on official figures for both the Peugeot and Renault.

CO_2 emissions were markedly higher for both PHEVs on this test compared to the hybrid 'default mode' most likely due to the lower battery SoC at the beginning of this test, longer test length and higher speeds reached. Compared to the WLTP extra high motorway phase, Peugeot's CO_2 was reduced by only 18% with no difference for the Renault. Compared to WLTP charge sustaining CO_2, Peugeot's CO_2 was reduced by

[24] Based on an analysis of ECU fuel rate. When per second fuel rate >0 it is assumed the ICE is on. During the hybrid 'default mode test' the BMW had an ICE usage rate of 26% compared to 10% for the Peugeot and 12% for the Renault.

13% and the Peugeot's increased by 7%. Peugeot's CO_2 was 4.6 times and the Renault's 4.4 times the official WLTP figures.

Engine use increased significantly on this test compared to the hybrid 'default mode' test. The Peugeot's ICE use increased from 10% on the hybrid default mode test to 60% on this test. Similarly, the Renault's increased from 12% to 61%. The Peugeot's engine turned on as soon as the car was started. This could be due to pre-heating of the exhaust to reduce pollutant emissions for later ICE use. As this did not occur either at the start or after the 20 minute break during the hybrid 'default mode' test this may be programmed to occur when the SoC of the battery and the engine/exhaust temperature is below a certain threshold. The ICE then stayed on for the majority of the test.

The Renault's ICE came on much sooner on this test than in the hybrid default mode test, after the first 7.3km, and stayed on for the majority of the rest of the test. The early switch on of the ICE is most likely due to the low SoC of the battery as the driving speed at the time (85km/h) and acceleration[25] did not exceed values previously driven in zero emission mode.

3.4 Anticipatory hybrid mode of the BMW

The BMW is fitted with an anticipatory hybrid driving mode. The technology is advertised to use the sat-nav in the car to plan and optimise the use of the internal combustion engine and the battery for efficient driving[26]. The effectiveness of this mode was tested on the commuter route starting with a fully charged battery with the planned route pre-programmed into the sat-nav.

[25] Previous acceleration prior to ICE on was 0.59 m/s^2 vs. 0.26 m/s^2 during the engine on acceleration.
[26] https://www.bmw.co.uk/en/topics/discover/efficientdynamics/efficient-driving.html Accesses 15th of October 2022.

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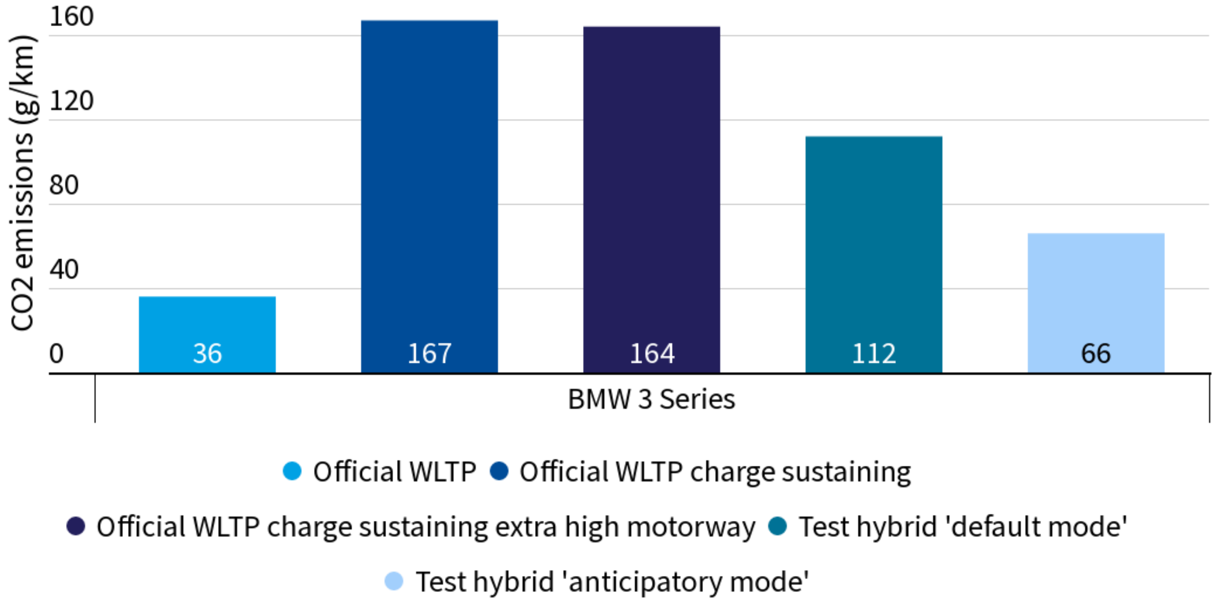

Fig. 10. Comparison of BMW CO_2 when driven on the commuter route starting with a fully charged battery in the default mode selected by the PHEV and the anticipatory hybrid mode which adapts performance based on sat-nav data. Use of the anticipatory mode resulted in an additional 40% decrease in CO_2.

The use of the adaptive hybrid mode resulted in a significant decrease in CO_2 emissions compared to the hybrid ‘default mode’ test driven on the same route detailed in section 3.2.3: CO_2 emissions decreased by 40%. Compared to the official WLTP charge sustaining CO_2 emissions were reduced by 60% on this test.

The decrease in CO_2 emissions during this test appears to be predominantly due to decreased use of the internal combustion engine and increased use of the electric motor and battery[27]. Engine usage decreased from 28% of driving time to 16%[28] and the battery state of charge at the end of the test was significantly lower than on the hybrid test with only around 25% of the battery charge left. The decrease in engine use is closely correlated with the decrease in fuel consumption with engine use decreasing by 37% and fuel consumption decreasing by 40% compared to the hybrid ‘default mode’ test.

3.5 Geo-fencing: BMW eDrive Zone

The BMW is fitted with geo-fencing technology. The geo-fencing capability, the so called eDrive Zone of the BMW is advertised to switch the vehicle into zero emission mode when driving in 138 cities including

[27] It is possible that some of the decrease in CO2 emissions may also be due to the lower temperature on the adaptive hybrid test compared to the hybrid test (25.5 vs. 30.6 ^{0}C)
[28] Based on engine rotation feed from the engine control unit. It is assumed that where RPM>0 the engine is running.

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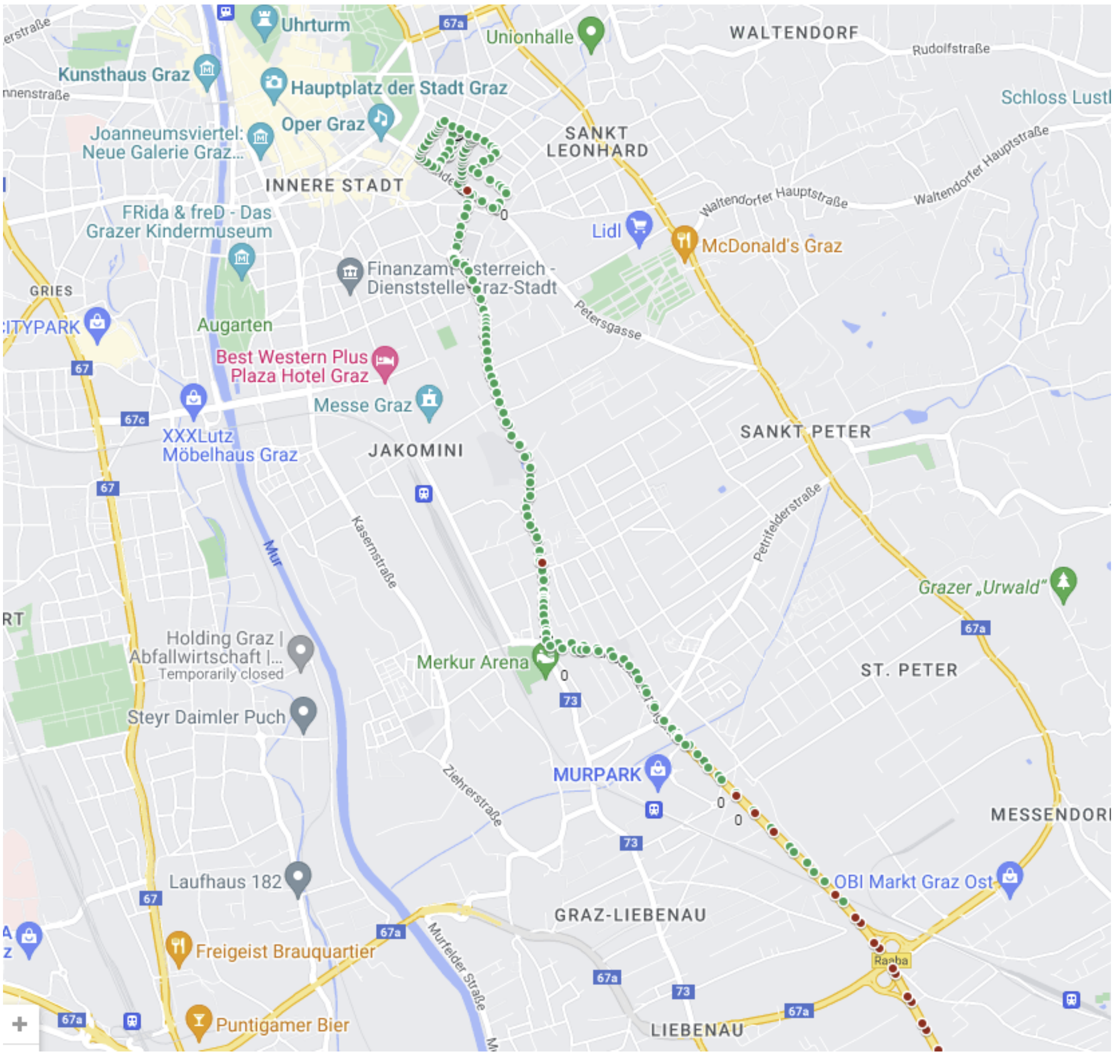
in Graz Austria[29]. The geo-fencing capability of the BMW is on by default and was on during both the hybrid 'default mode' and the anticipatory hybrid tests.

Geo-fencing during the hybrid 'default mode' test

In Fig. 11, the engine use data during the BMW's hybrid 'default mode' has been overlaid on google maps; red dots represent engine on driving and green represent engine off driving. The map, as well as the figure in Annex 7.3, shows that the BMW's engine switched on twice while driving in the city centre where the eDrive zone should have been active. This occurred on the journey into the city prior to the 20 minute break which proceeds the drive back out of town.On the first occasion the engine turned on for 7 seconds and on the second occasion for 9 seconds. From the data available it is unclear why the engine came on within the city where it can reasonably be expected for geo-fencing to be active, but it was not due to a depleted battery as the car finished the test with a battery SoC of between 50-75%.



A study by

Fig. 11. Map of engine use by the BMW during the default' hybrid' mode test when the geo-fencing 'eDrive Zones' was active. Red dots show that the engine came on twice while driving inside the city when the eDrive technology should have ensured that the car was driving zero emission. Map source: Google maps

Geo-fencing during the anticipatory hybrid test

During the anticipatory hybrid test, in which the route was pre-programmed into the sat-nav and the geo-fencing eDrive zones were active the engine did not switch on while driving in the city which can be seen from Fig. 12 as well as in Annex 7.4. This indicates that the vehicle is technically capable of staying in zero emission mode while driving within the city of Graz on the route, however the software on the vehicle is not necessarily capable of ensuring that zero emission driving always takes place within the city limits. It may suggest that the anticipatory hybrid mode may need to be active for eDrive Zones to work as intended.

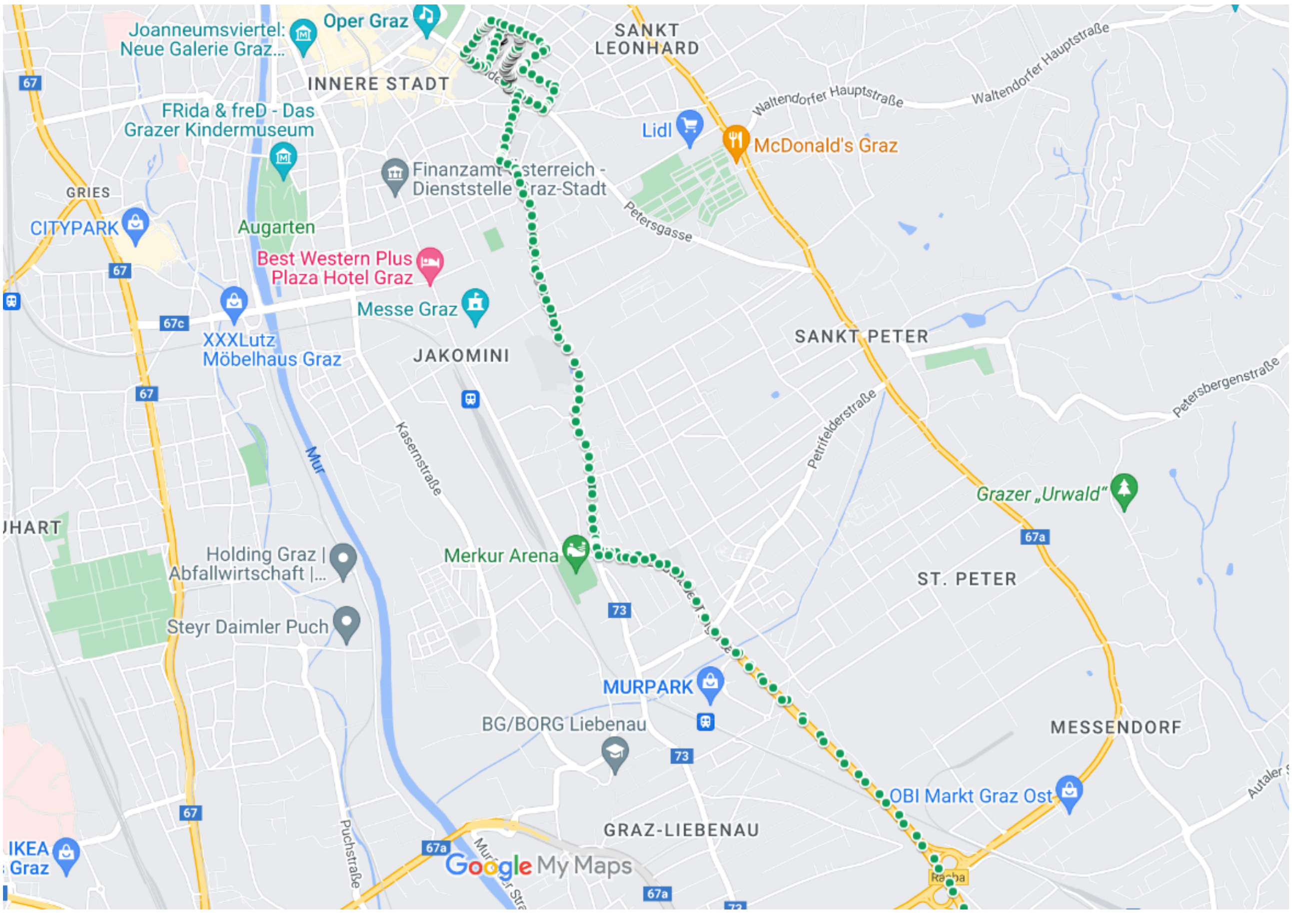


Fig. 12. Map of engine use by the BMW during the anticipatory hybrid mode test when the geo-fencing 'eDrive Zones' was active. Red dots show that the engine did not come on inside the city during this test when the route was pre-programmed into the satnav. Map source: Google maps

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4. Analysis of PHEV CO_2 and its impacts

Real world PHEV CO_2 emissions have been shown to be 3-5 times higher than official WLTP values[5]. This arises due to unrealistically optimistic assumptions on the share of electric kilometres driven by PHEVs within the WLTP regulation known as utility factors (UF). For example the regulation assumes that a PHEV with 50km of electric range will be driven electrically[30] 75% of the time, yet real world data shows that this is actually around 25%[31].

Such a large gap in official and real world CO_2 emissions is problematic as it allows carmakers to unfairly benefit from the sale of PHEVs when it comes to compliance with EU car CO2 standards. In this respect they can benefit twice. First from the significantly lower CO_2 emissions and secondly for PHEVs with emissions of less than 50g/km from Zero and Low Emission Vehicle (ZLEV) credits. It also allows carmakers to benefit from generous subsidies given to PHEVs and negatively impacts consumers through higher fuel costs than expected based on type-approval data.

This section provides an analysis of:

1. The impact of more realistic assumptions on the share of electric kilometres driven by PHEVs on CO2 emissions of the tested PHEVs.
2. The three carmakers' compliance with 2021 and 2022 EU car CO2 standards.
3. The subsidies given to carmakers for selling PHEVs in 2022.
4. The total cost of ownership of the three tested PHEVs compared to similar BEV models.

4.1. Realistic PHEV CO2 emissions

Realistic WLTP CO2

In 2022 the UFs within the WLTP regulation were updated to better reflect real world values. The PHEV WLTP UFs will be adjusted in a two step process in 2025 and 2027 (fig.13) fully aligning with the best known estimate of real world values on the latter date. A further review of UF is planned by 2024 based on data obtained from on board fuel consumption metres, which collect data on the real world fuel consumption (and therefore CO2 emissions) of all new cars sold in the EU since 2021.

[30] Based on WLTP electric range, driven electrically in charge depleting mode.
[31] Based on 2027 WLTP factors assuming a 50:50 split of company and private vehicles.

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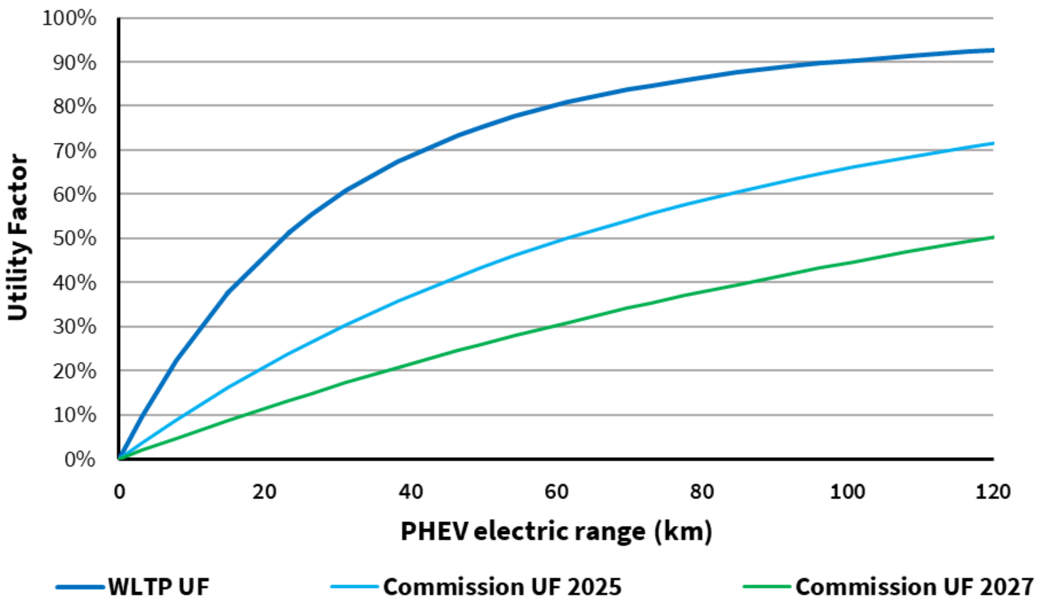

Fig. 13. Assumption on the share of electric kilometers driven by PHEVs depending on their electric range. Current (WLTP) UF are shown as well as the reduction scheduled in 2025 and 2027 which will result in a substantial increase in currently undercounted official PHEV CO_2 values.

For the three PHEVs tested the new UF implemented in 2025 and 2027 will result in a large decrease in the assumed share of electric kilometres driven, resulting in a large increase in official WLTP CO_2. For all three PHEVs the current official WLTP UF has been calculated by T&E to be 84%[32] meaning that the PHEVs are assumed to drive electrically (in charge depleting mode) 84% of the total driving distance, resulting in a very low official WLTP CO_2 of 27-36 gCO_2/km. This is despite having a limited official WLTP electric range of just 48-62 km and as demonstrated even less on road.

[32] Methodology in Annex 7.5.

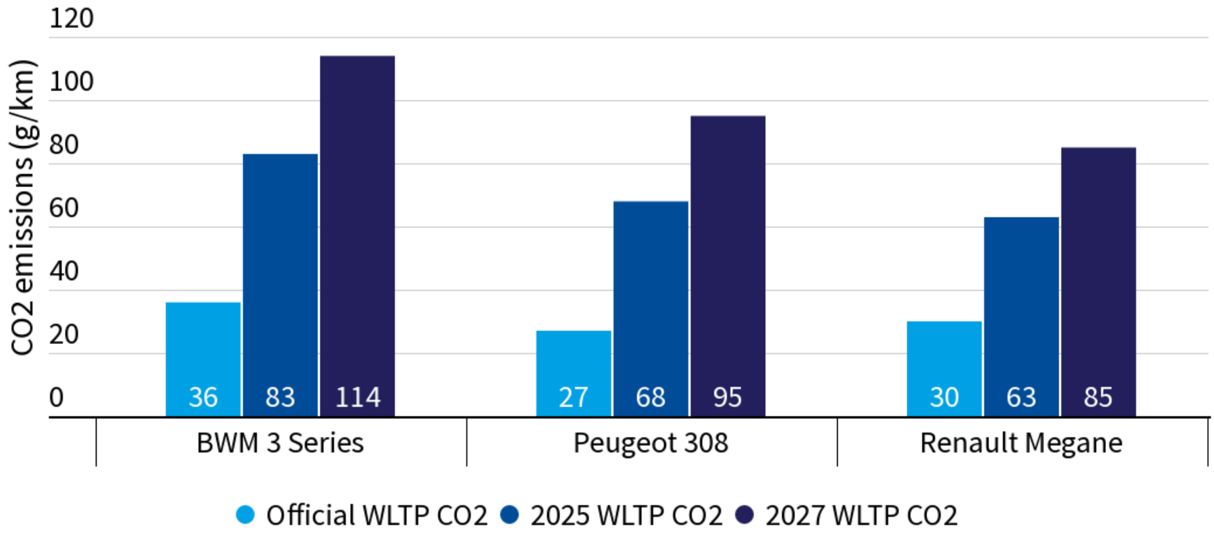

Fig. 14. Current official PHEV CO2 for the three tested PHEVs and the CO2 values based on more realistic utility factors due to be implemented in 2025 and 2027. 2027 will finally align official PHEV closely with real world CO2 values, this will triple official PHEV CO2.

In 2025, the UF for the three tested PHEVs will decrease to 54% with a further decrease to 34% in 2027. The impact on CO_2 emissions can be seen in Fig. 14. Today, the gap between official and real world CO_2 emissions stands at:

- 78 gCO_2/km for the BMW
-68 gCO_2/km for the Peugeot
- 55 gCO_2/km for the Renault

This is between 2.8-3.5 times the official values. Renault has the smallest gap due to having the lowest WLTP charge sustaining CO_2 emissions. In 2025 official CO_2 emissions for all three PHEVs will more than double, reducing the gap to:

- 31 g/km for the BMW
- 27 g/km for the Peugeot
- 22 g/km for the Renault

In 2027 CO_2 will triple compared to today, fully aligning with real world CO_2 emissions. From 2025 all of the PHEVs tested will no longer be eligible for ZLEV credits as their emissions will exceed the threshold of 50 g/km.

Realistic city emissions

While the WLTP test is used to determine the official CO_2 emissions for PHEVs, the test cycle is not necessarily representative of the real world use of these cars and therefore their real world CO_2 emissions. For example, PHEVs driven predominantly in cities will have a higher share of urban driving (and less driving on rural and motorway roads) and possibly more cold starts than the WLTP cycle assumes. In addition the WLTP test cycle has been shown to underestimate CO2 by around 14% compared to real world CO2 emissions[9].

The measurement of CO2 emissions during city driving as part of this testing programme allows the calculation of realistic real world CO2 emissions for city driving based on the share of electric kilometres driven by the PHEV (fig. 15)[33].

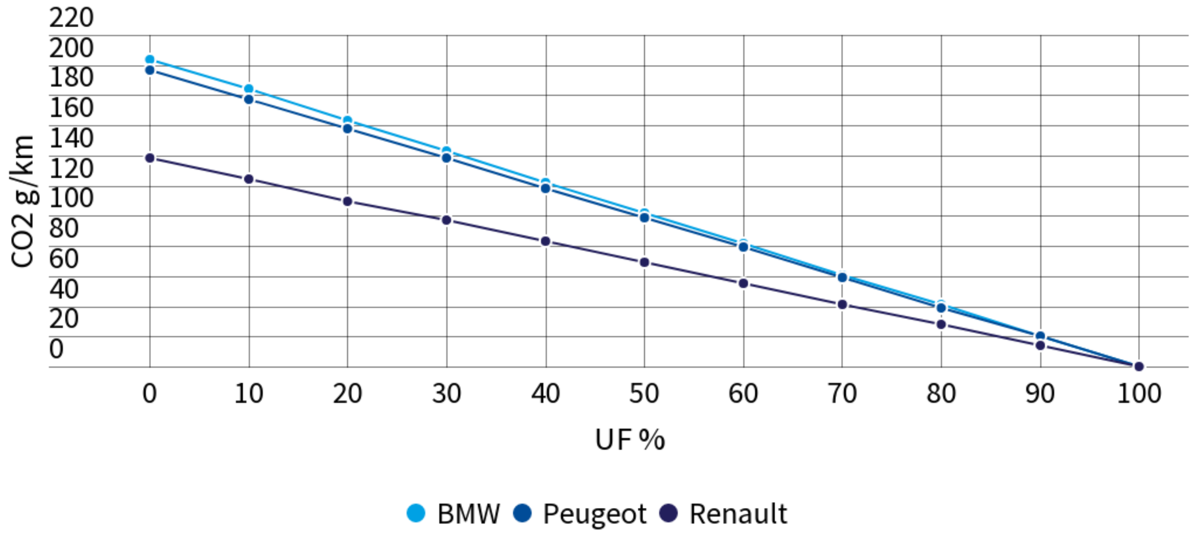

Fig. 15. Realistic city PHEV CO2 of the three tested PHEVs depending on the share (UF) of electric driving. If city electric driving share is the same as for all driving, city emissions are 3-5 times higher than official values.

A driver who never charges their PHEV would have urban emissions of 204 gCO_2/km for the BMW, 197 gCO_2/km for the Peugeot and 138 gCO_2/km for the Renault. In this case BMW's on road city emissions would be the same as the official WLTP CO2 emissions of the VW Tiguan 2.0L petrol SUV[34] and the Peugeot's of the Skoda Kodiaq 2.0L petrol SUV[35]. A driver who exclusively drives their PHEV electrically would have emissions close to zero. However, CO_2 emissions would not be completely eliminated as many PHEVs have to periodically turn the ICE on to maintain the engine and prevent fuel degradation. For example the manual for the Renault Captur PLUG-in hybrid states that if the car is not refilled with at least 10 litres of petrol every three months the ICE will come on automatically. In this case the car then has to be driven using the ICE long enough to reduce the fuel level of the tank by half and the tank must then be topped up with a minimum of ten litres of fuel[36].

[33] Charge sustaining emissions from the city driving test were used. It is assumed that charge depleting CO2 is zero since during the city electric range test the internal combustion engine came on once the battery state of charge was indicating as empty.
[34] Average WLTP CO2 of 204 g/km as reported on www.nextgreencar.com Accessed January 2023.
[35] Average WLTP CO2 of 197 g/km as reported on www.nextgreencar.com Accessed January 2023.
[36] https://gb.e-guide.renault.com/eng/Captur-2/E-TECH-Plug-Hybrid Accessed October 2022.

If the share of electric kilometres driven by PHEVs used exclusively in the city were equal the share of electric driving assumed by the updated 2027 UF then the real world city emissions would be:

-**BMW:** 139 gCO_2/km, 3.9 times the official WLTP CO_2
-**Peugeot:** 132 gCO_2/km, 4.9 times the official WLTP CO_2
-**Renault:** 96 gCO_2/km, 3.2 times the official WLTP CO_2

To achieve the official WLTP CO_2 in the city the BMW would have to be driven electrically approximately 82% of total kilometres, the Peugeot 86% and the Renault 78%.

4.2 Impact of more realistic WLTP emissions on OEM CO_2 compliance

PHEVs are a key compliance strategy for many carmakers for the EU car CO_2 standards, particularly BMW which has the highest PHEV sales share of any carmaker. 16.8% of its overall car sales were PHEVs in 2021 and this is further expected to increase to 19% for 2022[37] meaning that almost one in five cars sold by BMW will be a PHEV. Comparatively BMW's BEV share is much lower at 9%. Stellantis Group, whose brands include Peugeot (and count together for CO2 compliance), had PHEV sales share of 5.2% in 2021, this is expected to increase to 7.3% in 2022. Renault-Nissan-Mitsubishi (RNM), which are also counted together for compliance, had a PHEV share of 3.9% in 2021, in 2022 this is expected to decrease to 3.5% .

4.2.1. 2021 CO2 compliance

Each year carmakers have to meet their fleet average CO_2 targets. T&E calculates that the fleet average CO_2 target[38] in 2021 was 126g for BMW, 118g for Stellantis and 111g for RNM. All three carmakers complied with their targets in 2021, with BMW achieving CO_2 of 115g, Stellantis 112g and RNM of 109g[39]. However, if more realistic UF were used for the calculation of CO_2 - in line with the 2027 UF- BMW and RNM would no longer be compliant. T&E modelling[40] shows that the fleet average CO2 for each carmaker would increase by:

- **BMW**: 14g

[37] Based on an analysis of H1 2022 sales data obtained from Datforce.
[38] Adjusted for vehicle mass through the so- called mass adjustment factor
[39] Carmakers' emissions are calculated from carmakers' new car fleet emissions taking into account super credits and eco-innovations credits. Based on the analysis of 2021 new car sales data reported by the European Environment Agency.
[40] Carmakers' emissions were splitted by powertrains and PHEV's emissions were corrected to take into account the WLTP UF planned in 2027. The R_CDC is assumed to be the distance reached at the end of the test cycle in which the EAER is reached (electric range from carmakers website). The current UF is calculated from the R_CDC. Emissions in CD and CS mode are derived from the declared WLTP emissions (from carmakers website) and the UF. Emissions in CD mode are assumed to be non-zero values and are derived from testing data (same ratio between CD and CS emissions used for all models of a carmaker). From these values, average emissions of each PHEV model are calculated with the 2027 UF curve provided by the EC. Finally, based on OEM's PHEV average emissions and the share of each powertrain, the new fleet average emissions were calculated. The difference with this average emission including the 2027 UF and the original average emissions enable us to quantify the unrealistic PHEV UF loophole.

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- **Stellantis:** 5g
- **RNM:** 3g.

Stellantis would still comply by 1g, but BMW would have exceeded its target by 3g and RNM by 1g.

The artificially low PHEV CO_2 provides a monetary benefit to carmakers as each 1g of non-compliance with car CO_2 standards is charged at €95 and levied on every car in the fleet. In total PHEVs reduced CO_2 for the three carmakers to the value of[41]:

- **BMW:** €0.9 billion or €8,300 for every PHEV sold,
- **Stellantis:** €1 billion or €9,400 per PHEV
- **RNM:** €0.3 billion or €6,600 per PHEV.

This equates to 5% of BMW's profit for 2021, 15% for Stellantis and 13% for RNM[42]. While the CO_2 benefit for Stellantis from selling PHEVs was smaller than for BMW, Stellantis' much larger fleet sales resulted in a larger total monetary benefit. The total value of fines avoided (which would have resulted from CO_2 non-compliance) was €221 million for BMW and €140 million for RNM.

At the same time as providing a significant monetary benefit to carmakers in terms of CO_2 compliance, artificially low PHEV CO_2 reduced the number of truly zero emission (battery electric) cars which need to be sold. In total, this resulted in 208,000 less BEVs sold in 2021 than would have otherwise been the case if PHEV CO2 reflected real world values. BMW sold 81,000, Stellantis 95,000 and RNM 32,000 less BEVs than they would have otherwise needed to. Just for these three carmakers the BEVs lost is equivalent to 21% of 2021 BEV sales (993107)[43].

4.2.2 2022 CO2 compliance

In terms of compliance for 2022 T&E forecast - based on sales in the first half of 2022[44] - that the 2022 CO2 target for BMW would be 127g, 119g for Stellantis and 111g for RNM. It is expected that all three carmakers will overcomply with targets, BMW by 18g, Stellantis by 13g and RNM by 2g. However, the majority of the overcompliance is due to artificially low PHEV CO2 emissions. Taking into account the main loopholes which result in the weakening of the cars CO2 regulation (mass adjustment, eco-innovations,supercredits and PHEV UFs) the unrealistic PHEV UF is responsible for 79% of the weakening in CO2 standards for BMW, 73% for Stellantis and 64% for RNM[45]. If realistic PHEV CO2 were

[41] This is not equal to the fines avoided per PHEV but to the total monetary benefit of selling PHEVs. This is calculated by multiplying the fleet average CO_2 reduction due to unrealistic PHEV CO_2 emissions by the number of vehicle sales in the carmaker fleet and then multiplied by €95.
[42] Based on combined profit of Renault-Nissan group and Mitsubishi Motors.
[43] EEA 2021 sales data.
[44] Based on an analysis of H1 2022 sales data obtained from data force.
[45] T&E quantified the total amount of bonuses allocated to each OEM due to regulatory loopholes, taking into account both the bonus from the mass adjustment, eco-innovation credits and super credits as well as the unrealistic PHEV UF loophole (difference between average emissions with and without the 2027 UF, same methodology as in the section 4.2.1). The ratio of the unrealistic UF loopholes over the total amount of bonuses determines the share which can be assigned to unrealistic utility factors.

applied, BMW's compliance margin would be reduced to 2g and Stellantis' to 6g. RNM would no longer comply as their CO2 would be 0.4g higher than the target, resulting in about €48 million of fines for RNM.

The PHEV benefit to BMW and Stellantis increases in 2022 due to an increased share of PHEV sales. Artificially low PHEV CO2 are expected to help BMW avoid 16g and Stellantis 7g of CO2 an increase of 15% and 35%, respectively compared to 2021. For RNM the CO2 benefit stays largely constant. This, along with expected higher fleet sales, would increase the total monetary benefit to BMW by 9% vs. 2021 to €0.9 billion, and Stellantis by 22% to €1.3billion. Only for RNM would the monetary benefit be reduced by 12% due to expected lower PHEV sales. The per PHEV monetary benefit in 2022 is expected to remain fairly constant vs. 2021 at:

-**BMW** €8,200
-**Stellantis** €9,300
-**RNM** €6,900

Just for these three carmakers BEVs lost in 2022 increased by 19% to 247,000 or 22% of the forecast 2022 EU BEV sales[46]: 94,000 for BMW, 125,000 for Stellantis and 28,000 for RNM.

4.3 Cost of subsidies in 2022

EU PHEV sales continue to be supported by generous purchase incentives in many Member States including in the car manufacturing countries of Germany, France, Italy and Spain. Based on a forecast of BMW, Stellantis and Renault-Nissan-Mitsubishi PHEV 2022 EU sales, EU governments are expected to spend [47] €350 million on PHEV subsidies for BMW, Stellantins and RNM alone in 2022. This is based on an analysis of the 7 EU countries (Austria, France, Germany, Italy, Romania, Sweden[48] and Spain) which provide PHEV subsidies, for which H1 PHEV sales data was available and have PHEV sales of more than 200 cars per model.

[46]Assuming 1.14 million BEV, based on LMC Automotive's Global Hybrid & Electric Vehicle Forecast (Q2 2022).
[47] Excluding subsidies requiring scrappage of older vehicles. Methodology available in Annex 7.5.
[48] For Sweden only purchase subsidies for private cars are included, due to the difficulty in determining purchase subsidies for company PHEVs.

	Country	Subsidy total (euro)
	Austria	2,090,795
	France	47,496,000
	Germany	263,467,125
	Italy	11,171,040
	Romania	358,904
	Spain	21,137,064
	Sweden	4,694,433
	Total	**350,415,360**

Table 1: EU countries spend on PHEV purchase subsidies almost €350 million was spent in 2022 alone.

The majority of the money is spent by Germany which accounts for 75% of the total PHEV subsidy spent on the three carmakers with almost half (€126 million) spent on BMW alone. From 2023, Germany is removing the purchase incentive for PHEVs, thereby this should result in a large decrease in PHEV subsidy spending in the EU. Of the six countries detailed above, Italy and Spain have a higher share of PHEV vs. BEV sales. By the end of 2022 PHEVs had 57% of the EV market in Italy and 61% in Spain, likely at least in part due to the generous subsidies provided.

Overall the breakdown of total subsidy spend per carmaker (fig. 16) across all countries analysed shows that there is an equal split between BMW and Stellantis (€133 million each) with RNM benefitting less (€84 million) from the subsidies due to lower PHEV sales volumes. Overall if averaged over all PHEV sales of the three carmakers in the analysed countries, the subsidy per PHEV is equal to €1,540.

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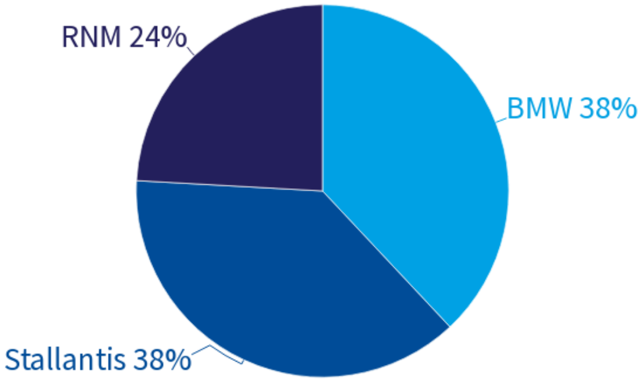

Fig. 16. Breakdown of the share of PHEV purchase subsidies to BMW, Stellantis and RNM in the six analysed EU countries. Overall Stallantis and BMW benefit almost equally, RNM benefits less due to lower PHEV sales.

4.4 Total cost of ownership

Unrealistic official CO2 emissions and therefore fuel consumption impact consumers through higher than expected running costs. While fuel consumption is highly dependent on individual PHEV usage and therefore varies between consumers, there is little clarity for consumers at the time of purchase on how the fuel consumption advertised for PHEVs is determined or how the consumer needs to use the PHEV to achieve the same performance. This leads to a lack of transparency of everyday running costs of PHEVs and the total cost of ownership.

T&E has calculated the average costs of ownership of the three PHEVs based on 4 years ownership and realistic utility factors, as well as the TCO of comparable BEV models. The PHEV and BEV versions of the Renault Megane are compared, the Peugeot 308 PHEV vs. the Citröen eC4 BEV and the BMW 3 series PHEV vs. the Tesla model 3. The Citröen and Tesla were chosen as a comparison for the Peugeot and BMW as they are BEVs of a similar class, weight, price and specification. The methodology for the TCO calculation can be found in Annex 7.6. The results presented in Table 2, show that for all three PHEV models consumers would save money by switching to a BEV.

Car	Total Cost of Ownership EU Average (€/km)
BMW 3 Series PHEV	0.72
Tesla BEV	0.68
Peugeot 308 PHEV	0.57
Citroën eC4 BEV	0.50
Renault Megane PHEV	0.52
Renault Megane BEV	0.50

Table 2: Comparison of the total cost of ownership of PHEVs vs. BEVs. In the EU, on average, it is cheaper to own a comparable BEV than the three PHEVs tested.

Even with today's historically high electricity prices, switching from the BWM 3 Series to a Tesla Model 3 would save €2,600 euro over 4 years, the Citröen eC4 would save €4,800 compared to the Peugeot 308 and the Megane BEV would save €1,300 compared to the PHEV version. This indicates that at least for these PHEVs, car drivers are worse off by buying a PHEV than buying a BEV.

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5. Discussion

5.1 Geo-fencing & PHEV suitability for cities

100 cities from the European Union have joined the EU mission to become climate-neutral by 2030[49] and at least thirty five cities across Europe including Amsterdam, Greater Paris and London[11] have committed to implementing zero emission zones (ZEZ) by the same date in order to reduce air pollution and CO2 emissions. With the recent proposal by the European Commission to revise the Ambient Air Quality Directive (AAQD) and reduce permissible ambient concentrations of NO_2 by 50% and $PM_{2.5}$ by 60%, it is likely that more cities will follow in announcing zero emission zones in order to meet these stricter limits. For ZEZ to achieve their aims of improving air quality and reducing CO2 emissions, zero emission driving has to be guaranteed within these zones. For BEVs, zero emission operation is certain, however for PHEVs the situation is less clear cut. However it should be noted that the aim should be to reduce harmful pollution and climate warming emissions in the real world throughout cities (and beyond), not just on paper compliance in zoned areas only.

Proponents of PHEVs argue that geo-fencing technology can guarantee zero emission operation of PHEVs within geo-fenced areas, such as within low and zero emission zones, and the European Commission hopes to have an official procedure for certifying cars with geo-fencing from 2025[50]. BMW is the first carmaker to put the technology into mass production. It is included as standard on many of their models including the 530e, 745e and X5. The technology currently covers 138 cities including Graz, Austria where T&E's testing took place.

However, the performance of BMW's eDrive technology during this testing programme shows that even PHEVs equipped with geo-fencing technology cannot be guaranteed to drive zero emissions in the center of the city, casting into doubt the potential enforceability of such technology. During one of the hybrid tests undertaken by the BMW in the city of Graz, in which the geo-fencing "eDrive zones" were active, the engine came on twice while driving in the city without a request to do so from the driver[51]. The reason for this is not clear from the data available but it was not due to a depleted battery as the car drove another 30 km and finished the test with between 50 and 75% of the battery charge left.

The high residual state of charge may be due to the vehicle conserving battery power in case of potential entry into geo-fenced areas. This would help to explain why the BMW's battery was depleted further on the anticipatory hybrid test for which the full route was programmed into the satellite navigation. If this the case, the use of geo-fencing for PHEVs could result in an increase in CO_2 emissions from PHEVs as maintaining the state of charge of the battery in case of entry into geo-fenced areas would result in a higher share of engine use and therefore a lower real world utility factor. This means that PHEV geo-fencing technology not only risks having negative impacts on air quality but also on CO_2 emissions.

[49] EU mission: 100 Climate-Neutral and Smart Cities by 2030.
[50] As part of the upcoming Euro 7 emission standards.
[51] According to BMW the driver can choose to switch out of eDrive zero emission driving at any time.

While geo-fencing in Graz is not a legally mandated requirement, eDrive Zones is advertised by BMW to switch to 'all-electric driving mode upon entering inner city areas'[52] therefore it is reasonably expected to perform as such. While the engine did not come on in the city during the anticipatory hybrid test where the route was pre-programmed into the sat-nav, the PHEV should drive exclusively zero emission in the city of Graz whenever eDrive Zones is active, not only when the sat-nav is in use. Especially since the sat-nav may not be used on frequently driven routes as drivers don't put it on for familiar routes.

The real world **zero emission range of PHEVs in cities is rather limited** as evidenced by T&E's testing. The zero emission range of between 34-49 km measured during city driving falls 26-47% short of the range that could be reasonably expected from customers based on official figures for the BMW and Peugeot. This is especially the case for the Peugeot whose zero emission range was almost half the advertised electric range even under the mild driving and weather conditions experienced on this test. In cold weather or with more auxiliaries running, the range could be decreased further reducing the utility of the PHEV as a zero emission car.

On top of the limited zero emission range of the three tested PHEVs, **a lack of fast charging capability** means that none of the 3 PHEVs tested could quickly or easily be topped up on the go when the battery runs out of charge. This was also the case for the three PHEVs T&E tested in 2020 indicating that carmakers are not improving in this area. The BMW and Renault charging rate is limited to 3.7 kW/h, meaning that it would take around 3 hours to charge the limited PHEV e-range to full. It is surprising that Renult decided not to put faster charging on the PHEV Megane given that the fully electric Megane is capable of fast charging the six times bigger battery in 1h 15 min (giving an estimated charging rate of 48 kW/h). The Peugeot is the only PHEV tested capable of slightly faster charging at 7.4 kWh, but to achieve the 34km of zero emission range achieved during city driving would still take at least 1h 40 minutes[53].

The limited zero emission range and slow charging raise the question of what would happen to a PHEV which runs out of electric charge in a geo-fenced area. At present the internal combustion engine would simply switch on, but in a future legally mandated zero emission area switching the ICE on should not be an option. The European Commission plans that PHEVs with geo-fencing would provide the driver with a 5km warning before the battery ran out and the car automatically stopped[54]. Yet with the limited zero emission range of most PHEVs - which is expected to be about 66km[55] by the time geo-fencing rules are expected to come into force in 2025 - and slow charging this would be a significant inconvenience to users. This could potentially result in tampering of geo-fencing systems and circumvention of geo-fenced area rules, something already seen in ICE with emissions control technology such as Selective Catalytic reduction (SCR) used for diesel NOx control and DPFs. Ultimately, what matters is a long-enough real-world electric range (and easy fast charging) for drivers to switch to zero emission km in cities, not software or test procedures that are open to tampering.

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52 https://www.press.bmwgroup.com/global/article/detail/T0361792EN/emission-free-city-centres:-bmw-edrive-zones-now-available-in-138-european-cities?language=en Accessed 10th September 2022.

53 https://www.peugeot.co.uk/electric-and-hybrid/drive-electric/hybrid-charging.html Accessed October 2022

54 According to the European Commission's Euro 7 proposal.

55 Based on a forecast of future PHEV battery size using a range proxy and 2021 WLTP data.

Aside from switching on the ICE in geo-fenced zones when the battery is empty, the ICE in PHEVs can come on for only brief periods as occurred for the BMW on the hybrid 'default mode' test. This makes **detection of PHEV ICE use in geo-fenced areas challenging**. Also BMW states that 'at temperatures below 0 degrees Celsius, the purely electric driving mode of plug-in hybrid models will not be available until the battery has warmed up to an operational condition after the vehicle has travelled a few miles'[56]. Combined, these caveats make the ability to effectively enforce PHEV zero emission operation in geo-fenced areas doubtful, especially if some PHEVs are not capable of driving zero emission under a range of normal conditions such as cold weather. To guarantee that PHEVs drive zero emission in a ZEZ a widespread network of movable remote emissions sensors which can detect emissions from exhausts would likely be needed to ensure that rules are not circumvented. As such, monitoring of PHEV emissions within zero emission zones would likely increase both the cost to cities and the administrative burden of enforcing ZEZ compared to ZEZ which only allow fully electric vehicles.

5.2 PHEV suitability for reducing CO_2 emissions

Carmakers are continuing to increase PHEV sales while claiming that these cars are an environmentally friendly option and a transition technology to fully zero emission cars. However this report and testing shows that even smaller non-SUV PHEVs are still not a good solution for the climate.

PHEVs still have very high CO_2 when only the engine is used

High CO_2 emissions when PHEVs are not charged and driven using the engine only show that PHEVs are not designed with CO2 savings in mind, resulting in very high CO_2 emissions if PHEVs are not regularly charged. The **BMW** and the **Peugeot** have official WLTP CO_2 of 167g/km and 176g/km when the cars are not charged; this is higher than the average CO_2 of a pure ICE car of 139 g/km and which can be as low as 100 g/km[4]. The CO_2 measured during city driving when the cars were not charged was even higher (by 23-39%).

This comes down to the design of these two PHEVs which are much closer to an ICE car than a BEV. The power of the ICE in both of these PHEVs is greater than that of the electric motor. The electric motors on both cars have just 60% of the power of the ICE and the engines on both cars are almost twice as powerful as that fitted to the Renault.

In contrast the **Renault**, which has much lower official (122 gCO_2/km)[57] and on road (138 gCO_2/km) emissions than the other two PHEVs, has an electric motor which is 7% more powerful than the ICE. The mass of the Renault is just 103 kg (6%) lower than that of the Peugeot, but the CO_2 emissions when the battery is not charged are 30% lower. Even when considering variations in driving and weather which will account for some of the difference in on-road city CO_2 between the two cars, **limiting the power of the ICE engine and having a more powerful electric motor appears to be an effective strategy to reduce CO_2**. A study by the International Council on Clean Transportation supports this: their study estimates that

[56] www.bmw.co.uk/en/all-models/3-series/touring/2022/bmw-3-series-touring-overview.html#plug-in-hybrid Accessed November 2022.
[57] WLTP combined, charge sustaining

for each additional 10kW of ICE power CO_2 increases by 0.8-2.4%[5]. For the BMW and the Peugeot this means between 5% to 17% higher CO_2 than if the PHEVs were fitted with an engine of the same power as the Renault.

Fitting a weak electric motor also increases the chance that the ICE will have to come on to assist the electric drive when more power is needed than the electric motor can provide, reducing the real world share of electric driving. This could be one of the reasons why the BMW ICE came on while it was driving in a supposedly geo-fenced area. Unfortunately, at present there is little policy incentive for carmakers to reduce CO_2 when the battery is not charged since both EU car CO_2 standards and Member State national taxation policies use very low official PHEV CO_2 values (which for most PHEVs is less than 50 g/km) and do not take into account the high CO_2 emissions of PHEVs when they are not charged.

Even the update of utility factors in 2025 and 2027 will at best only have a marginal impact on improvement of engine-only (charge depleting) CO_2. In 2022 BMW and Stellantis would have complied with their EU CO_2 targets if 2027 utility factors were used for compliance. Additionally, carmaker CO_2 targets are only reduced by 15% in 2025, meaning that car makers will have to do little to improve their PHEVs to meet their CO_2 targets. Therefore, the most effective way to incentivise reductions in the high charge sustaining CO_2 of PHEVs and improvements in other key aspects (e.g. electric range and fitting of a more powerful electric motor vs. ICE) is through taxing PHEV models for the CO_2 that they actually emit, not the average CO_2 performance of EU-wide PHEVs which is determined at type approval .

Some PHEVs are better designed for commuting than others

The CO_2 measured during this testing programme shows that some PHEVs are better than others at reducing CO_2 while commuting. The three PHEVs were tested on the commuter route which can be considered representative of what a typical PHEV commute to a city could look like. During the commute, the Peugeot reduced CO_2 by 78% and the Renault 62% compared to official figures[58], yet the BMW reduced CO_2 emissions by only 32% owing mainly to greater use of the ICE and less of the electrical drive. Substantial CO_2 savings were only realised when the route was plugged into the satellite navigation and the anticipatory hybrid mode was active.

Overall, considering the magnitude of BMW's CO_2 emissions on the commuter route when the sat-nav was not used (112 g/km), the BMW performs much worse on this type of route and distance than the Peugeot and Renault due to the greater use of the internal combustion engine (as detailed in Section 3.2.3). As already mentioned (in Section 5.1) this may be due to the BMW PHEV preserving battery charge in case of entry into a geo-fenced zone. As such, a customer driving this type of route without the use of satellite navigation is likely to see greater CO_2 emissions and fuel consumption reductions with the Renault and Peugeot than the BMW.

However, testing of the Peugeot and the Renault starting with a 50% charged battery shows that combining a not fully charged battery with a long distance drive results in at most only a small reduction in CO_2. As shown in T&E's 2020 PHEV report[6], to achieve substantial CO_2 savings PHEVs have to be driven

[58] WLTP

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with a fully charged battery and on trips which do not substantially exceed the car's electric range as CO_2 emissions increase rapidly once the internal combustion engine turns on. Carmakers should better inform and educate consumers on the type of PHEV use that will deliver the largest CO2 savings and best fuel economy. BMW's scheme to promote electric driving by rewarding consumers with free charging[12] is a step in the right direction and all carmakers selling PHEVs should adopt similar schemes.

Charging the battery using the engine still results in a large increase in CO2

Previous T&E PHEV testing has shown that charging of the PHEV battery using the ICE while driving results in a large increase in $CO_{2[6]}$, at the time all three PHEVs tested were equipped with this mode. This time only the BMW was equipped with this driving mode. As before, charging of the PHEV battery while driving resulted in a large increase in CO_2 of over 50% compared to official engine only CO2[59] and 7 times the official figures. The charging of the battery using the engine is also estimated to be 2.3 times less efficient than charging using the mains. Given the inefficiency of charging battery using the engine, BMW and other carmakers should follow in the footsteps of Renault and Peugeot and remove the ability to charge the battery in this way, especially since drivers are not provided with information on the associated fuel consumption and CO_2 emissions and therefore cannot make an informed decision about its use. This is particularly important if geo-fencing capability on PHEVs becomes more widespread as this may result in an increased use of this mode which could result in an increase in average PHEV CO_2.

5.3 Vehicle taxation should reward low CO_2 PHEVs and their drivers

Incentivising the sale of lower emissions PHEVs (with lower charge sustaining CO2, longer electric range and more powerful electric motors vs. ICE) can be achieved by shifting the national taxation of PHEVs from the official CO_2 determined at type-approval for each model variant to the individual performance and use of each PHEV. This is possible as all cars sold since 2021 with an ICE are fitted with an on-board fuel consumption metre (OBFCM), which continuously measures and records real world fuel consumption. OFBCM data from cars is already collected by Member States and the EU; it can be obtained from the car at service centres, since carmakers already have to collect this data when a car is brought in for service or repair. From May 2023 this data can also be obtained from centres which undertake Periodic Technical Inspections (PTI) since they are obliged to start collecting OBFCM data during PTI from this date. Obtaining data from on-board fuel consumption metres for the purpose of taxation should not be overly burdensome as new cars, especially company cars, are regularly serviced at the beginning of their lifetime (most often on an annual basis) and the obligation for Period Technical Inspections begins in most Member States after 3 years.

To ensure that PHEV taxation at national level encourages the purchase of more efficient PHEVs and rewards drivers for driving their cars electrically, ownership and company car benefit-in-kind taxation should be based on the actual CO2 emissions of each individual car based on data obtained on an annual basis from OBFCM. For efficient implementation T&E suggests that PHEVs are taxed based on the official WLTP engine only (charge sustaining) CO_2 at the start of the year. Then, based on a read-out of the OBFCM data at the end of the year, the driver can apply to receive a tax rebate if their real world CO_2 emissions

[59] Compared to both WLTP motorway charge sustaining CO2 and whole test WLTP combined charge sustaining CO_2.

were lower than the taxed value due to electric driving. The size of the rebate should be scaled based on the reduction in CO_2 achieved in order to incentivise the highest share of electric driving and largest reductions in CO_2. The tax rebate approach ensures that CO_2 emissions are fully taxed and reduces any concerns over data privacy as only those drivers who wish to benefit from the rebate would need to provide data to the relevant Member State authorities.

Basing ownership and benefit-in-kind taxation on the actual CO_2 savings delivered by individual PHEVs on the road would provide the fiscal incentive needed to encourage the sale of PHEVs which are designed to deliver CO_2 savings on the road, and for drivers to increase the share of electric kilometers driven. This is particularly important for company car drivers, who are often provided with free fuel cards, which reduces the incentive to use PHEVs electrically. Company car drivers drive the lowest share of kilometres electrically, just 11-15% vs. 45-49% for private drivers[5]. Tackling this through smarter benefit-in-kind taxation has the potential to substantially reduce CO_2 emissions and fuel consumption from the PHEV fleet considering that 71% of PHEVs sold in the EU are company cars, in Belgium this is as high as 90%[60].

5.4 Subsidies

Subsidies

EU Member States have spent large sums of money subsidising PHEV sales. For BMW, Stellantis and RNM alone EU governments are expected to spend €350 million subsidising PHEVs sales in 2022 alone, which do not deliver the expected CO_2 savings on the road. Quantity does not necessarily equal quality as, aside from maximum price thresholds, little additional criteria are placed on PHEVs in order to secure subsidies. When applied, these are mostly based only on the maximum official PHEV CO2 emissions. Since official CO_2 values are not a good indicator of the CO_2 reductions that the PHEV can achieve on the road, this approach fails to drive the production and sale of PHEVs which are more likely to reduce CO_2 emissions, such as those with a long electric range, fast charging and low engine only CO_2 emissions[61]. Sometimes electric range criteria is applied but this is not very stringent. When applied, the requirement is not very ambitious and varies from a minimum of 30-60 km.

Given the low share of electric kilometres driven by company cars (11-15%)[5] Member States should no longer provide subsidies for company car PHEVs. Subsidies for private cars, if given, should only be provided in those Member States where the electric vehicle market is still developing slowly and where BEV sales represent less than 10% of new cars sales. In this case, if Member States are set on subsidising private PHEVs they should ensure that these only go to the best performing PHEVs which are closer in design to a BEV than an ICE by setting stringent criteria for the PHEV subsidies. At the minimum this should require:

1) An electric range of at least 80km

[60] Based on 2021 sales data obtained from Datforce.

[61] A full overview of purchase subsidies given to PHEVs can be accessed in T&E. (2022) The good tax guide.

2) Electric motor power should be equal or greater to ICE power.
3) Be capable of fast charging at a minimum rate of 50 kW
4) Have engine only (charge sustaining) CO_2 no higher than the 2022 average for a pure ICE car of 139 g/km

Such criteria would ensure that subsidies are targeted at the most efficient PHEVs. If desired, subsidies could also be tied to individual CO_2 savings based on data from on board fuel consumption meters as suggested for ownership and benefit-in-kind taxation in section 3.2.

6. Conclusion and policy recommendations

T&E's testing of the BMW 3 series, Peugeot 308 and the Renault Megane PHEVs shows that 2 out of the 3 PHEVs tested have a shorter electric range in cities than expected based on official data (by 26-47%), with all three PHEVs having a rather limited range of 34- 49 km. CO_2 emissions when the PHEVs are not charged and driving in cities are very high for both the BMW and the Peugeot (~200 g/km), equivalent to the official CO_2 of the 2.0L VW Tiguan SUV. This is 6-7 times the official WLTP CO_2 values for these PHEVs. The Renault has lower emission of 138 gCO_2/km likely due to limited engine power and lower weight, yet this is still 5 times the official WLTP value. Both the BMW and the Peugeot are closer in design to an ICE car than a BEV due to their ICE being more powerful than the electric motor, only the Renault had an electric motor more powerful than the ICE. None of the PHEVs were capable of fast charging.

The Peugeot and Renault performed better than the BMW 3 series when fully charged and driving on a route representative of commuter driving and in the mode chosen by the car, delivering larger CO_2 savings (59-77% vs. using just the ICE) and achieving emissions of 33-50 gCO_2/km. Yet this is still 1-2-1.7 times the official WLTP values. The BMW reduced CO_2 by only 33% with emissions of 112 gCO_2/km (3.1 times the official values). For the BMW pre-programming of the driving route into the satellite-navigation (which activates BMW's 'anticipatory' driving mode) is needed to further reduce emissions when commuting. Use of this mode additionally reduced emissions by 40% to 67gCO_2/km (2 times the official WLTP CO_2). When not fully charged and driving at high speeds the Renault does not deliver any CO_2 savings compared compared to official WLTP data, the Peugeot reduced CO_2 by at least 13%

Only the BMW was fitted with a battery charging mode, use of this mode increased CO_2 by more than 50% to 255 g/km which is 7 times the official CO_2. T&E estimates that use of the engine to charge the battery is 2.3 times less efficient than charging from the grid and delivers no CO_2 savings for city driving. Overall, the test results show that even most non-SUV PHEVs are closer in design to ICE cars and not designed with CO_2 savings in mind.

As regards to the much touted geofencing, T&E's testing shows cars fitted with BMW's 'eDrive Zone' geo-fencing technology cannot be trusted to continuously drive zero emission in cities since the engine came on twice while driving in the city of Graz -a supposedly geo-fenced city according to BMW. This puts into doubt the usefulness and enforceability of the technology. It also suggests that geo-fencing may hinder the efficient use of the entire battery if electrical range must be maintained for possible entry into geo-fenced zones resulting in an increase in PHEV CO_2 emissions due to less overall electric driving.

PHEV continues to be used as a compliance mechanism for carmakers to easily meet their CO_2 targets due to their artificially low CO_2 emissions. For the three PHEVs real world CO_2 is around three times the official values resulting in a real world gap of 55-78 gCO_2/km. In 2021, if realistic CO_2 emissions were used for the calculation of fleet average CO2 standards neither BMW nor Renault -Nissan-Mitsubishi (RNM) would have complied, facing fines of €221 million and €140 million, respectively. While T&E calculates that all but RNM would have complied in 2022 even with realistic PHEV emissions, the monetary benefit of artificially low CO2 is huge: BMW will benefit €0.9billion or €8,200 per PHEV sold, Stellantis by €1.3billion or €9,300 per PHEV and 0.24 billion for RNM or €6,900 per PHEV. This also results in depressed BEV sales, T&E estimates, for the three carmakers, 247,000 less BEVs in 2022 or 22% of forecast BEV sales.

While not delivering the expected CO2 savings on the road PHEV sales are still supported by generous purchase incentives by many EU Countries. T&E forecasts that in 2022 BMW, Stellantis and RNM will receive €350 million in PHEV subsidies. This is despite the cost of owning a PHEVs being higher than comparable fully electric models. On average an EU driver switching from the BWM 3 series to a Tesla Model 3 would save €2,600 euro over 4 years, the Citröen eC4 would save €4,800 compared to the Peugeot 308, and the Magane BEV would save €1,300 compared to the PHEV version. Overall, PHEVs do not deliver the expected CO2 savings on the road, while being a cost burden to EU Governments and consumers.

Based on this study T&E provides the following policy recommendations:

1) **PHEVs should not be treated as zero emission even if they have geo-fencing capability.** Geo-fencing capability cannot guaranteed zero emission driving, therefore letting PHEVs into zero emission zones makes is harder to enforce and risks the integrity of the zone.

2) **PHEV ownership and company car benefit-in-kind taxation should be based on the actual CO2 reduction delivered by individual PHEVs in the real world.** Data from on-board fuel consumption meters (which are fitted to all cars with an engine since 2021) should be used to determine ownership and benefit-in kind taxes for individual PHEV to ensure that PHEV drivers pay for the CO_2 that they emit since official CO_2 values do not reflect real world CO_2 savings, especially for company cars.

3) **Purchase subsidies for privately owned PHEVs should - if at all - only be given to those PHEVs which are designed to actually deliver CO_2 savings on the road.** This means PHEVs which are closer in design to a fully electric car than a pure internal combustion engine car. This means PHEVs which have a minimum electric range of 80km, electric motor power which is equal or greater to that of the ICE, be capable of fast charging at a minimum rate of 50 kW and have maximum engine only CO_2 of 139 g/km which is the average for a pure ICE car.

4) **No purchase subsidies should be given to company cars** since company cars have been shown to have the lowest electric driving share of just 11-15% and therefore contribute little to reducing CO_2.

5) **Official PHEV CO_2 emissions need to be regularly updated with real world data.** In 2024 there is a review of PHEV utility factors (i.e. the assumption on the share of electric kilometers driven by PHEVs) this should be based on data gathered from on board fuel consumption meters collected by the Commission annually. To ensure that official PHEV CO_2 continues to reflect real world values another review should be scheduled in 2028, this would also provide the opportunity for carmakers to benefit from improvements that they make to their PHEVs.

6) **The option to charge the PHEV using the internal combustion engine should be removed by carmakers**. Using the engine to charge the battery results in a large increase in CO_2 and is at least 25% less efficient than charging from the mains. Both Peugeot and Renault no longer offer this mode of charging on the 308 or Megane. Other carmakers should follow in their footsteps. As for BEV, a ubiquitous public and semi-public fast charging network is needed instead, with cities, governments and the EU all working to deliver this.

7) **Carmakers should educate and reward PHEV drivers for driving electrically.** BMW has already introduced such a scheme which rewards PHEV drivers for driving electrically with free charging. Such a tool is a good example of driver education and should be implemented by all carmakers selling PHEVs.

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7. Annex

7.1 Vehicle details of the three tested PHEVs as recorded on the PHEV's certificates of conformity

	BMW 330e	Peugeot 308	Renault Megane
Type- approval	WLTP Euro 6d-ISC-FCM	WLTP Euro 6d-ISC-FCM	WLTP Euro 6d-ISC-FCM
Registration year	2022	2022	2021
Fuel	Petrol	Petrol	Petrol
Engine size (cm^3)	1998	1598	1598
Mass in running order (kg)	1965	1708	1605
Power combustion engine (kW)	135	132	69
Battery size (kW)	12.4	12	9.8
Electric range: EAER (km)	56	63	48
Electric range: EAER city (km)	59	69	62
Electric motor max net power (kW)	83	81	74
Mileage at start of testing	7625	3962	9338
Combined WLTP CO2 emissions (g/km)	36	27	30
Combined WLTP fuel consumption (l/100km)	1.6	1.2	1.3
Electrical consumption, weighted (Wh/km)	147	157	155

7.2 Technical details of the test driving routes

Test	Ambient temperature [°C]	Urban share [%]	Rural share [%]	Motorway share [%]	Avg. urban speed [km/h]	Avg. rural speed [km/h]	Avg. motorway speed [km/h]
BMW City electric range	23	99.1%	0.9%	0.0%	26.1	60.7	-
BMW City charge sustaining	30	97.2%	2.8%	0.0%	25.4	61.9	-
BMW Charge increasing	23	8.1%	4.4%	87.5%	28.7	76.3	122.4
BMW Hybrid 'default mode'	31	18.2%	10.7%	71.2%	12.5	75.6	116.4
BMW Anticipatory hybrid	25	20.2%	7.2%	72.6%	13.4	75.6	114.3
Peugeot City electric range	21	99.1%	0.9%	0.0%	21.1	60.7	-
Peugeot City charge sustaining	31	97.2%	2.8%	0.0%	22.7	64.1	-
Peugeot Hybrid '50% battery'	31	7.7%	6.5%	85.8%	27.9	77.4	123.5
Peugeot Hybrid 'default mode'	25	17.9%	9.1%	73.1%	10.7	76.2	107.2

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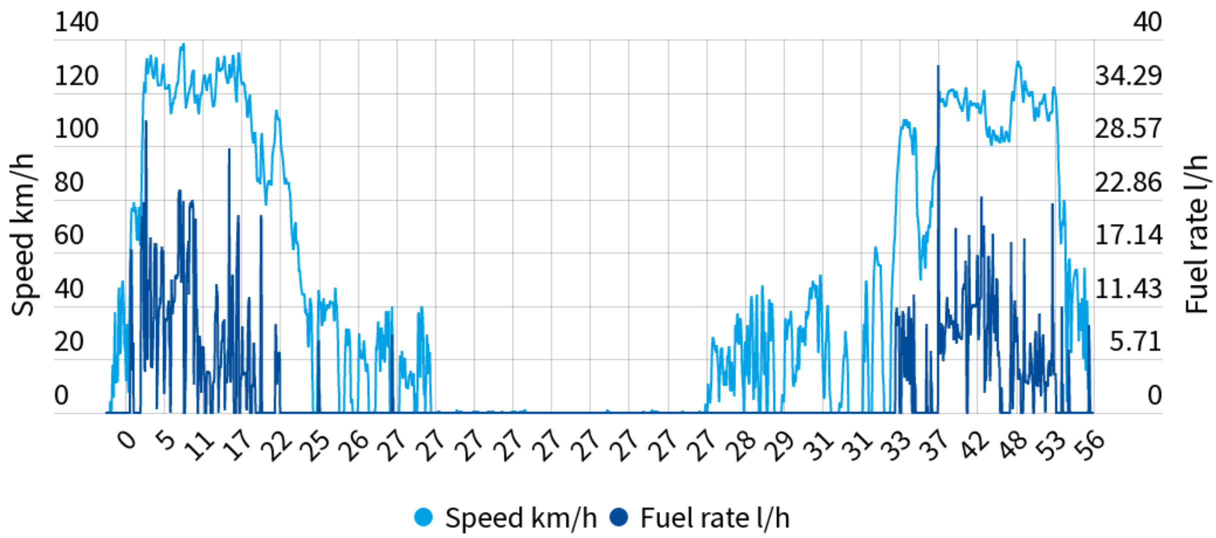
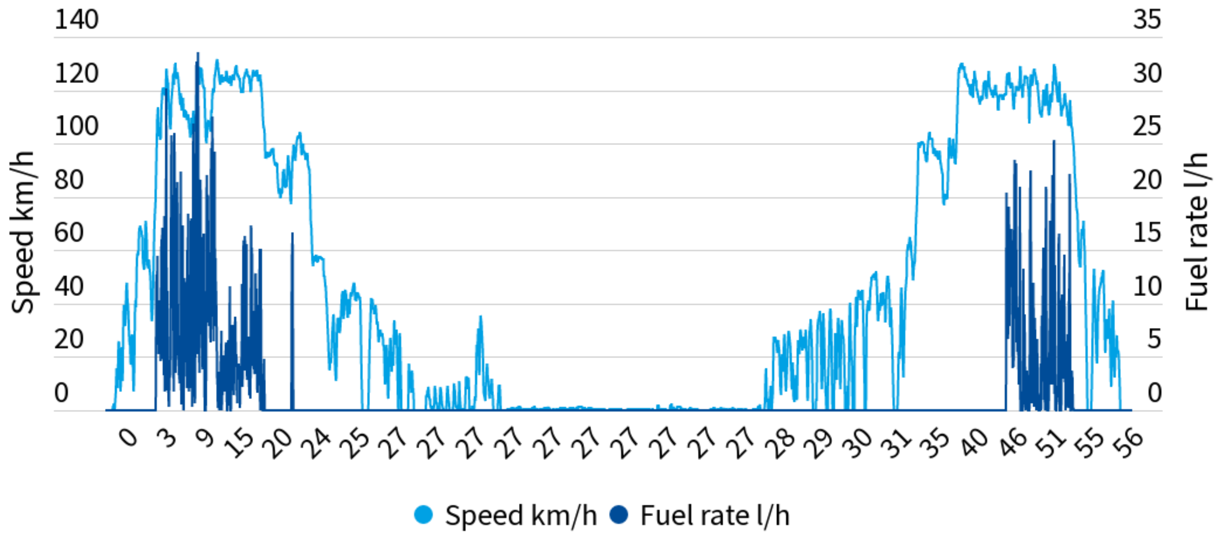
Renault City electric range	30	98,4%	1,6%	0,0%	25,8	61,8	-
Renault City charge sustaining	34	97,9%	2,1%	0,0%	24,5	61,9	-
Renault Hybrid '50% battery'	34	8,0%	8,2%	83,8%	28,2	82,1	124,6
Renault Hybrid 'default mode'	27	18,0%	11,7%	70,3%	12,9	75,1	115,6

7.3 BMW engine data from the hybrid 'default mode' test



7.4 BMW engine data from the anticipatory hybrid test



7.5 Methodology for the calculation of WLTP Utility factors, charge depleting CO2 and PHEV CO2 emissions in 2025 and 2027.

To calculate the impact of of updated utility factors on the CO2 emissions of the three tested PHEVs the following steps were taken:

1. Firstly the official type-approval WLTP utility factor and charge depleting CO2 emissions had to be calculated as these are not available in the Certificate of Conformity. As the range in charge depleting mode used for determination of the UF is not publicly available, this was estimated based on the Equivalent All Electric Range (EAER) detailed in the Certificate of Conformity. For the purpose of this analysis, the range in charge depleting mode is assumed to be the distance reached at the end of the test cycle in which the EAER is also reached. For all three PHEVs this was 69.8km.
2. Based on this electric range the UF used at type approval was obtained from the WLTP UF curve. The assumed UF for all three PHEVs is 0.84.
3. Using a re-arranged version of the WLTP utility factor equation as reported in T&E(2022)Update: T&E's analysis of electric car life cycle emissions combined with the charge depleting CO2 emissions obtained from the CoC, the range in charge depleting mode obtained in step 1 and UF obtained in step 2, the charge depleting CO2 emissions for each PHEV were calculated.
4. The PHEVs 2025 and 2027 UF were determined from the respective UF curves based on the same assumption of electric range as assumed in step 1.
5. The UFs were used in the same equation to determine the expected CO2 emissions for the three vehicles in 2025 and 2027.

7.5 Methodology for the calculation of PHEV subsidies

The value of purchase subsidies[62] given to BMW, Stellantis and Renault-Nissan-Mitsubishi in 2022 were calculated on the basis of subsidies reported in T&E. (2022) The good tax guide and H1 2022 EU sales data obtained from Dataforce. Of the countries which provide subsidies for PHEVs data on H1 PHEV sales data was analysed for Austria, France, Germany, Italy,Romania, Spain and Sweden. The following steps were taken:

1. H1 sales data was scaled by two to estimate 2022 whole year sales.
2. As most subsidies have a price ceiling, price data was obtained from each car manufacturer in December. The base price for each model was used. Any PHEV with sales of less than 200 units over the whole year in a given country were excluded from the analysis to streamline the price data collection process. This equated to ~2% of data points and excluded Latvia and Croatia from the analysis.
3. Since in some countries different subsidies are given to company and privately purchased cars the number of each were calculated based on the latest available data on the percentage of new cars sold as company cars. The latest data available was from 2021 and it was assumed that the share stayed constant in 2022. Where data was not available for the specific country the EU average was used.
4. The applicable subsidies available for private and company PHEVs in each country were multiplied by the number of private and company cars sold to obtain the total value of subsidies in each country.

Additional information: The minimum 60km threshold for PHEVs in Germany was applied from October as per Germany's subsidy criteria. Subsidies calculated for Sweden only include company cars (due to the complexity of calculating purchase subsidies for company PHEVs) and were calculated based on information available at https://www.transportstyrelsen.se/en/road/Vehicles/bonus-malus/bonus.

7.6 Methodology for the calculation of the total cost of ownership of the three tested PHEVs and comparable BEV models.

The methodology used for the calculation of the total cost of ownership for both the PHEV and BEV models is aligned with that reported in T&E. (2021) E-fools: why e-fuels in cars make no economic or environmental sense with an update to the following assumptions:

- Electricity price: 0.31€/kWh. Calculated based on a 6 month EU average from July to December 2022 with prices extracted from the Household Energy Price Index tracker[63].
- Fuel price: 1.7 €/L (inclusive of duties and taxes). Calculated based on a 6 month EU average from July to December 2022 with prices extracted from the Weekly Oil Bulletin[64].
- Ownership period: 4 years.
- Purchase price obtained from the respective carmakers websites in the respective countries in November 2022.

[62] Subsidies given upon scrappage of a vehicle were excluded from this analysis.
[63] https://www.energypriceindex.com/price-data
[64] https://energy.ec.europa.eu/data-and-analysis/weekly-oil-bulletin_en

- Fuel consumption: PHEV fuel consumption in charge sustaining mode derived from WLTP data with a 14% increase to take into account the real world fuel consumption[65].
- Electricity consumption: electricity consumption derived from WLTP data with a 5% increase to take into account real world fuel consumption[66].
- PHEV utility factor: derived from WLTP data.
- Charging: no fast charging assumed.
- Maintenance: PHEVs are assumed to be 25% cheaper to maintain than diesel cars (about 330€ per year) and BEVs are assumed to be 50% cheaper.
- Residual value: based on trends of residual value data acquired from Element Energy, we assumed that both PHEV and BEV would retain 45% of their purchase value after 4 years.
- Financing: paid upfront.

[65] According to ICCT, the average difference between WLTP and real world emissions for all ICEs is about 14%. We assume that this difference can be applied for PHEVs used in charge sustaining mode. https://theicct.org/sites/default/files/publications/On-the-way-to-real-world-WLTP_May2020.pdf
[66] T&E calculations from efficiency data of BEVs provided by the EV-Database show that electricity consumption in real-world conditions is, on average, 5% higher than WLTP values. It is assumed that this relationship is also applicable for PHEVs used in charge depleting mode.

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