

ONE GOAL, MULTIPLE PATHWAYS:

A REVIEW OF APPROACHES FOR TRANSFERRING
ON-BOARD FUEL CONSUMPTION METER DATA TO
THE EUROPEAN COMMISSION

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EXECUTIVE SUMMARY

The new light-duty CO₂ standards adopted in April 2019 require the European Commission to monitor the real-world fuel and electric energy consumption of light-duty vehicles to analyze the development over time of the gap between real-world and type-approval CO₂ emissions. The data for the analysis will be recorded by on-board fuel and energy consumption monitoring devices (OBFCM), introduced in all new light-duty vehicles over a two-year period starting January 1, 2020.

A prerequisite for the analysis is the transfer of the OBFCM data from vehicles to the European Commission, for which the European Commission must develop a procedure. This paper analyzes the data transfer requirements, four transfer pathways, the potential use cases of the OBFCM data, and how the data can be complemented with vehicle parameters needed for the analysis.

TRANSFER PATHWAYS

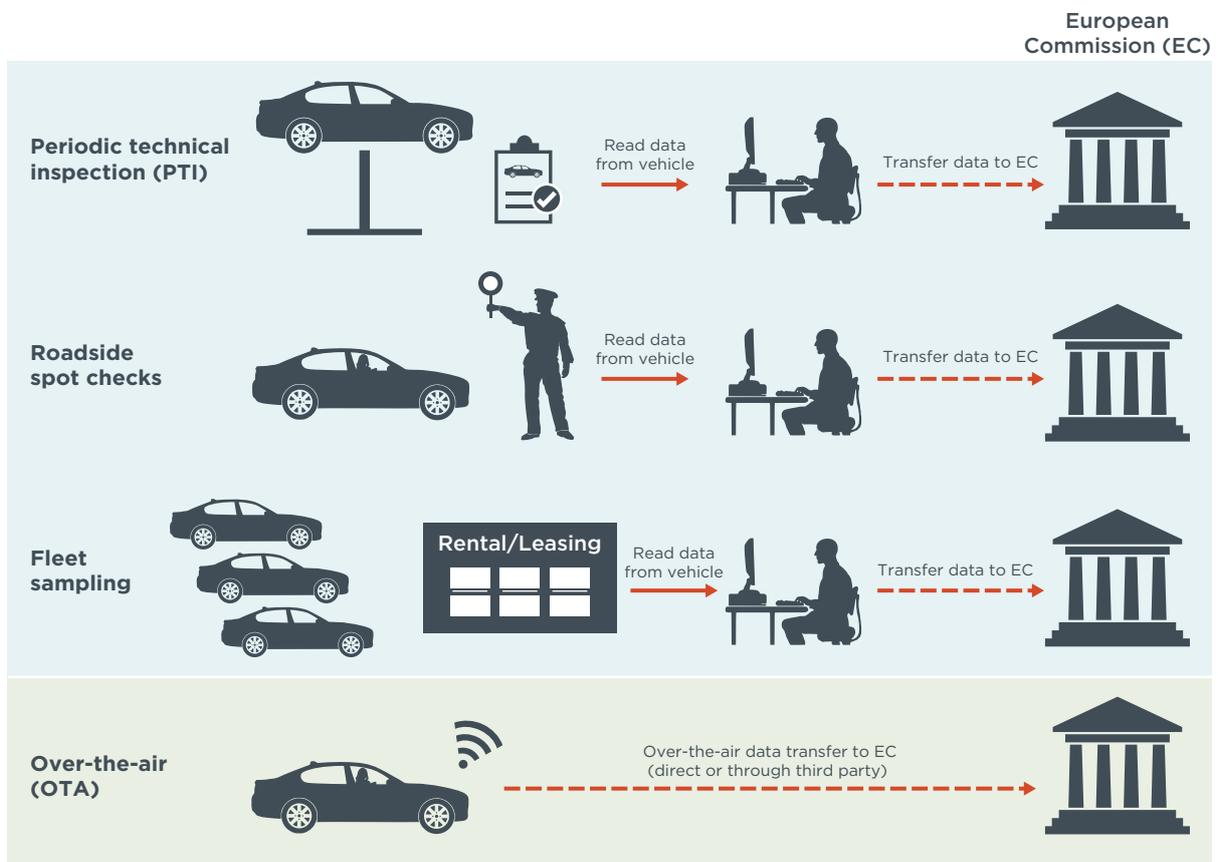


Figure ES 1: Options for transmitting OBFCM data from the vehicle to the European Commission. PTI, roadside spot checks and fleet sampling require periodic access to the vehicle. OTA is suitable for automatic transfer. Icons based on graphics from www.pixabay.com

We considered the four transfer pathways shown in Figure ES 1. For the first three methodologies, the data is first read from the vehicle and then transferred to the European Commission by a third party. Those options are data collection from periodic technical inspections (PTI), roadside spot checks, or managed fleets like rental or company cars. The fourth option is over-the-air (OTA) data transfer directly from the vehicle to the European Commission.

We do not consider PTI a suitable option as the first PTI for new vehicles isn't required for four years. Even though many member states require the first PTI after three years, the time period before the first OBFCM data would be available is too long.

The major drawback of roadside spot checks is the large effort required to perform the checks and the challenge of retrieving the OBFCM data for a representative number of vehicles for each model and manufacturer.

Collecting the OBFCM data from managed vehicle fleets also has considerable deficiencies. Although driving and fuel consumption data is often already determined and recorded by fleet operators, the fleet composition is not likely to be representative of the vehicle market, and fleet vehicles are often driven in a nonrepresentative way.

Thus, **we recommend the OTA technology as the preferred solution for the data transfer.** Automatic OTA transfer is the only solution that realistically allows for regular fleetwide collection of the OBFCM data. Existing telemetry hardware should be used, preferably the already mandatory eCall system, to minimize introduction lead time and cost. This option makes manufacturers responsible for the data transfer and minimizes the risk of errors during transfer. The privacy of vehicle owners can be ensured by applying cryptography principles.

Roadside spot checks by national authorities could be used to collect OBFCM data until an automated OTA system is ready for use.

ACCURACY VERIFICATION

The OBFCM data, which is determined using algorithms developed and calibrated by manufacturers, need to be verified. The regulation currently defines an accuracy requirement only for fuel consumption, which is applicable for the laboratory Worldwide Harmonized Light Vehicles Test Procedure (WLTP) chassis dynamometer test. As the main focus of the OBFCM data analysis is the determination of real-world fuel and energy consumption, **we recommend a similar accuracy requirement be defined for real-world testing and that it includes electric energy consumption.** It also needs to be verified that the data reported from the vehicle to the European Commission is identical to the data measured by the OBFCM device.

Verification is preferably done during in-service conformity checks and at the PTI. In addition to spot checks, OBFCM accuracy over longer time periods can be verified by comparing OBFCM values with, for example, fuel logbook data.

DATA UTILIZATION

The main goal for collecting the OBFCM data is monitoring the development of the gap between type approval and real-world CO₂ emissions. Eventually, this information will be used to develop regulatory measures to ensure that the gap will not grow over time.

The OBFCM data is also valuable for other purposes. Informing consumers about real-world fuel and energy consumption allows them to identify and buy more climate-friendly vehicles. **The OBFCM data should also be used in the future to determine more realistic type-approval CO₂ emission values for plug-in hybrid vehicles** by analyzing the real-world share of electric driving.

Other important research could be based on the OBFCM data, such as analyzing the effect of vehicle age or driving conditions on CO₂ emissions, or the effectiveness of eco-innovations on reducing the gap. To allow the research community to perform these analyses and to account for the high public interest in the OBFCM data for both climate protection and economic reasons, **we recommend that anonymized raw data be made accessible to the public.**

TABLE OF CONTENTS

Executive summary	i
1 Introduction	1
2 Data collection	3
3 Data utilization	4
4 Data transfer	8
4.1 Data transfer requirements	8
4.2 Possible transfer pathways.....	10
4.3 Reporting date, lagged transfer and acknowledgement	12
4.4 Complementing OBFCM data with vehicle characteristics	13
4.5 Coverage and transfer status documentation	14
5 Data verification	16
6 Summary and policy recommendations	17
7 References	20

1 INTRODUCTION

When the first round of carbon dioxide (CO₂) emissions standards for passenger cars was introduced in the European Union in 2009, it targeted only official type-approval CO₂ emissions and fuel consumption levels (European Union, 2009). Monitoring the development of real-world levels was not foreseen by the regulation. Similarly, the second set of standards, passed in 2014, focused solely on type-approval data (European Union, 2014b). As a result, until today, manufacturers have been required neither to measure nor to report real-world CO₂ emissions and fuel consumption of vehicles. Instead, analyses of real-world trends have to rely on a statistical evaluation of voluntarily self-reported consumer or fleet operator data (Tietge et al., 2019).

Meanwhile, the gap between official fuel consumption and CO₂ emission values declared by manufacturers and those values experienced by vehicle users during real-world operation has widened substantially, from about 8% in 2001 to about 40% in 2015. This growth of the gap significantly undermined the climate change mitigation efforts of the EU CO₂ standards and resulted in higher-than-expected fuel cost for consumers as well as foregone tax revenue for governments (Tietge et al., 2019).

In April 2019, the European Parliament and Council adopted a third round of light-duty CO₂ standards, setting mandatory targets for the years 2025 and 2030 (European Union, 2019). This latest set of standards includes a provision requiring the European Commission to monitor and publish real-world fuel and electric energy consumption of light-duty vehicles. In the future, this data is to be used to prevent the gap between type-approval and real-world emissions from growing.

The prerequisite for this new provision was the introduction of on-board fuel and energy consumption monitoring (OBFCM) devices in the amendment (EU) 2018/1832 (European Commission, 2018) to the type-approval regulation (EU) 2017/1151 in November 2018. Article 4a of the amendment requires manufacturers to install OBFCMs in all passenger cars and light commercial vehicles,¹ following the timeline shown in Figure 1. The devices are required for new type-approved passenger vehicles and N1 class I light commercial vehicles (LCVs) by January 1, 2020, and for all new vehicles of these types by January 1, 2021. For N1 class II and III LCVs, the introduction dates are delayed by one year.

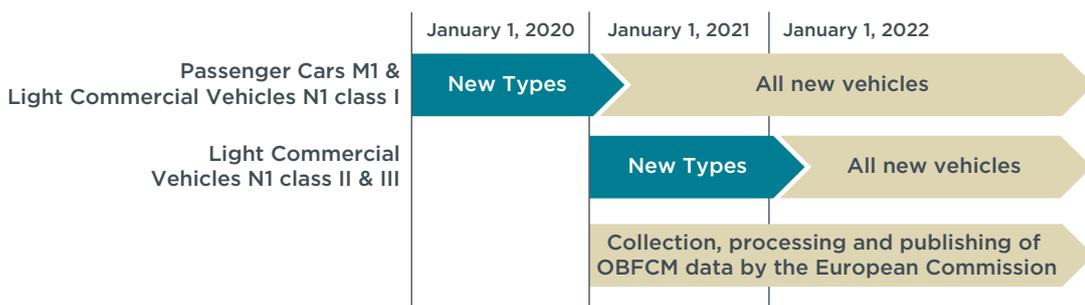


Figure 1: Timeline for the introduction of on-board fuel and energy consumption monitoring devices in passenger cars and light commercial vehicles and for the collection and publication of the data by the European Commission.

In addition to the requirement of installing OBFCMs, the regulation defines which parameters need to be determined and stored by the devices and sets some requirements regarding the accuracy of the data. How these parameters are determined

¹ Exempted are pure electric vehicles, fuel-cell hybrid-electric vehicles and all vehicles that are not powered by diesel, bio-diesel, gasoline, ethanol, or mixtures of these fuel types.

is not specified, and although the name suggests that additional hardware will be installed, manufacturers will most likely use software algorithms based on existing sensor signals instead. Furthermore, the European Commission still needs to define the modalities for transferring the data collected from vehicles to the European Commission to allow for analysis and publication of the results as required by the regulation.

It is the objective of this paper to assess methods for transferring the data and to evaluate alternative approaches with regard to data security, required effort, achieved coverage and being future-proof. The paper also provides technical input and recommendations for the development of data transfer implementing acts and for the verification of the transferred OBFCM data.

This paper is based on the preliminary results of a project commissioned by the German Federal Environmental Agency.² The project's goal was the development and evaluation of procedures for the automatic determination of real-world fuel-consumption data. This project was executed by a consortium consisting of the German Aerospace Center (DLR), the Institut für Energie- und Umweltforschung Heidelberg (ifeu) and the International Council on Clean Transportation (ICCT). However, the opinions and recommendations expressed in this paper are the ICCTs' own and do not necessarily coincide with those of the project contractee nor the consortium partners.

2 Umweltbundesamt (UBA), project number FKZ 3717 57 104 0, project title: Bestimmung der Realverbräuche von Pkw und leichten und schweren Nutzfahrzeugen durch automatische Datenerfassung. [Determination of real-world fuel consumption of passenger cars and light and heavy commercial vehicles using automated data acquisition.]

2 DATA COLLECTION

The required parameters to be determined by the OBFCM device depend on vehicle powertrain type. Not all parameters that are measured need to be stored permanently. Signals representing instantaneous or time-resolved information must be made accessible only for reading and recording by commercially available external devices connected to the standardized on-board diagnostic (OBD) interface.

The regulation specifies the following parameters to be determined for pure internal combustion engine (ICE) vehicles and plug-in hybrid electric vehicles (PHEVs)³:

- » Lifetime values (permanently stored in engine control unit):
 - » Fuel consumption (in liters)
 - » Total mileage (in kilometers)
- » Instantaneous values (not stored):
 - » Engine fuel consumption (in grams per second and liters per hour)
 - » Vehicle fuel consumption⁴ (in grams per second)
 - » Vehicle speed (in km per hour)

Due to their second external energy source, PHEVs need to store additional parameters:

- » Lifetime values (permanently stored in engine control unit):
 - » Fuel consumption in battery-depleting operation (in liters)
 - » Fuel consumption in user selectable battery charging operation (in liters)
 - » Mileage in battery-depletion operation with combustion engine off (in kilometers)
 - » Mileage in battery-depletion operation with combustion engine on (in kilometers)
 - » Mileage in user selectable battery-charging operation (in kilometers)
 - » Total electric grid energy supplied to the battery (in kilowatt hours)

Even though the main objective of OBFCM data acquisition is to determine distance-specific real-world fuel and energy consumption, verifiable accuracy requirements exist only for volumetric fuel consumption and only when tested in the laboratory following the official Worldwide Harmonized Light Vehicles Test Procedure (WLTP).⁵ During the WLTP, fuel consumption in liters is determined by both the OBFCM device and the laboratory equipment. The deviation of these two values must be less than 5%. This must be demonstrated both for type approval and for conformity-of-production tests (European Commission, 2017).

For real-world driving, no verifiable accuracy requirements are defined in the regulation. The OBFCM device is required to provide only the fuel and energy consumption values determined by the vehicle with the highest accuracy. However, as only the manufacturers have access to the signals processed in the engine control unit and due to the lack of a procedure to determine the accuracy outside the WLTP, this requirement is not verifiable in practice.

³ Referred to in the type-approval regulation (EC) 2017/1151 as off-vehicle charging hybrid electric vehicles (OVC-HEVs).

⁴ Engine fuel consumption is the fuel injected into the engine, whereas vehicle fuel consumption includes in addition the amount of fuel directly injected into the exhaust aftertreatment system for pollutant emission reduction.

⁵ Defined in Annex XXI of the type-approval regulation (EU) 2017/1151.

3 DATA UTILIZATION

The intended use-case of the OBFCM data, foreseen by the post-2020 CO₂ regulation, is ensuring that future reductions of vehicle CO₂ emissions under real-world driving conditions follow the regulatory targets, which are based on laboratory testing conditions (European Union, 2019). Even though the OBFCM device is to monitor and report fuel consumption values, the data can be converted into CO₂ emissions with reasonable accuracy using fuel properties. This requires, however, that the OBFCM data be complemented with the vehicle fuel type (refer to section 4.4). For an accurate determination of the CO₂ emissions of flex-fuel ethanol vehicles,⁶ OBFCM data on fuel type would need to be recorded separately.

Furthermore, the OBFCM data, especially when complemented with vehicle characteristics, can be used for additional equally important analyses and reports, relevant to policymakers and consumers. The following discussion provides a list of foreseen and potential use cases for the OBFCM data.

MONITORING THE GAP AND ADJUSTING MANUFACTURERS' AVERAGE CO₂ EMISSIONS

For the purpose of monitoring and reporting the gap between real-world and official type-approval CO₂ emission values, the European Commission is asked in Article 12 of the post-2020 CO₂ standards to regularly collect and publish the real-world CO₂ emissions from January 2021 onward (European Union, 2019). The regulation requires the collected OBFCM data to be anonymized and aggregated at a minimum on the manufacturer level.

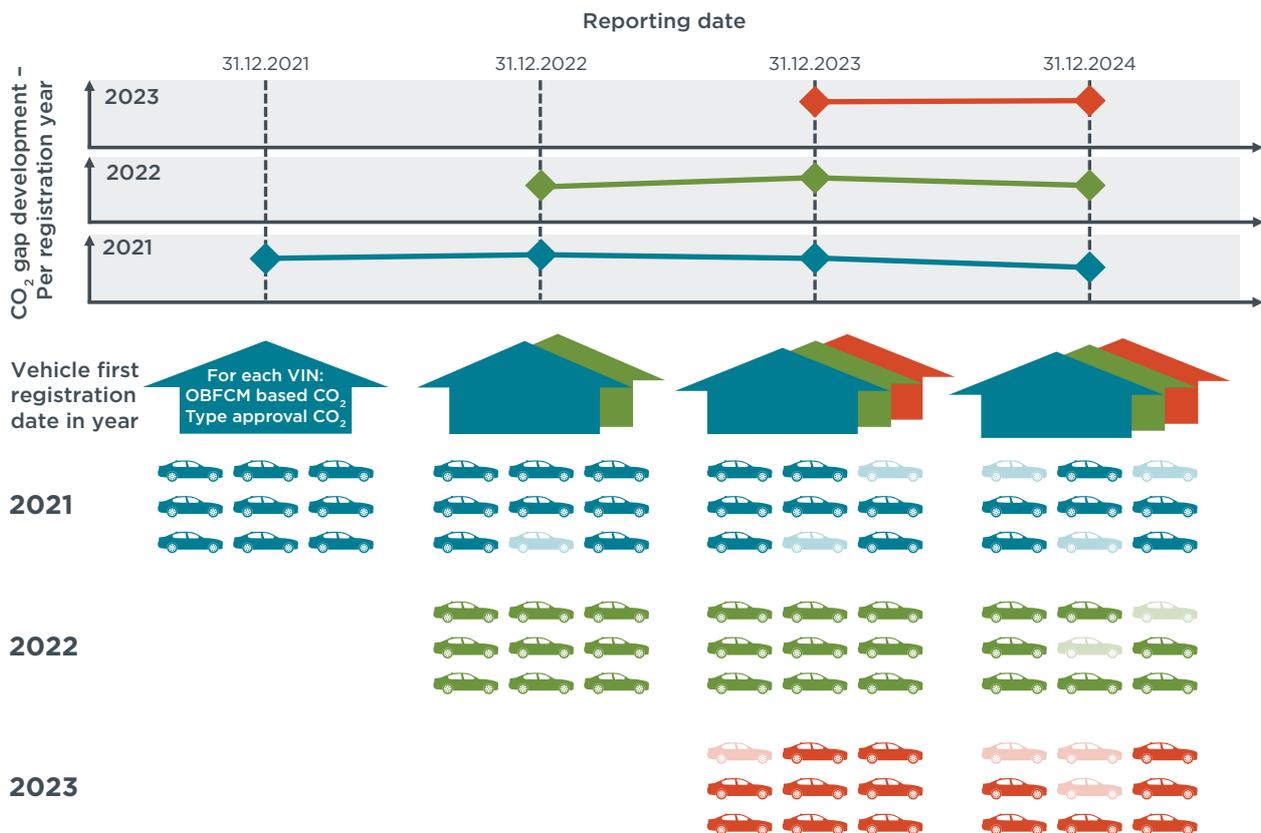


Figure 2: For each manufacturer, the CO₂ gap is to be determined separately for the vehicles registered in one calendar year. Vehicles no longer registered in the EU are excluded from the calculation. Icons based on graphics from www.pixabay.com

⁶ Flex-fuel ethanol vehicles can operate with a mixture of gasoline and ethanol of up to 85% ethanol (E85). Due to the different carbon content of the gasoline and ethanol, the CO₂ emissions per liter of fuel blend burned vary from less than 1,700 to almost 2,300 grams. These values are calculated based on the fuel properties of gasoline E10 and ethanol E85, as defined in regulation (EU) 1151/2017 (European Commission, 2017).

To analyze whether real-world CO₂ emissions follow the reduction over time in type-approval CO₂ for each manufacturer, it is necessary to determine the CO₂ gap separately for subsets of the entire vehicle fleet based on the year of first registration as shown in Figure 2. At the end of each reporting period, the vehicles registered at that time in the EU transmit the OBFCM dataset to the European Commission. Based on the vehicle identification numbers (VINs), the average type-approval CO₂ emissions of each sub-fleet can be determined and compared with real-world CO₂ emissions, based on the OBFCM data. A CO₂ gap value can therefore be determined annually for the vehicles registered in one calendar year and individually for each manufacturer. Furthermore, the European Commission is also required to assess whether and how the OBFCM data can be used to prevent the gap from growing by potentially adjusting the calculation of the manufacturer fleet CO₂ emissions (European Union, 2019).

Independently of the aggregate level, the average gap can be calculated in two ways. One approach would be to calculate the sales-weighted average gap as the average of the individual gap of each vehicle. This would be in line with the calculation method of the annual manufacturer CO₂ performance. Alternatively, the mileage-weighted average real-world CO₂ emissions could be calculated and compared with the average for the type-approval CO₂ values. The latter takes into account the mileage share of the individual vehicles and thereby the real CO₂ emissions of the manufacturer fleet.

INFORMING CONSUMERS

Consumers could be supported in purchasing vehicle models with low real-world CO₂ emissions if the collected OBFCM data were made available at a more granular level, such as by vehicle model, engine model, and transmission type. For this purpose, the reported CO₂ emissions and the CO₂ gap should be the average of all vehicles at the respective aggregation level. Practical use cases include the European Commission-funded “MILE21” (More Information Less Emissions - Empowering Consumers for a Greener 21st Century) project,⁷ whose objective is to inform consumers about the real-world fuel consumption of different vehicle models and thereby support consumers in buying more cost-efficient and climate-friendly vehicles (European Commission, n.d.). The OBFCM data could improve the value and reliability of the project by providing unbiased, fleetwide, real-world fuel-consumption data instead of relying solely on simulation models and user-reported values. OBFCM data could also help to raise general awareness and would allow consumers to compare their individual fuel consumption with the real-world fleet average of their respective vehicle model.

ADJUSTING THE UTILITY FACTOR FOR PHEVS

Another important use case for the OBFCM data is the analysis of the real-world operating pattern of PHEVs. For this vehicle type, the share of electric driving and thereby the real-world CO₂ emissions are strongly affected by the recharging behavior of the owner. The type-approval regulation refers to the relative share of driving in charge-depleting mode⁸ as the Utility Factor (UF). It assumes that a vehicle is more likely to be operated in charge-depleting mode with increasing charge-depleting range, or higher battery capacity, and therefore has a disproportionately higher UF. As the type-approval CO₂ emissions of a PHEV are calculated as average CO₂ emissions in charge-depleting and charge-sustaining operation, weighted by the UF, a higher UF results in lower

⁷ <https://www.mile21.eu/>

⁸ A plug-in hybrid electric vehicle has two main operating modes, charge-depleting and charge-sustaining. The charge-depleting mode is characterized by using electric energy from the battery to power the vehicle. Even during charge-depletion mode, the combustion engine can be occasionally active, but on average the level of charge diminishes. During the charge-sustaining mode, the battery charge level is on average constant as the vehicle is mainly powered by the internal combustion engine.

type-approval CO₂ emissions. The real-world emissions, however, are strongly affected by actual user behavior (Riemersma & Mock, 2017).

For the development of the currently applicable UF, only user data of conventional vehicles was available, and it was assumed that a PHEV would be recharged once a day. The developers of the initial UF therefore recommend continuously checking the UF and when necessary updating it (GRPE, 2017). With the OBFCM data, the real operating and recharge pattern of PHEVs could be analyzed. As it is likely that the recharge pattern of PHEVs depends on other parameters than only the range in charge-depleting mode, the OBFCM data in combination with vehicle information could be used to determine representative and more vehicle-specific UFs that take into account additional factors, such as vehicle power, power-to-mass ratio, footprint, mass, and conventional-to-electric power ratio.

VERIFYING THE EFFECTIVENESS OF ECO-INNOVATION TECHNOLOGIES

The provision on eco-innovations in the European CO₂ standards incentivizes manufacturers to invest in innovative technologies that yield notable CO₂ savings during real-world driving but have only a minor effect on the official CO₂ emissions values determined during type approval (European Union, 2009, 2019). Manufacturers are eligible to deduct the real-world CO₂ savings due to eco-innovations when determining compliance with their CO₂ targets. This means that the manufacturer has to achieve a lower CO₂ reduction performance as it is assumed that the real-world CO₂ emissions are already reduced by the amount of the eco-innovation CO₂ savings. Verification of this assumption is important to ensure that the granted lower reduction performance of the official CO₂ values does not result in higher real-world emissions. (Tietge, Mock, & Dornoff, 2018)

When comparing similar vehicles with similar technologies but without eco-innovations, the gap between real-world CO₂ emissions and official values must not be higher for vehicles that use eco-innovations. The OBFCM data coupled with the relevant vehicle characteristics provide a solid basis for fleetwide verification. Different aspects can be statistically analyzed, such as the effectiveness of individual eco-innovations or the real-world performance of eco-innovations for different manufacturers. This information can be used to adjust or annul the considered real-world CO₂ savings.

The CO₂ savings of currently approved eco-innovations are in the range of 1 to 4 g/km (Tietge et al., 2018). Once available, a detailed analysis of the OBFCM data should be performed to investigate whether the statistical variations allow an evaluation of the real-world effect of eco-innovation technologies.

DETERMINING THE EFFECT OF AGING ON CO₂ EMISSIONS

In the type-approval regulation, pollutant-specific emissions-deterioration factors are determined to account for the performance losses of the exhaust aftertreatment system due to aging. For CO₂ emissions, however, no aging effect is considered. (European Commission, 2017)

Annual OBFCM data will allow investigation into how fuel and energy consumption develops over a vehicle's lifetime. If combined with the appropriate vehicle parameters, this analysis can be performed, for example, for individual vehicle models, engine models, or interpolation families.

However, it must be noted that fuel and energy consumption is also affected by other parameters, such as variations in average annual temperature or a shift of ownership

from company car to privately owned, reflecting different driving profiles and styles. Therefore, an initial analysis needs to investigate whether and how the effect of aging on CO₂ emissions can be isolated.

STUDYING PARAMETERS INFLUENCING REAL-WORLD FUEL AND ENERGY CONSUMPTION

As described in the previous section, the OBFCM device not only records lifetime fuel and energy consumption but also provides instantaneous values at the OBD interface. This data can be collected by low-cost, commercially available OBD data loggers, which also record additional signals like acceleration, location, engine speed, and ambient temperature. Collecting this data at random allows analysis of the effect of parameters like ambient temperature, traffic situation, and driving style on fuel and energy consumption.

4 DATA TRANSFER

The latest CO₂ standards for the target years 2025 and 2030 require the European Commission to develop a procedure for the collection and processing of OBFCM data. The European commission should ensure that the data is “made available at regular intervals to it, from manufacturers, national authorities or through direct data transfer from vehicles, as the case may be” (European Union, 2019). In this section, we define the requirements for the data transfer and assess four possible methodologies.

4.1 DATA TRANSFER REQUIREMENTS

The data collected by OBFCM can be considered sensitive as it contains private information and will eventually be used for lawmaking or enforcement. We therefore consider it essential that the transfer of OBFCM data respect four fundamental data security requirements, independent of the chosen transfer methodology:

- » **Confidentiality:** During transfer, the OBFCM data is linked to the VIN and thus needs to be considered personally identifiable. It must therefore be ensured that the data can be read only by the intended authorized recipients.
- » **Integrity:** Data transmitted from one point to another is susceptible to manipulation, both intentionally and by accident. The recipient must therefore be able to verify that the data received is unaltered. Checking the integrity of the data does not prevent manipulation but can identify it.
- » **Authenticity:** To prevent the injection of false data in the OBFCM database, such as data sent by an entity that only pretends to be a certain vehicle, it must be possible to positively identify and verify the sender before adding new data to the database.
- » **Nonrepudiation:** As the transferred OBFCM data will be used to monitor the gap between type-approval and real-world values and may eventually be used for enforcement, what the data reveals could result in costly consequences for manufacturers. It must be ensured that the sender cannot dispute that the OBFCM data was actually sent by the respective vehicle.

To ensure these security requirements, a combination of cryptography measures such as encryption and digital signatures can be used. The principle is illustrated in Figure 3 and would work as follows.

Before sending OBFCM data, it would be encrypted using a public, nonconfidential key. The public key could be used only for encryption but not for the decryption of the message. For deciphering, the related private key would be required. This key must be known only to the authorized recipients, such as the European Commission, so that data cannot be deciphered by third parties. Using this so-called asymmetric cryptography would improve safety by ensuring that only a small group knows the decryption key while the key for encryption can be public. (Pohlmann, 2019)

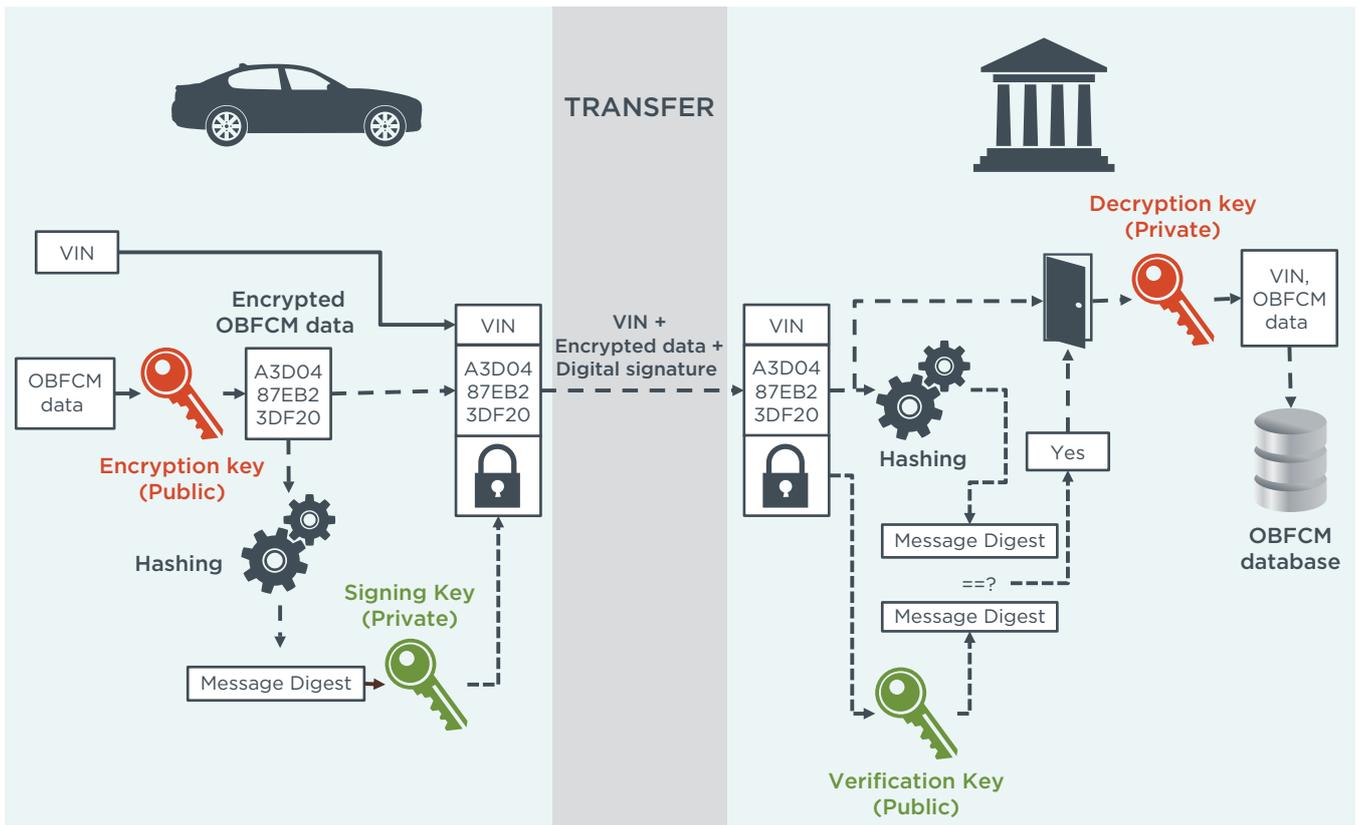


Figure 3: Data protection during the transfer of OBF data could be ensured through a combination of encryption and by applying a digital signature. Icons based on graphics from www.pixabay.com

With the help of a digital signature applied to the encrypted message, the recipient could verify whether the message was manipulated during the transfer. To generate the digital signature, the encrypted OBF data could be processed by a hash algorithm that outputs a so-called message digest: a value that is theoretically unambiguously tied to the encrypted message but can't be inverted to its original value. This message digest would then be encrypted using a vehicle-specific private signing key, which would be stored in the vehicle during production. Subsequently, the digest would be transferred together with the encrypted message to the European Commission. The recipient first would need to decrypt the message digest with a public key that is linked to the VIN-specific signing key of the sending vehicle. Based on the transferred VIN, the public key could preferably be obtained from a certification authority.⁹ Then, the recipient could generate the message digest for the received OBF data by applying the same hash algorithm and comparing it with the now-decrypted message digest that was sent with the OBF data. If the two message digests were identical, the recipient would be assured that the received data was not manipulated and that the data was without any doubt sent by the vehicle (Pohlmann, 2019).

Encryption and digital signing can be performed by crypto-processors, which are available for automotive applications and are, for example, integrated in the communication modules of eCall¹⁰ systems (Hanna, 2017; Infineon Technologies AG, 2018;

⁹ Certification authorities (CAs) are part of a public key infrastructure. A CA issues certificates that link the identity of a user, such as the VIN, to the public keys of a user and other relevant parameters such as validity status, validity period, etc. (Pohlmann, 2019).

¹⁰ eCall is the abbreviation for the pan-European in-vehicle emergency call system, which automatically transmits relevant data about vehicle, time, location, and driving direction to a 112 emergency call center in case of an accident. This technology is mandatory for new type approvals since March 31, 2018, for all passenger cars and light commercial vehicles of category N1 (European Union, 2015).

STMicroelectronics, 2019). The encryption keys can be stored inside these chips and can neither be altered nor extracted (Pohlmann, 2019).

In addition to these security requirements, the transfer methodology should be selected considering the following additional criteria:

- » **Transfer frequency and reporting period:** The main objective of collecting the OBFCM data is the monitoring of the gap between real-world and official type-approval CO₂ emissions. The type-approval values are published for each calendar year by the European Environmental Agency (European Environment Agency, 2019a, 2019b). For consistency, it would be reasonable to analyze the development of the real-world versus type-approval CO₂ gap, as explained in the previous section, for each calendar year. Therefore, the chosen transfer path should support at least an annual transmission of OBFCM data.
- » **Lead time:** The CO₂ regulation requires the European Commission to collect, process and publish the OBFCM data starting in January 2021 (European Union, 2019). This relatively short lead time must be supported by the chosen transfer method, or an intermediate solution must be defined. The same is true for the data protection method. While the encryption and digital signing can most likely be performed by the eCall hardware, vehicle software modifications are required, and the public key infrastructure to handle the verification keys needs to be set up.
- » **Effort and cost:** Even though the collection of OBFCM data and its regular transfer is of high importance, especially for climate protection, the effort and cost expected for the transfer should be minimized.
- » **Responsibility and reliability:** For meaningful monitoring of the CO₂ gap, it is important that the OBFCM data from the majority of the registered vehicles be transferred to the European Commission on time. To ensure clear responsibilities for data transfer, as few parties as possible should be involved. Preferably only the manufacturer would be responsible for initiating a timely transfer of accurate OBFCM data for all its vehicles to the European Commission.
- » **Risk of errors:** The transfer methodology should be robust by design to prevent errors due to human interaction.
- » **Coverage and representativeness:** As discussed in the previous section, the collected OBFCM data can be used for a number of regulatory purposes as well as for consumer information. To allow for a detailed and unbiased analysis, the chosen transfer methodology should cover the entire fleet.
- » **Future-proof:** To fulfill the current requirements of the CO₂ regulation, only limited amounts of data need be transferred at relatively long time intervals. However, future technologies such as on-board emission monitoring (OBM) for all vehicles will most likely require a more frequent data transfer of larger datasets. To be future-proof, the selected transfer methodology and data security measures should take these additional requirements into account.

4.2 POSSIBLE TRANSFER PATHWAYS

The type-approval regulation (EU) 2017/1151 requires that OBFCM data be accessible on a standard OBD interface. In principle, this would allow the data to be read with standardized OBD reader equipment. However, this requires physical access to the vehicle, and both the reading and transfer need to be done manually. Therefore, an automatic OTA data transfer should be considered as an alternative.

Taking into account the requirements identified in the previous section, we discuss four potential transfer pathways as illustrated in Figure 4. For all pathways, we assume that the transferred data is encrypted and digitally signed by the vehicle hardware. This allows the data privacy and security requirements to be fulfilled, regardless of the data

being directly transferred to the European Commission or relayed by the manufacturers or national authorities.

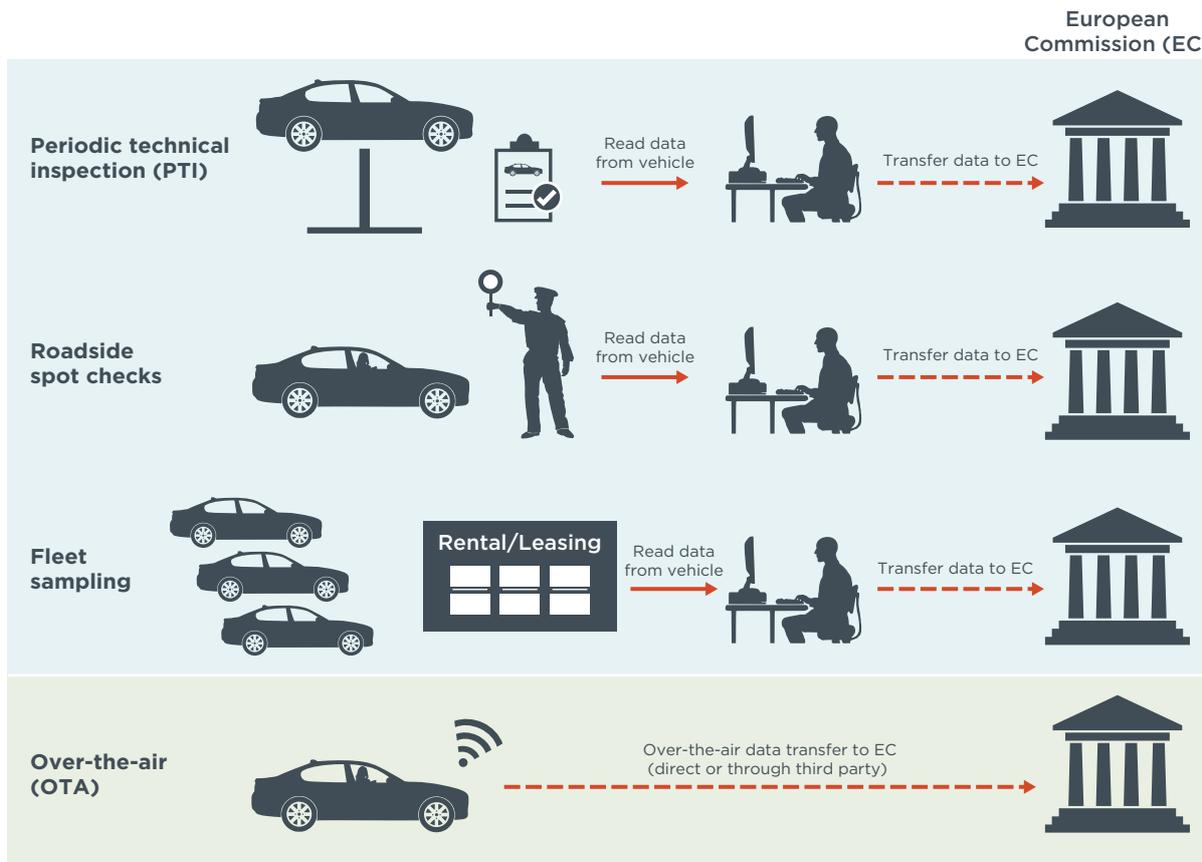


Figure 4: Illustration of four potential transmission pathways for OBCFM data—Three wire-bound methodologies (periodic technical inspection, roadside spot checks and fleet sampling require human interaction) and wireless over-the-air data transmission. Icons based on graphics from www.pixabay.com

PERIODIC TECHNICAL INSPECTION (PTI)

Every vehicle registered in the European Union is required to regularly undergo a roadworthiness test performed by the member state where it is registered or by their authorized bodies. Reading the OBCFM data during this periodic technical inspection (PTI) would seem a suitable approach to ensuring full coverage of the vehicle fleet.

However, the European Directive 2014/45/EU on periodic roadworthiness tests requires the first PTI for new passenger cars and light commercial vehicles four years after the date of first registration and thereafter at least every two years (European Union, 2014a). New vehicle models would therefore not be monitored for several years after market introduction.

Furthermore, as for all OBD interface-based data transfer methodologies, the data fetched with the OBD reader must be transferred to the European Commission via a web or e-mail interface. Relying on human interaction always increases the risk of errors. Another drawback is the shifting of responsibility and cost for the data transfer from the manufacturers to the vehicle owners and bodies that perform the PTI.

ROADSIDE SPOT CHECKS

Performing random roadside spot checks could increase the frequency of the wired data transfer compared with a PTI solution. The lead time for technical implementation is considered low, but national laws will be required to entitle authorities to perform the checks.

A large number of labor-intensive checks would have to be performed to ensure high fleet coverage. Because covering the entire fleet is not feasible using roadside spot checks, this methodology can fulfill the target objective only to a limited extent and cannot be considered future-proof. Also, the selection of sampling spots can influence the representativeness of the collected data. The responsibility and cost for acquiring the data would be transferred from manufacturers to national authorities.

FLEET SAMPLING

As an alternative to monitoring the entire vehicle fleet, the OBFCM data of a sub-fleet, such as rental cars, company cars, or car-sharing vehicles, could be transferred. The advantage of this would be that these smaller, controlled groups of vehicles are often equipped with monitoring devices and regularly return to a single location (TomTom Telematics, 2019). For companies that already collect and centrally store vehicle usage data, a short implementation period and relatively low additional effort for the OBFCM data transfer could be expected.

However, historical data suggest that such fleet vehicles are not driven in the same manner as privately owned vehicles (Tietge et al., 2019). In addition, the vehicle models typically used in rental and leasing fleets constitute only a subset of all models. Monitoring only commercial fleets would not be likely to reflect representative real-world fuel consumption. Furthermore, fleet sampling means additional workload and therefore cost for the fleet owners without any benefit. The responsibility for timely and comprehensive data collection would be shifted from manufacturers to fleet owners.

OVER-THE-AIR TRANSFER (OTA)

As an alternative to the wire-based solutions, which require periodic access to the vehicle OBD interface, the data could be transferred automatically over the air.

To minimize cost and lead time, existing vehicle wireless data transfer technologies could be used. The mandatory eCall system in particular seems to be suitable for performing the required data transfers. The European Commission projects in its eCall impact assessment “that many of the vehicles will also offer added value services using the eCall functionalities as platform” (European Commission, 2011). As described in section 4.1, the data security requirements can also be addressed by the eCall hardware. For many manufacturers, OTA transfer of vehicle data is already a standard technology used for connectivity solutions, and the required hardware is standard equipment (BMW AG, 2019; Daimler AG, 2019; Volvo Cars Germany, 2019).

Whereas the effort required for data transfer from wire-based solutions increases almost proportionally with the number of vehicles, the human effort needed for an OTA solution is minimally affected by the number of vehicles monitored. It is therefore suited to cover the entire vehicle fleet. Since data transfer is triggered and executed automatically by the vehicle, a high level of reliability could be expected, and only the manufacturer would be responsible for the data transfer.

An OTA solution also would allow for more frequent and demand-responsive transfer compared with the wired solutions. This along with comprehensive coverage makes OTA

well suited for future on-board emissions monitoring and need-based periodic technical inspection or maintenance.

4.3 REPORTING DATE, LAGGED TRANSFER AND ACKNOWLEDGEMENT

As discussed in sections 3 and 4.1, all vehicles should report at least once every year the OBFCM data of the previous calendar year to account for the effects of weather and temperature on fuel consumption and for better comparability. On a decided due date, all vehicles would store a snapshot of the OBFCM data locally (Figure 5). If the vehicle is not operated on the reporting date, it should create the snapshot the next time it is activated.

For resources and processing reasons, it is not desirable that all vehicles transfer their data at the same time. However, vehicles should transmit the data without being externally triggered, especially as, for example, the eCall module which could be used for the data transfer is deactivated when not in use for data security reasons and can therefore not receive signals from outside the vehicle. Each vehicle should have assigned an individual, random transfer date when the data snapshot would be sent. To take into account that vehicles of some segments often have only seasonal license plates and that the OBFCM data should be published without much delay, a transfer within the first five to six months of the following calendar would be reasonable. As shown in Figure 5, a vehicle that is not able to send the data at its individual transfer date should send it at the earliest possible time.

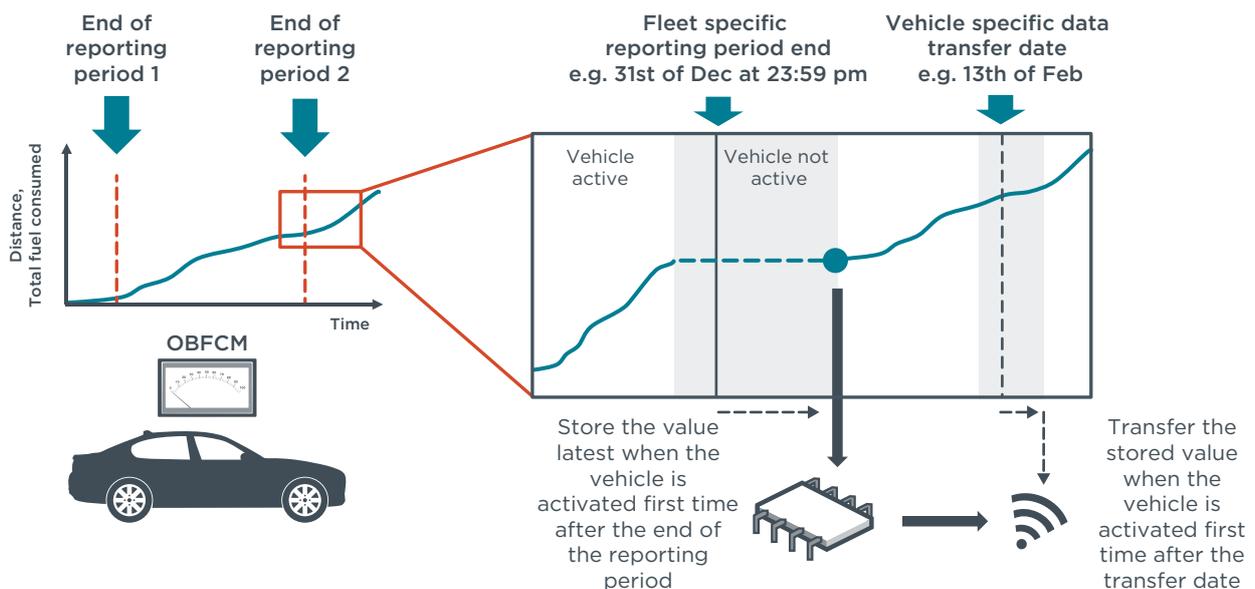


Figure 5: Transfer of OBFCM data requires the definition of a reporting period. For OTA transfer it must be ensured that not all vehicles send the data at the same time and that a sufficient time window is allowed for the transfer. Icons based on graphics from www.pixabay.com

There is a risk that an OTA data transfer fails on multiple attempts. It is therefore important that the vehicle continues transmitting the OBFCM data until it receives a positive acknowledgement from the receiver. The eCall system would support this acknowledgement functionality. In normal mode, the eCall system is inactive to avoid unauthorized access to vehicle electronics by hackers and is activated only in case of an emergency. After transmitting the emergency message, the system stays active for a certain time to receive further requests from the emergency coordination center. (European Union, 2015)

4.4 COMPLEMENTING OBFCM DATA WITH VEHICLE CHARACTERISTICS

The CO₂ regulation requires that OBFCM data be aggregated at least by manufacturer to monitor the development of the gap between real-world emissions and official type-approval values (European Union, 2019). To determine the gap, official CO₂ emissions are needed as a reference value (refer also to section 3). As the official CO₂ emissions value is declared vehicle-specific since the introduction of the WLTP type-approval procedure in September 2017, the entire VIN needs to be transmitted to retrieve each vehicle's official CO₂ emissions value. The VIN is also needed to determine the manufacturer and to query the vehicle fuel type, which is required for the conversion of fuel consumption to CO₂ emissions, and to select the vehicle-specific verification key to decrypt the message digest. For this purpose the CO₂ regulation requires the VIN to be transmitted along with the OBFCM dataset (European Union, 2019).

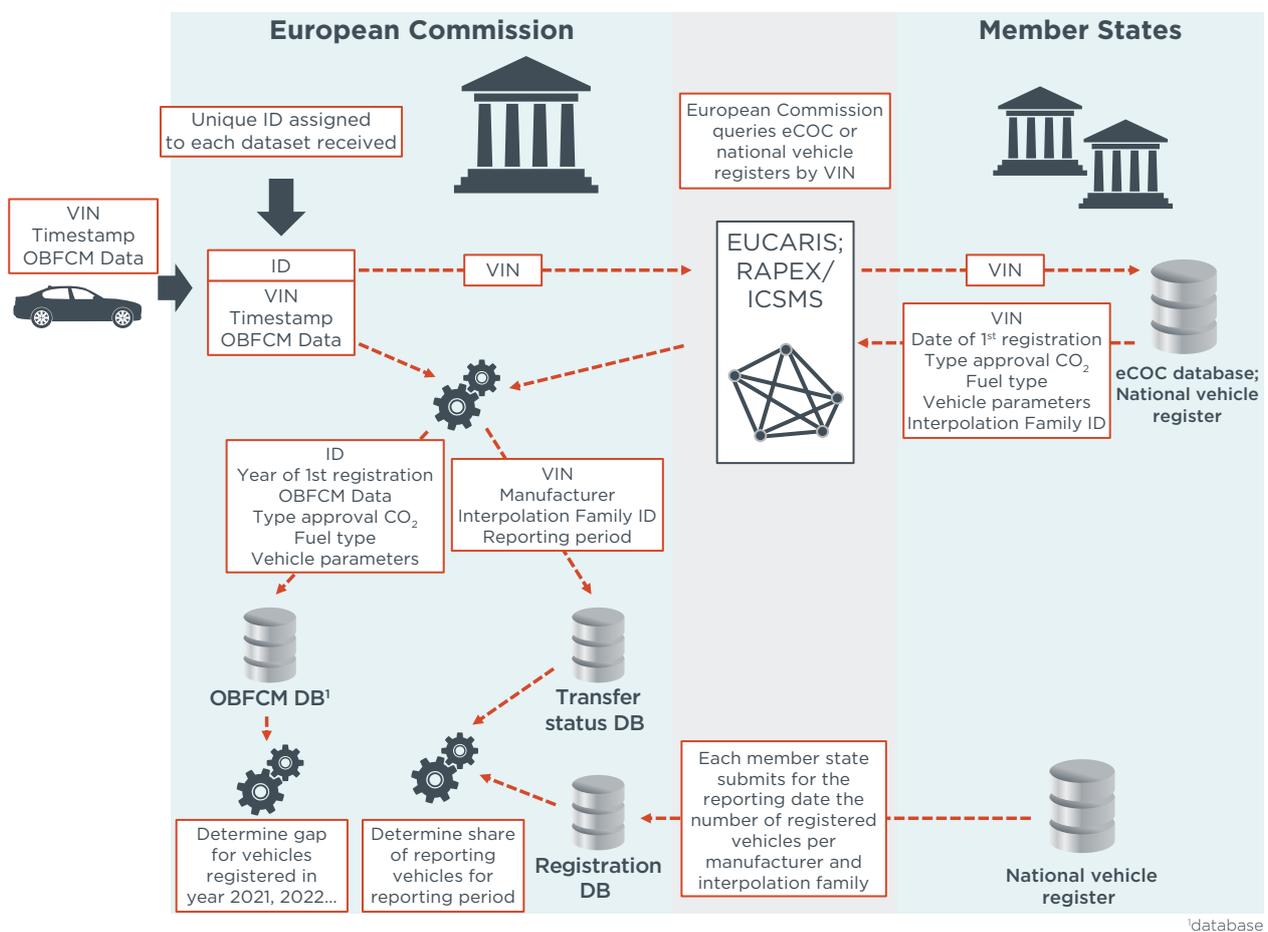


Figure 6: OBFCM data needs to be complemented with vehicle information to analyze the CO₂ gap over time and the quota of reporting vehicles. Icons based on graphics from www.pixabay.com

Figure 6 illustrates a possible process to complement the OBFCM data with the requisite vehicle-specific information based on the VIN and how to store this information in an anonymized way.

After vehicle data is received and decrypted, a unique message ID is assigned to it. The VIN is then used to query the date of first registration, the type-approval CO₂ emissions value, the registration status, and other relevant vehicle parameters from the national vehicle registers, or from July 5, 2026, onward, the electronic certificates of conformity (eCoC) (European Union, 2018). Until the eCoC data exchange platform is established,

the EUCARIS¹¹ system seems to be a possible intermediate solution for data transfer, although not all EU member states participate in EURCARIS and the system does not contain certain data such as type-approval CO₂ emissions and CO₂ interpolation family identifier (EUCARIS, 2000). An amendment to the EUCARIS treaty does allow for adding parameters relatively quickly, but it is up to member states to provide the data on a voluntary basis (EUCARIS, 2017).

Alternatively, the vehicle information needed for data analysis could be stored on-board the vehicle and transmitted together with the OBFCM data. When defining the parameters to be stored, the potential use cases discussed in section 3 should be considered. To account for additional use cases and ensure standardization, preferably the eCoC could be stored and transmitted. Using the “EReg IVI message” format defined by the Association of European Vehicle and Driver Registration Authorities (EReg) and applying data compression would require the storage and transmission of 15 – 50 kilobytes of data for each vehicle¹² (EReg Association, 2018).

If the vehicle is still registered in the European Economic Area at the reporting date, the vehicle-specific data retrieved from the member states would be merged with the OBFCM data and stored in the OBFCM database using the unique ID and excluding the VIN to ensure privacy. To determine development over time, the average manufacturer-specific gap between real-world and declared CO₂ emissions would be calculated for each calendar year, grouped by year of first registration (see also Figure 2).

4.5 COVERAGE AND TRANSFER STATUS DOCUMENTATION

To analyze the quota of data transfer, a transfer status database needs to be maintained so that it contains the manufacturer and the transfer status per reporting period for each VIN, as shown in Figure 6. With this information, it can be evaluated whether a vehicle has already transmitted its data for the reporting period, and duplicate entries in the database can be avoided.

A high rate of coverage of the entire fleet of each manufacturer, without excluding a particular model, is essential for determining a representative real-world CO₂ emissions value. Since the CO₂ emissions values of all vehicles belonging to one CO₂ interpolation family are related and depend only on differences in the road load, defining a minimum quota per interpolation family seems suitable. For this purpose, the interpolation family ID should also be stored in the transfer status database.

By comparing the transfer status database with the number of registered vehicles per interpolation family in the member states at each reporting date, the absolute number and quota of reporting vehicles can be determined.

11 EUCARIS is the EUROpean CAR and driving license Information System and was established June 29, 2000. One of the purposes of EUCARIS is the rapid exchange of accurate and reliable vehicle and driver license information between member states to increase administrative efficiency (EUCARIS, 2000).

12 Depending on the chosen compression method and level.

5 DATA VERIFICATION

The OBFCM data is determined on-board the vehicle using algorithms programmed and calibrated by the manufacturers. Therefore, the data can be considered self-reported by the manufacturer. As the data will eventually be used to adjust the manufacturer CO₂ reduction performance and thereby might lead to considerable penalties, there is a strong incentive to report artificially low real-world CO₂ emission values.

It is therefore essential to verify the OBFCM data by procedures that ensure that (1) the values determined by the OBFCM devices are accurate and (2) the vehicle transfers the OBFCM data exactly as measured to the European Commission.

In case of violation of the accuracy requirements or transferring false data, a deterrent enforcement procedure should automatically be triggered.

OBFCM DATA ACCURACY

As described in section 2, the accuracy of OBFCM data must be demonstrated for the WLTP test during type approval and be verified during the conformity-of-production tests. For vehicles in-use, there is currently no defined verification procedure. However, in article 13 of the new CO₂ standards, the European Commission is called upon to develop an in-service conformity (ISC) procedure for CO₂ emissions. (European Union, 2019)

This provides the opportunity to include OBFCM accuracy verification in the CO₂ ISC procedure, both during chassis dynamometer testing and real-world driving. The latter requires the definition of accuracy limits that can be verified with a portable emission measurement system (PEMS).

In addition to these spot-check tests, OBFCM accuracy over longer time periods can be verified by comparing the OBFCM values with, for example, fuel logbook data. Due to user interaction, a manual fuel logbook entails a risk of error and can cover only a relatively short time period to limit the effort by the user. Therefore, an automated digital fuel logbook would be the preferred solution. Many third-party companies that offer app- and dongle-based solutions to record and process vehicle OBD data are partnering with fuel stations to offer app-based payment for fuel (HEM, 2019; Petrol Plaza, 2019; ThinxNet GmbH, 2019). As the refueling amount is documented automatically, a continuous comparison of real fuel consumption and the OBFCM value is possible.

CORRECT DATA TRANSFERRED

To ensure that the data reported from the vehicle to the European Commission is identical to the data measured by the OBFCM device, robust verification procedures are needed.

For direct comparison, the fuel and energy consumption calculated based on the last transferred OBFCM dataset should be stored together with the VIN by the European Commission. During ISC checks and at the PTI, those values can be compared with the ones stored on-board the vehicle. On average, no significant deviation between the values must be observed.

To ensure traceability, the vehicles could store and provide at the OBD interface the snapshot of the last OBFCM dataset transferred to the European Commission.

6 SUMMARY AND POLICY RECOMMENDATIONS

The new light-duty CO₂ standards adopted in April 2019 require the European Commission to monitor and publish the real-world fuel and electric energy consumption of light-duty vehicles and to analyze the development of the gap between real-world and type-approval CO₂ emissions (European Union, 2019). The data for the analysis will be recorded by on-board fuel and energy consumption monitoring devices (OBFCMs), which will be mandatory in all new passenger cars and light commercial vehicles and will be implemented over two years starting January 1, 2020 (European Commission, 2018).

A prerequisite for the analysis is the transfer of the consumption data recorded on-board vehicles to the European Commission. For this purpose, the European Commission is tasked with developing a data transfer procedure. To support this development, this paper analyzes the general data transfer requirements, four transfer paths, the potential use cases of the OBFCM data, and how the data can be complemented with vehicle parameters needed for the analysis.

This paper identifies four options as potential data transfer paths. Three options are indirect, meaning the data is first read from the vehicle and then transferred to the European Commission by a third party. Those options are the collection of the data from periodic technical inspections (PTIs), roadside spot checks or managed sub-fleets like rental or company cars. The fourth option is direct, over-the-air (OTA) data transfer from the vehicle to the European Commission.

DATA TRANSFER PATHWAYS

Based on our analysis, we recommend the OTA technology as the preferred solution for the data transfer. It is the only solution that realistically allows for a regular and fleetwide collection of the OBFCM data. Existing telemetry hardware should be used, preferably the mandatory eCall system, to minimize the introduction lead time and additional cost. Nevertheless, the short introduction time until January 1, 2021, when the European Commission is required to start the OBFCM data collection, might require an intermediate solution.

We do not consider a PTI-based solution to be suitable because the first PTI for new vehicles isn't required under EU directive 2014/45/EU for the first four years (European Union, 2014a). Even though many member states require the first PTI after three years, the time period until the first OBFCM data would be available is too long. However, during PTI it can be verified that the values transferred to the European Commission are the same as those stored in the vehicles.

The major drawback of roadside spot checks is the considerable effort required to perform the checks and the challenge of retrieving the OBFCM data for a representative number of vehicles for each model and manufacturer. However, roadside spot checks performed by national authorities could be used to collect OBFCM data until an automated, over-the-air system is ready for use.

Collecting the OBFCM data from managed vehicle fleets seems to be a viable path as driving and fuel consumption data is often already determined and recorded. However, the vehicles selected for fleets are not likely to represent the vehicle market and are driven in a nonrepresentative way. We therefore do not consider these fleets as a good source for representative real-world fuel consumption data. However, automated fuel logbook data of fleets could be used to verify the accuracy of the OBFCM devices.

ACCURACY VERIFICATION

The OBFCM data, which is determined using algorithms developed and calibrated by manufacturers, needs to be verified. The regulation currently defines an accuracy requirement only for fuel consumption, which is applicable for the WLTP chassis dynamometer test, both during type approval and conformity-of-production tests (European Commission, 2017). As the main focus of the OBFCM data analysis is the determination of real-world fuel and energy consumption, we recommend that a similar accuracy requirement be defined for real-world testing. The European Commission is required by the new light-duty CO₂ standards to develop a CO₂ in-service conformity procedure (European Union, 2019). This provides the opportunity to include mandatory compliance checks of the OBFCM accuracy in all in-service conformity tests, both in the laboratory and in real-driving emissions (RDE) tests.

For PHEVs, electric energy consumption in different operating modes is recorded by the OBFCM device. However, no accuracy requirement exists for these values. We consider it a high priority to define verifiable requirements for these parameters as well, both for laboratory and real-world operation.

In general, the accuracy requirements focus only on the accumulated consumption values but do not include any instantaneous values. At a minimum it should be required that the integrated instantaneous values match the values accumulated by the OBFCM. To prevent the exploitation by manufacturers of accuracy tolerances, it should be required that for each interpolation family no bias in the accuracy deviation be observed.

Independent third-party testing should be included in the CO₂ in-service conformity checks, similar to what is performed in the pollutant emissions ISC procedure. For a systematic vehicle selection for ISC, national authorities should also take into account results of independent analyses that signal suspicious OBFCM accuracy.

To ensure compliance, an effective and deterrent enforcement procedure needs to be developed.

DATA UTILIZATION

The main goal for collecting the OBFCM data is the determination of real-world fuel and energy consumption. With this information, the European Commission can monitor the gap between type-approval and real-world CO₂ emissions and eventually develop regulatory measures to ensure that the gap does not grow over time. The regulation currently stipulates that this correction mechanism would not be applicable before 2030. Considering the urgency of reducing anthropogenic CO₂ emissions, we recommend that a correction mechanism be introduced much earlier, preferably by 2023, the year in which the effectiveness of the CO₂ standards are reviewed. (European Union, 2019)

The OBFCM data is also valuable for other purposes. Informing consumers about real-world fuel and energy consumption would allow them to identify and buy a more climate-friendly vehicle. This data should therefore be considered an important element of a future efficiency label, which is to be reviewed by the European Commission by the end of 2020 (European Union, 2019).

Furthermore, the OBFCM data should be used to derive representative utility factors for PHEVs, which will result in more realistic type-approval fuel and energy consumption values.

Other important investigations based on the OBFCM data, such as analyzing the effects of vehicle age or driving conditions on CO₂ emissions or the effectiveness of eco-innovations on reducing the gap, should preferably be carried out by the scientific

research community. In combination with high public interest in this data for climate protection and economic reasons, we recommend that the anonymized raw data be made accessible to the public with as much detail as privacy protection allows.

POLICY RECOMMENDATIONS SUMMARIZED

Based on this analysis, we offer the following recommendations for the transfer, accuracy-verification and utilization of the OBFCM data:

- » Use automated over-the-air data transfer to collect OBFCM data of the entire vehicle fleet.
- » Define OBFCM accuracy requirements for real-world driving and include electric energy consumption.
- » Include OBFCM accuracy verification in the CO₂ in-service conformity procedure.
- » Use the OBFCM data to continuously derive representative utility factors for PHEVs.
- » Provide public access to the anonymized raw OBFCM data complemented by vehicle parameters for consumer information and further analysis.

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